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SABINE PASS TO GALVESTON BAY, TEXAS COASTAL STORM RISK MANAGEMENT AND ECOSYSTEM RESTORATION: FINAL INTEGRATED FEASIBILITY REPORT—ENVIRONMENTAL IMPACT STATEMENT

COMMUNICATION

FROM

THE ASSISTANT SECRETARY OF THE ARMY, CIVIL WORKS, DEPARTMENT OF DEFENSE

TRANSMITTING

THE CORPS' REPORT ON SABINE PASS TO GALVESTON BAY, TEXAS COASTAL STORM RISK MANAGEMENT AND ECOSYSTEM RESTORATION: FINAL INTEGRATED FEASIBILITY REPORT—ENVIRONMENTAL IMPACT STATEMENT FOR DECEMBER 7, 2017

PART 1 OF 2

DECEMBER 19, 2018.—Referred to the Committee on Transportation and Infrastructure and ordered to be printed

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DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
CIVIL WORKS
108 ARMY PENTAGON
WASHINGTON DC 20310-0108

SEP 25 2018

The Honorable Paul D. Ryan
Speaker of the House
U.S. House of Representatives
Washington, D.C. 20515

Dear Mr. Speaker:

In response to a resolution from the Committee on Environment and Public Works on June 23, 2004, the Secretary of the Army supports the authorization and construction of the Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Project. The proposal is described in the report of the Chief of Engineers, dated December 7, 2017, which includes other pertinent documents.

The project study was conducted to investigate alternatives that would develop a comprehensive plan for severe erosion along coastal Texas and coastal storm damages, providing for environmental restoration and protection, increasing natural sediment supply to the coast, restoring and preserving marshes and wetlands, improving water quality, and other related purposes to the interrelated ecosystem along the coastal Texas area. The recommended plan will significantly contribute to the reduction of the risks of tropical storm surge impacts in Orange, Jefferson, and Brazoria Counties through the construction of structural measures.

The recommended plan includes: (i) increasing the level of performance and resiliency of the existing Port Arthur and Vicinity Hurricane Flood Protection (HFPP) project in Jefferson County, Texas (the Port Arthur and Vicinity Coastal Storm Risk Management (CSRM) Plan); (ii) the construction of a new levee/floodwall system (the Orange 3 CSRM Plan) along the edge of the Sabine and Neches River floodplains from Orange, Texas to the vicinity of Orangefield, Texas that is approximately 26.7-miles; and (iii) increasing the level of performance and resiliency of the existing Freeport and Vicinity HFPP project in Brazoria County, Texas (the Freeport and Vicinity CSRM Plan). This plan is the National Economic Development plan.

Based on October 2017 (FY 18) price level, the estimated project first cost of the recommended plan, which includes three separable elements, is $3,318,772,000. All construction work will be cost shared in accordance with the cost sharing provisions of Section 103 of the Water Resources Development Act (WRDA) of 1986, as amended (33 U.S.C. 2213). The Federal share of the project first costs of the hurricane and storm damage risk reduction features is estimated to be $2,157,202,000 (65 percent) and the total non-Federal share is estimated to be $1,161,570,000 (35 percent). The total cost of non-Federal contribution of lands, easements, rights-of-way, relocations, and dredged or excavated material disposal areas is estimated to be $52,451,000. The total annual cost of Operation, Maintenance, Repair, Replacement and Rehabilitation (OMRR&R) of the project is currently estimated to be $5,585,000 per year. The OMRR&R estimate includes $41,000 per year for monitoring of the environmental mitigation component after the commencement

of OMRR&R. Based on a 2.75 percent discount rate and a 50-year period of analysis, the total equivalent average annual costs of the three separable elements for the project are estimated to be $141,799,000 including OMRR&R. Additionally, the non-Federal sponsors would be fully responsible for removing and relocating utilities and discharge pipelines on the project site that are non-compensable, at a total cost estimated to be $128,320,000. The equivalent average annual benefits for the three separable elements are estimated to be $452,633,000 with net average annual benefits of $310,834,000 and a benefit-to-cost ratio of 3.2 to 1.

An Environmental Impact Statement and Record of Decision were prepared in accordance with the National Environmental Policy Act. The recommended plan has been identified as the environmentally preferred plan. Adverse environmental impacts have been avoided and minimized where practicable. The Port Arthur and Vicinity and Freeport and Vicinity CSRM Plans follow the existing projects' rights-of-way, resulting in no new impacts. The Orange 3 CSRM Plan follows the wet/dry interface of the marshes along the Sabine and Neches Rivers floodplains to the maximum extent possible, resulting in a narrow footprint and minimizing environmental impacts. Compensatory mitigation for unavoidable impacts to 2,409 acres of forested wetlands and estuarine marsh is required. The mitigation plan restores 453 acres of estuarine marsh in four proposed areas and preserves 559.5 acres of forested wetlands in perpetuity in two proposed areas providing 263 AAHUs to fully compensate for the recommended plan's impacts.

Jefferson County Drainage District No. 7 will be the non-Federal cost-sharing sponsor for the Port Arthur and Vicinity CSRM Plan; Orange County, Texas will be the non-Federal cost-sharing sponsor for the Orange 3 CSRM Plan; and the Velasco Drainage District will be the non-Federal cost-sharing sponsor for the Freeport and Vicinity CSRM Plan.

The Office of Management and Budget (OMB) advised that it had no objection to the submission of the report to Congress. However, OMB concluded that the Orange County, Texas, separable element of the project is not consistent with the policy and programs of the President. The OMB also noted that the Army intends on using emergency supplemental funds appropriated in Title IV of Division B, Subdivision 1 of the Bipartisan Budget Act of 2018 (Public Law 115-123) to implement the project. A copy of OMB's letter, dated September 5, 2018, is enclosed. I am providing a copy of this transmittal to the Subcommittee on Water Resources and Environment of the House Committee on Transportation and Infrastructure and the Subcommittee on Energy and Water Development of the House Committee on Appropriations. I am also providing an identical letter to the President of the Senate.

Sincerely,

R.D. James
Assistant Secretary of the Army
(Civil Works)

Enclosures

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5 Enclosures

1. Report of the Chief of Engineers, December 7, 2017
2. OMB Letter, September 5, 2018
3. Record of Decision
4. State & Agency Review
5. Integrated Feasibility Report & Environmental Impact Statement/Report, May 2017

DEPARTMENT OF THE ARMY
CHIEF OF ENGINEERS
2600 ARMY PENTAGON
WASHINGTON, DC 20310-2600

DAEN

DEC 0 7 2017

THE SECRETARY OF THE ARMY

SUBJECT: Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Study

1. I submit for transmission to Congress my report on Coastal Storm Risk Management (CSRM) and Ecosystem Restoration (ER) within six counties of the upper Texas coast (Orange, Jefferson, Chambers, Harris, Galveston, and Brazoria Counties). It is accompanied by the report of the Galveston District Engineer and the Southwestern Division Engineer. These reports are a partial response to a resolution from the Committee on Environment and Public Works dated June 23, 2004, entitled "Coastal Texas Protection and Restoration Study." The resolution requested that this study be undertaken to "develop a comprehensive plan for severe erosion along coastal Texas for the purposes of shoreline erosion and coastal storm damages, providing for environmental restoration and protection, increasing natural sediment supply to coast, restoring and preserving marshes and wetlands, improving water quality, and other related purposes to the interrelated ecosystem along the coastal Texas area." The project area was hit by a Category 4 hurricane, Hurricane Harvey, on August 25, 2017. At the time of signature of this Report of the Chief of Engineers damage assessments are still underway. Early reports indicate extensive flooding and damages across the project area in addition to the loss of 10 lives in Orange County and four lives in Jefferson County. Preconstruction engineering and design (PED) activities, if funded, would be continued under the authorities provided by the resolution cited above.

2. The reporting officers' recommendation for the upper Texas coastal region encompassing the six counties along 120 miles of coastline include authorization of a plan to reduce the risks of tropical storm surge impacts in Orange, Jefferson and Brazoria Counties through the construction of structural measures and the continuation of the study of the Galveston region (Galveston, Harris, and Chambers Counties) for CSRM. Continuation of the study of ER alternatives assessed in the six counties will be conducted under the comprehensive Coastal Texas Protection and Restoration feasibility study. The recommended plan was developed utilizing a region-wide systems approach to achieve the full range of benefits, although the CSRM plans are separable and able to function individually. The plan includes (i) increasing the level of performance and resiliency of the existing Port Arthur and Vicinity Hurricane Flood Protection (HFPP) project in Jefferson County, Texas (the Port Arthur and Vicinity CSRM Plan); (ii) the construction of a new levee/floodwall system (the Orange 3 CSRM Plan) along the edge of the Sabine and Neches River floodplains from Orange, Texas to the vicinity of Orangefield, Texas that is approximately 26.7-miles; and (iii) increasing the level of performance and resiliency of the existing Freeport and Vicinity HFPP project in Brazoria County, Texas (the Freeport and Vicinity CSRM Plan).

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DAEN
SUBJECT: Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Study

3. Based on October 2017 price levels, the estimated project first cost of the recommended plan, which includes three separable elements, is $3,318,772,000. All construction work will be cost shared in accordance with the cost sharing provisions of Section 103 of the Water Resources Development Act (WRDA) of 1986, as amended (33 U.S.C. 2213). The Federal share of the project first costs of the hurricane and storm damage risk reduction features is estimated to be $2,157,202,000 (65 percent) and the total non-Federal share is estimated to be $1,161,570,000 (35 percent). The total cost of non-Federal contribution of lands, easements, rights-of-way, relocations, and dredged or excavated material disposal areas (LERRDs) is estimated to be $52,451,000. The total annual cost of Operation, Maintenance, Repair, Replacement and Rehabilitation (OMRR&R) of the project is currently estimated to be $5,585,000 per year. The OMRR&R estimate includes $41,000 per year for monitoring of the environmental mitigation component after the commencement of OMRR&R. Based on a 2.75 percent discount rate and a 50-year period of analysis, the total equivalent average annual costs of the three separable elements for the project are estimated to be $141,799,000 including OMRR&R. Additionally, the non-Federal sponsors would be fully responsible for removing and relocating utilities and discharge pipelines on the project site that are non-compensable, at a total cost estimated to be $130,887,000. The equivalent average annual benefits for the three separable elements are estimated to be $452,633,000 with net average annual benefits of $310,834,000. The recommended plan is the National Economic Development plan.

a. The first element of the recommended plan is the Port Arthur and Vicinity CSRM Plan.

(1) The Port Arthur and Vicinity CSRM Plan would raise approximately 5.5 miles of the existing 27.8 miles of earthen levee to elevations ranging from 14.4 to 17.2 feet North American Vertical Datum (NAVD 88), and construct or reconstruct approximately 5.7 miles of floodwall to elevations ranging from about 14.4 to 19.4 feet NAVD 88. A separate 1,830 feet of new earthen levee would be constructed in the Port Neches area northwest of the existing northern terminus. Additionally, 26 vehicle closure structures would be replaced and erosion protections would be added.

(2) The existing Port Arthur HFPP local sponsor, Jefferson Country Drainage District No. 7, will be the non-Federal cost-sharing sponsor for the Port Arthur and Vicinity CSRM Plan. Based on October 2017 price levels, the estimated project first cost of the recommended plan is $744,865,000. All construction work will be cost shared in accordance with the cost sharing provisions of Section 103 of WRDA 1986, as amended. The Federal share of the project first costs of the hurricane and storm damage risk reduction features is estimated to be $484,162,000 (65 percent) and the total non-Federal share is estimated to be $260,703,000 (35 percent). The non-Federal contribution of LERRDs for the improvements associated with the Port Arthur and Vicinity CSRM Plan would be about $8,376,000. The non-Federal sponsor's cost for removing and relocating utilities and discharge pipelines associated with the Port Arthur and Vicinity CSRM Plan that are non-compensable would be about $39,315,000. The non-Federal sponsor would be responsible for the OMRR&R of the project after construction. OMRR&R is currently estimated at $199,000.

(3) Based on a 2.75 percent discount rate and a 50-year period of analysis, the total average annual costs of the project are estimated to be $29,757,000, including OMRR&R. The recommended plan would reduce average annual coastal storm damages by about 76 percent and would leave average total equivalent annual residual damages estimated at $42,604,000. The equivalent average annual benefits for Port Arthur and Vicinity CSRM Plan is estimated to be $139,106,000 with net average annual benefits of $109,349,000, which results in a BCR of approximately 4.7 to 1. The recommended plan is the National Economic Development plan.

b. The second element of the recommended plan is the Orange 3 CSRM Plan.

(1) This element includes 15.6 miles of newly constructed levee ranging from 12.0 to 17.5 feet NAVD 88 in elevation and 10.7 miles of newly constructed floodwalls and gates ranging from 13.5 to 16 feet NAVD 88. Seven pump stations, 56 drainage structures, and 32 closure gates located at road and railway crossings would be constructed to mitigate interior flooding during surge events. Finally, two navigable sector gates with adjacent vertical lift floodgates for normal channel flows would be constructed in Adams and Cow Bayous to reduce surge penetration. Unavoidable direct and indirect environmental impacts to 2,409 acres of forested wetlands and estuarine marsh associated with the Orange 3 CSRM Plan would be fully compensated by the implementation of the mitigation plan. Monitoring and adaptive management of the mitigation areas will be conducted until the mitigation measures have been demonstrated to be successful.

(2) Orange County, Texas will be the non-Federal cost-sharing sponsor for the Orange 3 CSRM Plan. Based on October 2017 price levels, the estimated first cost of the recommended Orange 3 CSRM Plan is $1,967,826,000. All construction work will be cost shared in accordance with the cost sharing provisions of Section 103 of WRDA 1986, as amended. The Federal share of the first costs of the hurricane and storm damage risk reduction features is estimated to be $1,279,087,000 (65 percent) and the total non-Federal share is estimated to be $688,739,000 (35 percent). The non-Federal contribution of LERRDs for the newly constructed levee/floodwall system associated with the Orange 3 CSRM Plan would be about $33,199,000. The non-Federal sponsor's cost for removing and relocating utilities and discharge pipelines associated with the Orange 3 CSRM Plan that are non-compensable would be about $63,635,000. The non-Federal sponsor would be responsible for OMRR&R of the project after construction. OMRR&R is currently estimated at $4,663,000.

(3) Based on a 2.75 percent discount rate and a 50-year period of analysis, the total average annual costs of the Orange 3 CSRM Plan are estimated to be $87,268,000, including OMRR&R. The recommended plan would reduce average annual coastal storm damages by about 64 percent and would leave average total equivalent annual residual damages estimated at $60,496,000. The equivalent average annual benefits for Orange 3 CSRM Plan is estimated to be $105,919,000 with net average annual benefits of $18,651,000, which results in a benefit-cost ratio (BCR) of approximately 1.2 to 1. The recommended plan is the National Economic Development plan.

c. The third element of the recommended plan is the Freeport and Vicinity CSRM Plan.

(1) The recommended Freeport and Vicinity CSRM Plan would raise approximately 13.1 miles of the existing earthen levee system and construct or reconstruct approximately 5.5 miles of floodwall, improving approximately 43 percent of the existing 43-mile long system. Final elevations would range from 15.8 to 23.8 feet NAVD 88. Navigable sector gates would be installed in the Dow Barge Canal to reduce surge penetration in that area. Ten vehicle closure structures at road and railroad crossings would be replaced and erosion protection would be added. Other project features include raising and reconstructing the Highway 332 crossing, installation of four drainage structures, including one at the head of the Dow Barge Canal, and raising the floodwall at Port Freeport's Berth 5 dock.

(2) The existing Freeport Harbor Flood Protection Project local sponsor, the Velasco Drainage District, will be the non-Federal cost-sharing sponsor for the Freeport and Vicinity CSRM Plan. Based on October 2017 price levels, the estimated project first cost of the recommended plan is $606,081,000. All construction work will be cost shared. In accordance with the cost sharing provisions of Section 103 of WRDA 1986, as amended, the Federal share of the project first costs of the hurricane and storm damage risk reduction features is estimated to be $393,953,000 (65 percent) and the total non-Federal share is estimated to be $212,128,000 (35 percent). The non-Federal contribution of LERRDs for the improvements associated with the Freeport and Vicinity CSRM Plan would be about $10,876,000. The non-Federal sponsor's cost for removing and relocating utilities and discharge pipelines associated with the Freeport and Vicinity CSRM Plan that are non-compensable would be about $27,937,000. The non-Federal sponsor would be responsible for the OMRR&R of the project after construction. OMRR&R is currently estimated at $723,000.

(3) Based on a 2.75 percent discount rate and a 50-year period of analysis, the total average annual costs of the Freeport Harbor CSRM Plan are estimated to be $24,774,000, including OMRR&R. The recommended plan would reduce average annual coastal storm damages by about 66 percent and would leave average total equivalent annual residual damages estimated at $107,006,000. The equivalent average annual benefits for Freeport and Vicinity CSRM Plan is estimated to be $207,608,000 with net average annual benefits of $182,834,000, which results in a BCR of approximately 8.4 to 1. The recommended plan is the National Economic Development plan.

d. The recommended plan is intended to prevent damages to structures and content and critical infrastructure from coastal storm surge and waves. It should be noted, however, that reducing the risk of loss of life during major storm events can only be achieved by adhering to existing procedures for evacuation of residents and visitors well before expected hurricane landfall, thus removing people from harm's way. This study recommends continuation of the evacuation policy both with and without the project.

4. In accordance with USACE Sea Level Change (SLC) Guidance, Engineer Regulation (ER) 1100-2-8162, the study evaluated potential impacts in SLC in its plan formulation and engineering of the recommended plan. Three levels of Relative Sea Level Change (RSLC) were considered for both the without-project and with-project conditions. The risk reduction system has been designed to provide a risk reduction against a 1 percent annual chance exceedance probability storm event based on the 2070 intermediate RSLC forecast condition. In recognition of the uncertainty presented by sea level rise, adaptation capacity has been incorporated into the final feasibility-level design to maximize the systems' overall usefulness over the life of the project. The adaptability will allow for limited overtopping of wave and minor still water overtopping that would then be mitigated for using interior drainage features or height increases to the floodwall if required. The equivalent average annual benefits are estimated to range from nearly $55,000,000 to $164,000,000 under the low SLC scenario, $104,000,000 to $203,000,000 under the intermediate SLC scenario, and to nearly $157,000,000 to $291,000,000 under the high SLC scenario. Corresponding annual net benefits for the recommended plan range from approximately $16,000,000 to $178,000,000 with BCRs ranging from 1.2 to 8.2. The recommended plan also shows high project performance with a 99 percent conditional non-exceedance probability over a 50-year period under all SLC scenarios.

5. The goals and objectives included in the Campaign Plan of the USACE have been fully integrated into the Sabine Pass to Galveston Bay study process. The recommended plan was developed in coordination and consultation with various Federal, state, and local agencies using a systematic and regional approach to formulating solutions and evaluating the benefits and impacts that would result. The feasibility study evaluated shoreline erosion and coastal storm damage problems as well as opportunities for environmental restoration and protection. Risk and uncertainty were addressed during the study by sensitivity analysis that evaluated the potential impacts of sea level change and economic assumptions as well as cost uncertainties.

6. In accordance with the USACE Engineer Circular (EC) 1165-2-214 on review of decision documents, all technical, engineering and scientific work underwent an open, dynamic and rigorous review process to ensure technical quality. This included District Quality Control review, Agency Technical Review, Major Subordinate Command review, Independent External Peer Review, Public Review, and a USACE Headquarters policy and legal review. All comments from the above referenced reviews have been addressed and incorporated into the final documents. Overall, the reviews resulted in improvements to the technical quality of the report.

7. Washington-level review indicates that the project recommended by the reporting officers is technically sound, environmentally and socially acceptable, and economically justified. The plan complies with all essential elements of the 1983 U.S. Water Resources Council's *Economic and Environmental Principles and Guidelines for Water and Land Related Resources Implementation Studies* and complies with other administrative and legislative policies and guidelines. Also the views of interested parties, including Federal, state and local agencies have been considered.

DAEN
SUBJECT: Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Study

8. Federal implementation of the project would be subject to the non-Federal sponsors agreeing in a binding written agreement to comply with applicable Federal laws and policies, and to perform the following non-Federal obligations, including, but not limited, to the following:

a. Provide 35 percent of initial project costs assigned to hurricane and storm damage reduction, and 100 percent of initial project costs assigned to protecting undeveloped private lands and other private shores which do not provide public benefits, as further specified below:

(1) Enter into an agreement that provides, prior to construction, 35 percent of design costs;

(2) Provide all lands, easements, and rights-of-way, and perform or ensure the performance of any relocations determined by the Federal Government to be necessary for the initial construction or the operation and maintenance of the project, all in compliance with applicable provisions of the Uniform Relocation and Assistance and Real Property Acquisition Policies Act of 1970, as amended (42 U.S.C. 4601-4655) and the regulations contained n 49 C.F.R. Part 24;

(3) Provide, during construction, any additional amounts as are necessary to make the total contribution equal to 35 percent of initial project costs assigned to hurricane and storm damage reduction, and 100 percent of initial project costs assigned to protecting undeveloped private lands and other private shores which do not provide public benefits;

b. For so long as the project remains authorized, operate, maintain, repair, rehabilitate, and replace the project, or functional portion of the project, including any mitigation features, at no cost to the Federal Government, in a manner compatible with the project's authorized purposes and in accordance with applicable Federal and State laws and regulations and any specific, directions prescribed by the Federal Government;

c. Inform affected interests, at least annually, of the extent of protection afforded by the project; participate in and comply with applicable Federal floodplain management and flood insurance programs; comply with Section 402 of the Water Resources Development Act of 1986, as amended (33 U.S.C. 701b-12); and publicize floodplain information in the area concerned and provide this information to zoning and other regulatory agencies for their use in adopting regulations, or taking other actions, to prevent unwise future development and to ensure compatibility with protection levels provided by the project;

d. Prevent obstructions or encroachments on the project (including prescribing and enforcing regulations to prevent such obstructions or encroachments) that might reduce the level of protection the project affords, hinder operation and maintenance of the project, or interfere with the project's proper function;

e. Give the Federal Government a right to enter, at reasonable times and in a reasonable manner, upon property that the non-Federal sponsors own or control for access to the project for

the purpose of completing, inspecting, operating, maintaining, repairing, rehabilitating, or replacing the project;

f. Hold and save the United States free from all damages arising from design, construction, operation, maintenance, repair, rehabilitation, and replacement of the project, except for damages due to the fault or negligence of the United States or its contractors;

g. Perform, or ensure performance of, any investigations for hazardous substances that are determined necessary to identify the existence and extent of any hazardous substances regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Public Law 96-510, as amended (42 U.S.C. 9601-9675), that may exist in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for construction, operation, and maintenance of the project. However, for lands that the Federal government determines to be subject to the navigation servitude, only the Federal Government shall perform such investigations unless the Federal Government provides the non-Federal sponsors with prior specific written direction, in which case the non-Federal sponsors shall perform such investigations in accordance with such written direction;

h. Assume, as between the Federal Government and the non-Federal sponsors, complete financial responsibility for all necessary cleanup and response costs of any hazardous substances regulated under CERCLA that are located in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for construction, operation, and maintenance of the project; and

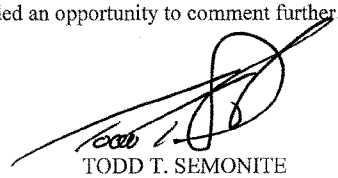
i. Agree, as between the Federal Government and the non-Federal sponsors, that the non-Federal sponsors shall be considered the operator of the project for the purpose of CERCLA liability, and to the maximum extent practicable, operate, maintain, repair, rehabilitate, and replace the project in a manner that will not cause liability to arise under CERCLA.

9. I concur in the findings, conclusions, and recommendations of the reporting officers. Accordingly, I recommend that the plan to reduce the risks of tropical storm surge impacts in Orange, Jefferson and Brazoria Counties, Texas be authorized in accordance with the reporting officers' recommended plan at an estimated project first cost of $3,318,772,000, with such modifications as in the discretion of the Chief of Engineers may be advisable. My recommendation is subject to cost sharing, financing, and other applicable requirements of Federal and state laws and policies, including Section 103 of WRDA 1986, as amended.

10. The recommendation contained herein reflects the information available at this time and current departmental policies governing formulation of individual projects. It does not reflect program and budgeting priorities inherent in the formulation of a national civil works construction program or the perspective of higher review levels within the executive branch.

DAEN
SUBJECT: Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Study

Consequently, the recommendation may be modified before it is transmitted to the Congress as a proposal for authorization and implementation funding. However, prior to transmittal to Congress, the state, interested Federal agencies, and other parties will be advised of any significant modifications and will be afforded an opportunity to comment further.



TODD T. SEMONITE
Lieutenant General, USA
Chief of Engineers

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

September 5, 2018

The Honorable R.D. James
Assistant Secretary of the Army (Civil Works)
108 Army Pentagon
Washington, DC 20310-0108

Dear Mr. James:

As required by Executive Order 12322, the Office of Management and Budget has reviewed a May 2017 Army Corps of Engineers (Corps) Final Integrated Feasibility Report and Environmental Impact Statement for the Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration project. The report estimates a total project cost of $3,318,772,000 ($2,157,202,000 federal) at October 2017 prices, of which an estimated $336,759,000 would be for preconstruction engineering and design work.

According to the information provided in the report, the benefit-cost ratio of the project is 3.2 to 1 at a discount rate of 2.75 percent, which is the discount rate the Corps is required to use for FY 2018 under section 80 of the Water Resources Development Act of 1974. The Corps estimates the benefit-cost ratio is 1.3 to 1 at a seven percent discount rate, which is the discount rate that the Administration uses in the Budget to measure the performance of Corps construction projects whose primary purpose is to provide an economic return to the Nation.

According to the report, the recommended project is composed of three separable elements that will require the execution of three separate project partnership agreements with three separate non-Federal sponsors. The report estimates that the benefit-cost ratios for the three separable elements at a discount rate of 7 percent are: 0.5 to 1 for the recommended plan in Orange County, Texas; 2.0 to 1 for the recommended plan in Jefferson County, Texas; and 3.7 to 1 for the recommended plan in Brazoria County, Texas.

The Army announced July 5, 2018 that it will allocate the full amount of funding that the Corps estimates that it will require for the initial construction of this project, using emergency supplemental funds appropriated in Title IV of Division B, Subdivision 1 of the Bipartisan Budget Act of 2018 (Public Law 115-123). The Army did so based upon a determination by the Corps that this law allows for the funding of projects of this kind, which the Congress has not specifically authorized for construction, as long as the Chief of Engineers signed a report on the project prior to the enactment of that subdivision.

The Office of Management and Budget does not object to you submitting this report to the Congress. However, when you do so, please advise the Congress that the Orange County, Texas, separable element of the project is not consistent with the policy and programs of the

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EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
WASHINGTON, D.C. 20503

President because its costs exceed its benefits from a National investment perspective. In addition, should the Congress authorize this project for construction, future funding for this project would need to compete with other proposed investments in future Budgets.

Sincerely,

John Pasquantino
Deputy Associate Director
Energy, Science, and Water

RECORD OF DECISION

SABINE PASS TO GALVESTON BAY, TEXAS COASTAL STORM RISK MANAGEMENT AND ECOSYSTEM RESTORATION PROJECT ORANGE, JEFFERSON, AND BRAZORIA COUNTIES, TEXAS

The Final Integrated Feasibility Report and Environmental Impact Statement (IFR/EIS) dated May 2017, for the Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration Project addresses hurricane and storm damage risk reduction opportunities and feasibility for three counties of the upper Texas coast (Orange, Jefferson, and Brazoria Counties). The final recommendation is contained in the report of the Chief of Engineers, dated 7 December 2017. Based on these reports, the reviews by other Federal, State, and local agencies, Tribes, input of the public, and the review by my staff, I find the plan recommended by the Chief of Engineers to be technically feasible, environmentally justified, cost effective, and in accordance with environmental statutes and the public interest.

The Final IFR/EIS, incorporated herein by reference, evaluated various alternatives that would reduce the risk of damage from tropical/hurricane storm surge flooding in the study area. The recommended plan is the National Economic Development (NED) Plan and includes:

- Construction of a 26.7 mile levee/floodwall system along the edge of the Sabine and Neches River floodplains from Orange, TX to the vicinity of Orangefield, Texas, consisting of earthen levee, floodwalls, floodgates, drainage canals, drainage structures, and pump stations.
- Raising or reconstructing 11.6 miles of the existing levees/floodwalls in the Port Arthur and Vicinity Area. The work would consist of replacing vehicular closure structures, constructing navigable surge gate structures, and increasing resiliency by installing erosion protection.
- Raising or reconstructing 18.2 miles of the existing levees/floodwalls in the Freeport and Vicinity Area. The work would consist of replacing vehicular closure structures, constructing navigable surge gate structures, and increasing resiliency by installing erosion protection.
- Implementation of the environmental compensatory mitigation and associated monitoring and adaptive management plan. Monitoring will continue until the mitigation is determined to be successful based on the identified criteria within the Monitoring and Adaptive Management Plan included in Appendix P. Federal monitoring is expected to last no more than 5 years.

In addition to a "no action" plan, an array of alternatives was evaluated. Four alternatives were carried forward and were evaluated in detail for comparison and plan selection.[1] The first alternative, Brazoria and Sabine (S11 & B5), is a non-structural alternative where buyouts/relocations would be ancillary to the implementation of new levees/floodwalls in Orange and Jefferson Counties and to the enhancement of features

[1] 40 CFR 1505.2(b) requires a summary of the alternatives considered.

ENCL 3

in the Port Arthur and Freeport Coastal Storm Risk Management (CSRM) project areas. The first alternative, Brazoria and Sabine (S11 & B5), was not selected because it was not economically justified. The second alternative, Orange 3 CSRM, is a structural levee that follows the edge of the Sabine and Neches River floodplains from Orange, Texas to the vicinity of Orangefield, Texas. The third alternative, Port Arthur and Vicinity CSRM, includes improvements to the existing levee system in Port Arthur increasing the level of risk reduction and resiliency. Also included is a new levee segment in the vicinity of Port Neches, west of the Neches River. The fourth alternative, Freeport and Vicinity CSRM, comprises improvements to the existing levee system in Freeport increasing the level of risk reduction and resiliency.

The recommended plan includes the Orange 3 CSRM alternative, the Port Arthur and Vicinity CSRM alternative, and the Freeport and Vicinity CSRM alternative. The recommended plan was identified as the environmentally preferable alternative.[2]

For all alternatives, the potential effects to the following resources were evaluated:

	In-depth evaluation conducted	Brief evaluation due to minor effects	Resource unaffected by action
Aesthetics	☐	☒	☐
Air quality	☒	☐	☐
Aquatic resources/wetlands	☒	☐	☐
Invasive species	☒	☐	☐
Fish and wildlife habitat	☒	☐	☐
Threatened/Endangered species	☒	☐	☐
Historic properties	☒	☐	☐
Other cultural resources	☒	☐	☐
Floodplains	☒	☐	☐
Hazardous, toxic & radioactive waste	☒	☐	☐
Hydrology	☒	☐	☐
Land use	☒	☐	☐
Navigation	☒	☐	☐
Noise levels	☐	☒	☐
Public infrastructure	☒	☐	☐
Socio-economics	☒	☐	☐
Environmental justice	☒	☐	☐
Soils	☒	☐	☐
Tribal trust resources	☒	☐	☐
Water quality	☒	☐	☐
Climate change	☒	☐	☐

[2] 40 CFR 1505.2(b) requires identification of which alternative is the environmentally preferable alternative.

All practical means to avoid or minimize adverse environmental effects were analyzed and incorporated into the recommended plan. Best management practices (BMPs) as detailed in the IFR/EIS will be implemented to minimize impacts.[3] Planning for the avoidance and minimization of impacts began with the layout of the first draft alignment, with additional rounds of alignment revisions to minimize wetland impacts to the greatest extent possible. The levee construction was located as close to the upland-wetland margin as possible to minimize wetland impacts, while also minimizing social effects and maximizing economic impacts. All remaining unavoidable impacts are fully compensated with in-kind mitigation.

The recommended plan will result in unavoidable adverse impacts including the loss of 69.5 acres for forested wetlands and 203 acres of estuarine marsh, as well as functional impacts to 2,137 acres of estuarine marsh. Wetland Value Assessment (WVA) coastal marsh, swamp, and bottomland hardwood community models were used to evaluate ecosystem impacts. WVA provides ecosystem impacts in the form of average annual habitat units (AAHUs).

To mitigate for these unavoidable adverse impacts, the U.S. Army Corps of Engineers will restore 453 acres of estuarine marsh within four designated areas and will preserve 559.5 acres of forested wetlands in perpetuity, providing 263 AAHUs to fully compensate for these impacts. A detailed description of the mitigation plan is presented in Appendix O of the IFR/EIS.

Pursuant to Section 7 of the Endangered Species Act of 1973, as amended, the U.S. Army Corps of Engineers determined that the recommended plan will have no effect on federally listed species or their designated critical habitat. The Biological Assessment for Endangered Species Act Coordination is in Appendix J of the IFR/EIS.

Pursuant to Section 106 of the National Historic Preservation Act of 1966, as amended, the U.S. Army Corps of Engineers determined that historic properties may be affected by the recommended plan. The Corps and the Texas State Historic Preservation Officer entered into a Programmatic Agreement (PA), dated February 2017, to address the identification and discovery of cultural resources that may occur during the construction and maintenance of proposed or existing facilities. All terms and conditions resulting from the PA shall be implemented in order to avoid, minimize, or mitigate adverse effects to historic properties.[4] The detailed information on the National Historic Preservation Act coordination is documented in Appendix L of the IFR/EIS.

Pursuant to the Clean Water Act of 1972, as amended, the discharge of dredged or fill material associated with the recommended plan has been found to be compliant with Section 404(b)(1) Guidelines (40 CFR 230). The Clean Water Act Section 404(b)(1) Guidelines evaluation is found in Appendix H of the IFR/EIS.

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[3] 40 CFR 1505.2(C) all practicable means to avoid and minimize environmental harm are adopted.
[4] Required by 36 CFR 800.14(b)(1)(ii) meeting the terms and conditions of the PA

A water quality certification pursuant to section 401 of the Clean Water Act was obtained from the Texas Commission on Environmental Quality. All conditions of the water quality certification shall be implemented in order to minimize adverse impacts to water quality. The Texas Commission on Environmental Quality's correspondence, dated 17 November 2016, is provided in Appendix H of the IFR/EIS.

A determination of consistency with the Texas Coastal Zone Management program (TCMP) pursuant to the Coastal Zone Management Act of 1972 was obtained from the Texas General Land Office. All conditions of the consistency determination shall be implemented in order to minimize adverse impacts to the coastal zone. The TCMP coordination correspondence, dated 24 November 2015, is provided in Appendix M of the IFR/EIS.

National Marine Fisheries Service has determined that USACE has addressed the Essential Fish Habitat Conservation Recommendations and no further consultation is required. The full record of consultation is presented in Appendix G of the IFR/EIS.

Public review of the draft IFR/EIS was completed on 26 October 2015. All comments submitted during the public comment period were responded to in the Final IFR/EIS. A 30-day waiting period and state and agency review of the Final IFR/EIS was completed on 14 July 2017.[5] Comments from state and federal agency review did not result in any changes to the final IFR/EIS.

Technical, environmental, economic, and cost effectiveness criteria used in the formulation of alternative plans were those specified in the Water Resources Council's 1983 Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies. All applicable laws, executive orders, regulations, and local government plans were considered in evaluation of alternatives.[6] Based on the review of these evaluations, I find that benefits of the recommended plan outweigh the costs and any adverse effects. This Record of Decision completes the National Environmental Policy Act process.[7]

10/2/18
Date

R.D. James
Assistant Secretary of the Army
Civil Works

[5] 40 CFR 1506.10(b) requires the EIS to be publically available/30-day waiting period prior to the ROD being signed.
[6] 40 CFR 1505.2(B) requires identification of relevant factors including any essential to national policy which were balanced in the agency decision.
[7] 40 CFR 1505.2 requires clearly stating the NEPA decision.

XX

Bryan W. Shaw, Ph.D., P.E., *Chairman*
Toby Baker, *Commissioner*
Jon Niermann, *Commissioner*
Richard A. Hyde, P.E., *Executive Director*

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Protecting Texas by Reducing and Preventing Pollution

June 16, 2017

Mr. Douglas C. Sims, RPA
Department of the Army
US Army Engineer District, Galveston
PO Box 1229
Galveston, Texas 77553

Official Business
ATTN: CESWF-PEC-CC

Via: E-Mail

Re: TCEQ NEPA Request #2017-180, Notice of Availability for the Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Final Integrated Feasibility Report and Environmental Impact Statement; Galveston, Texas, Orange, Jefferson and Brazoria Counties

Dear Mr. Sims:

The Texas Commission on Environmental Quality (TCEQ) has reviewed the above-referenced project and offers the following comments:

A review of the project for general conformity impact in accordance with 40 CFR Part 93 indicates that the proposed action is located in Jefferson and Orange Counties, which is currently unclassified or in attainment of the National Ambient Air Quality Standards for all six criteria air pollutants. Therefore, general conformity rules do not apply.

A review of the project for General Conformity impact in accordance with 40 CFR Part 93 indicates that the proposed project is located in Brazoria County, which is currently classified by the United States Environmental Protection Agency as moderate nonattainment for the 2008 ozone National Ambient Air Quality Standard. Therefore, general conformity rules apply.

The two primary precursors to ozone formation are volatile organic compounds (VOCs) and nitrogen oxides (NO_x). A general conformity analysis may be required when a project results in an emissions increase of 100 tons per year or greater for either VOCs or NO_x. Because the emissions from this proposed project are expected to be below these thresholds it is not anticipated to impact the state implementation plan; therefore a general conformity analysis is not required.

ENCL 4

The Office of Water does not anticipate significant long term environmental impacts from this project as long as construction and waste disposal activities associated with it are completed in accordance with applicable local, state, and federal environmental permits, statutes, and regulations. We recommend that the applicant take necessary steps to ensure that best management practices are used to control runoff from construction sites to prevent detrimental impact to surface and ground water.

The management of industrial and hazardous waste at the site including waste treatment, processing, storage and/or disposal is subject to state and federal regulations. Construction and Demolition waste must be sent for recycling or disposal at a facility authorized by the TCEQ. Special waste authorization may be required for the disposal of asbestos containing material.

Thank you for the opportunity to review this project. If you have any questions, please contact the agency NEPA Coordinator, at (512) 239-3500 or NEPA@tceq.texas.gov.

Sincerely,

Ryan Vise
Division Director
Intergovernmental Relations

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Chairman-Emeritus
Fort Worth

Carter P. Smith
Executive Director

June 23, 2017

Ms. Janelle Stokes
U.S. Army Corps of Engineers, Galveston District
Attn: CESWF-PEC-CC
P.O. Box 1229
Galveston, Texas 77553-1229

Re: Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Final Integrated Feasibility Report and Environmental Impact Statement

Dear Ms. Stokes:

Texas Parks and Wildlife Department (TPWD) has reviewed the subject Final Integrated Feasibility Report and Environmental Impact Statement (IFR-EIS), dated May, 2017, for coastal storm risk management (CSRM) projects in Orange, Jefferson and Brazoria counties, Texas. The Recommended Plan is comprised of the following elements: Freeport and Vicinity CSRM Plan, Port Arthur and Vicinity CSRM Plan, and Orange 3 CSRM Plan. The first two elements consist of improvements to existing hurricane flood protection projects at Port Arthur and Freeport. The Orange 3 CSRM Plan element would construct approximately 15.4 miles of new levees, approximately 11.4 miles of new floodwalls and gates, and installation of navigable surge gates and pump stations on Adams Bayou and Cow Bayou.

TPWD reiterates the importance of the Blue Elbow Swamp/Tony Houseman State Park and Wildlife Management Area (WMA) from our letter dated August 16, 2016. This WMA is a cooperative effort between the Texas Department of Transportation (TxDOT) and TPWD. TxDOT's Texas Travel Information Center, located on Interstate 10 in the WMA, provides interpretive exhibits, signage, and other information about the Blue Elbow Swamp including a 650-foot boardwalk leading from the center into the swamp and a scenic deck overlooking cypress forest and other wetland areas. The Tony Houseman WMA is one of the most frequently and intensively-visited natural sites in the state of Texas. TxDOT reports that approximately 415,000 visitors filed through this site in 2015 visiting the boardwalk, watching wildlife, and reading interpretive messages to learn about the values of wetland habitats and marshes in this part of the state. Therefore, this WMA functions as one of the greatest examples of demonstration and education about wildlife habitat in Texas.

TPWD does not at this time, wish to register a particular preference for a chosen mitigation strategy for this project at Blue Elbow Swamp/Tony Houseman WMA. We would certainly be open to a fair mitigation strategy and we trust that strategy will emerge from this process. However, we have indicated that according to our

4200 SMITH SCHOOL ROAD
AUSTIN, TEXAS 78744-3291
512.389.4800
www.tpwd.texas.gov

mission, goals, objectives and responsibilities to the public and our partners, the Tony Houseman WMA serves as a primary example of public outreach and landowner outreach and educational demonstration for appropriate and responsible management of marshland in this part of the state. If the U.S. Army Corps of Engineers (USACE) agrees, this could certainly include the mitigation that the USACE proposes for acquisition of like or better-quality marsh adjacent to the WMA. However, we would also request that the USACE consider the potential value of doing at least some restoration work on the WMA that could be demonstrated for educational purposes.

TPWD appreciates the USACE's efforts to address our concerns throughout this feasibility study and emphasizes the importance of continued coordination with our agency through all planning, engineering, design, construction, and maintenance phases of this project.

Questions can be directed to Mr. Mike Morgan (281-534-0146) in the Dickinson Marine Lab.

Sincerely,

Rebecca Hensley
Regional Director, Ecosystem Resources Program
Coastal Fisheries Division

RH:WD:MNM

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June 23, 2017

USACE
Galveston District
Attn: CESWF-PEC-CC
P.O. Box 1229
Galveston, Texas 77553-1229

1. Concern: Accuracy of statements
   Report/Section: Main report
   Location: Table 6-10

   The authorized channel depth in the "bench" area is 51 ft MLLW, not 55 ft. If the 45 ft Navigation channel project created a "negative impact" to the levee slope stability as stated, does that mean the 45 ft navigation project has a design deficiency?

2. Concern: Impacts to vessels schedules during construction
   Report/Section: Main report
   Location: Section 6.6

   Port vessel traffic and schedules cannot be interrupted/delayed by construction. No work can occur while vessels are docked. How has contractor standby time been factored into the construction cost estimates and schedule?

3. Concern: OMRR&R
   Report/Section: Main report
   Location: Section 6.12

   The report estimates OMRR&R costs of $5,468,000 for the whole system. For taxpayer transparency, provide estimate by separable element. The purpose is to show taxpayers how their taxes may be affected.

4. Concern: Width of gate
   Report/Section: App. D; S-04
   Location: Sta 246+00

   How was the width of the gate determined?

PORT COMMISSION

RAVI K. SINGHANIA, CHAIRMAN; BILL TERRY, VICE CHAIRMAN; PAUL KRESTA, SECRETARY; RUDY SANTOS, ASST. SECRETARY;
SHANE PIRTLE, COMMISSIONER; JOHN HOSS, COMMISSIONER; PHYLLIS SAATHOFF, EXECUTIVE DIRECTOR/CEO

5. Concern: Levee raise
   Report/Section: App. D; C-59
   Location: Sta 155+00 to 160+00

   The NFS for the 'Freeport' levee system (VDD) has questioned the need of a levee raise and the use of STWAVE. Is the Corps willing to check their results using Boussinesq based models such as COULWAVE as the VDD has suggested? The proposed levee raise of 3.5 ft is not conducive to container terminal operations. Will the Corps consider a levee route that excludes Port Freeport? See Appendix F, VDD question #4 and #15.

6. Concern: Panel type floodwall
   Report/Section: App. D; C-59
   Location: Sta. 155+00 to 180+00

   The panel should be of the automatic deploying type, able to withstand 215 Kip wheel loads. Alternatively, please consider rerouting the flood protection system around the Port so that the Port is no longer included inside it.

7. Concern: Levee
   Report/Section: App. D; C-60
   Location: 228+00 to 243+000

   Port Freeport has plans to extend the existing wharf. Levee or floodwall should be re-routed to accommodate another 450 ft of wharf.

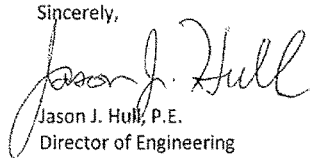
8. Concern: All port areas
   Report/Section: App. D
   Location: General

   Port Freeport insists on having Port Engineering Staff representation at the PDT meetings in order to reduce harmful impacts to the development and economic growth of the Port.

9. Concern: Floodwall
   Report/Section: App. D; S-06
   Location: Assumption 4

   The note indicates that the design of wall will go through modification during PED. The design, construction, M&O of this structure has the potential to severely impact the short and long term operations at these docks. Port Freeport insists on having input and the ability to review the design during PED to minimize the harmful impacts to the economic growth of the Port.

Sincerely,



Jason J. Hull, P.E.
Director of Engineering

A GOVERNMENT AGENCY
OF THE
State of Texas

(409) 746-2192
FAX (409) 746-3780

SABINE RIVER AUTHORITY
of Texas

P.O. BOX 579
ORANGE, TEXAS
77631

June 23, 2017

U.S. Army Corps of Engineers, Galveston District
Attn: CESWF-PEC-CC
P.O. Box 1229
Galveston, Texas 77553-1229

Re: Comments on May 2017 Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Final Integrated Feasibility Report and Environmental Impact Statement (FIFR-EIS)

The Sabine River Authority of Texas (SRA-TX) appreciates this opportunity to provide its comments on the above-referenced report.

The SRA-TX was created by the Legislature in 1949 as an official agency of the State of Texas. SRA-TX was created as conservation and reclamation district with responsibilities to control, store, preserve and distribute the waters of the Sabine River and its tributary streams in Texas for useful purposes. The boundaries established by the Act of the Legislature comprise all of the area lying within the watershed of the Sabine River and its tributary systems within the State of Texas. The watershed area in Texas includes all or parts of twenty-one counties, including parts of Orange County. SRA-TX has taken an active role in water supply and water quality matters since initial operational activities began in 1954 and has the responsibility to manage the long-term water supply needs of the Sabine River Basin, Texas.

Our comments on the FIFR-EIS pertain to the new Orange 3 coastal storm risk management (CSRM) system, proposed to reduce the risks of tropical storm surge impacts in Orange County, Texas. The SRA-TX *John W. Simmons Gulf Coast Canal System* supplies freshwater to nine major industries, a municipality, and other small water users throughout Orange County. As described in Section 6.2.1 Orange CSRM Project Area, the Orange 3 system, consisting of earthen levee and floodwalls, begins at Interstate-10 at its northeast end, about 1.75 miles west of where I-10 crosses the Sabine River. While this configuration protects some of our customers from tropical storm surge impacts to some degree, it lacks protection of the raw water source they rely on from severe storm surge damage such as inundation with high salinity Gulf waters experienced during Hurricane Rita in 2005 and Hurricane Ike in 2008.

SABINE RIVER AUTHORITY of Texas

Appendix A of the FIFR-EIS, Measure Information Sheets, refers to and uses portions of a feasibility study of alternatives to address storm surge flooding in Orange County, Texas.[1] Measure 3-7 Sabine River Crossing, Orange County and Calcasieu Parish (Louisiana), includes a closure structure on the Sabine River and a connecting earthen levee protection system that would protect fresh water supplies delivered by SRA-TX. The Sabine River closure structure would tie-in to a segment of Measure 3-4, the east bank Sabine River earthen levee/floodwall system (which appears to be similar in concept to the new proposed Orange 3 CSRM), just south of I-10 and a levee would extend eastward to higher ground on the outskirts of Toomey, Louisiana. The Sabine River Crossing or similar closure structure would protect SRA-TX's industrial and municipal customers, which would further reduce risk to critical infrastructure in Orange County (chemical manufacturing and electric generation), a stated Planning Objective of the Recommended Plan (Objective 5, pg. ES-4).

SRA-TX, for the reasons stated above, urges the USACE Galveston District to include a closure structure along the Sabine River for protection of freshwater supplies managed by SRA-TX in its efforts to reduce the risk of storm surge impacts in Orange County, Texas.

Thank you again for this opportunity to submit our comments and for your consideration. Please contact Travis Williams, P.E., Water Resources Manager, at 409-746-2192 or twilliams@sratx.org if further details or clarification is needed.

Sincerely,

David Montagne
General Manager and Executive Vice President
Sabine River Authority of Texas

JDM:TCW:jeb

[1] Flood Protection Planning Study Hurricane Flood Protection System Orange County Texas. Prepared for: Orange County Economic Development Corporation and Texas Water Development Board. Prepared by: Carroll & Blackman, Inc., Costello, Inc., and LJA Engineers, Inc. December 2012. Accessed on the Internet at http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1004831089_orange.pdf.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Region 6
1445 Ross Avenue, Suite 1200
Dallas, TX 75202-2733

July 7, 2017

Mr. Douglas C. Sims, Acting Director
U.S. Army Corps of Engineers
Galveston District Regulatory Office
Regional Planning and Environment Center
P.O. Box 1229
Galveston, TX 77553-1229

Dear Mr. Sims:

In accordance with Section 309 of the Clean Air Act (CAA), the National Environmental Policy Act (NEPA), and the Council on Environmental Quality (CEQ) regulations for implementing NEPA (40 CFR 1500-1508), the U.S. Environmental Protection Agency (EPA) Region 6 office in Dallas, Texas, has completed its review of the Sabine Pass to Galveston Bay Coastal Storm Risk Management (CSRM) and Ecosystem Restoration (ER) Final Integrated Feasibility Report (IFR)/Environmental Impact Statement (EIS) prepared by the U.S. Army Corps of Engineers (USACE) and the Texas General Land Office (GLO). The IFR/EIS examine the CSRM and ER opportunities along the Texas coast within Orange, Jefferson, Chambers, Harris, Galveston, and Brazoria counties.

The EPA's provided comments to USACE on the Draft IFR/EIS on October 30, 2015, and rated the Draft IFR/EIS as EC-2 (Environmental Concerns – Insufficient Information). With the Final IFR/EIS, the USACE has addressed many of the concerns within the Draft IFR/EIS by including additional information for air, environmental justice, and wetlands and Waters of the U.S. However, EPA continues to have concerns for impacted wetland resources. Detailed comments are enclosed with this letter which clarify our concerns.

EPA appreciates the opportunity to review the Final IFR/EIS. If you have any questions or concerns, please do not hesitate to contact me, or have your staff contact Keith Hayden at hayden.keith@epa.gov or 214-665-2133.

Sincerely,

Robert Houston,
Chief, Special Projects Section

DETAILED COMMENTS

SABINE PASS TO GALVESTON BAY FINAL IFR/EIS

Clean Water Act Section 404 Guidelines

Section 6.15.2 of the Final IFR/EIS states that the alignment of the Orange 3 CSRM Plan has been carefully situated to avoid and minimize impacts to special aquatic sites and the aquatic ecosystem to the greatest extent practicable as required in the CWA 404(b)(1) Guidelines. While a checklist for compliance with the CWA 404(b)(1) Guidelines is included in Appendix H, there is no specific information included in the Main Report to support the conclusions of the checklist regarding compliance with the Guidelines and selection of the least environmentally damaging practicable alternative (LEDPA). Section 5.4.6.5 also contains the general statement that the TSP for each of the CSRM Plans is the environmentally preferable alternative because it is generally the lowest height of all action alternatives evaluated, resulting in a narrower footprint. Since the Orange 3 CSRM system has what the Final IFR/EIS describes as significant wetland impacts, adding specific information describing efforts to avoid and minimize impacts to aquatic resources, such as changes made to the levee alignment or size, would more clearly demonstrate compliance with the CWA 404(b)(1) Guidelines.

No Net Loss of Wetlands

Section 6.15.12 of the Final IFR/EIS states that the impacts to wetlands resulting from construction of the Orange CSRM Plan will be fully compensated by the mitigation plan so that there will be no net loss of wetlands. Due to the use of preservation of existing forested wetlands as mitigation for permanent impacts to bottomland hardwood wetlands, it appears there may in fact be a net loss of wetlands resulting from the Orange 3 CSRM Alternative. Additional mitigation that results in an increase in wetland functions would be needed to avoid a net loss of wetlands. As addressed in the following comments, the 404(b)(1) Guidelines allow wetlands to be preserved as compensatory mitigation under certain circumstances, but preservation is considered a less preferable mitigation option in comparison to restoration or other compensation that increases wetland functions, because it results in a net loss of wetlands.

Final IFR/EIS: Appendix O and Appendix P; Mitigation Plan

Per the 2008 Mitigation Rule, restoration should generally be the first option for compensatory mitigation because the likelihood of success is greater and the impacts to potentially ecologically important uplands are reduced compared to establishment, and the potential gains in terms of aquatic resource functions are greater, compared to enhancement and preservation (40 CFR 230.93(a)(2)). The mitigation plan has proposed preservation only for all compensation for forested wetland impacts resulting from the Orange 3 CSRM Alternative. The Final IFR/EIS should explain why restoration mitigation opportunities do not exist for forested wetlands.

The 2008 Mitigation Rule has requirements for the use of preservation as compensatory mitigation, described in 40 CFR 230.93(h). Specifically, mitigation sites using preservation as compensation for impacts to wetlands should be under threat of destruction or adverse modifications (40 CFR 230.93(h)(iv)). Section 8.3 of Appendix O discusses silviculture as a threat to cypress swamps and development as a threat to bottomland hardwood wetlands.

However, additional analysis about the degree of threat is necessary to demonstrate compliance with (40 CFR 230.93(h)(iv)). For instance, the degree of threat of silviculture to Mitigation Area 11, is unclear and may be relatively low, since the analysis provided in Section 8.3 of Appendix O states that an average of 4.27 percent of forested wetlands in the lower Sabine River area were disturbed by logging between 1989 and 2015. In addition, the exemption from Clean Water Act Section 404 for certain silviculture activities (40 CFR 232.2(3)(iii) and 40 CFR 232.3(c)) requires the wetlands to be part of an established silviculture operation (i.e. ongoing), so that regeneration of the forested resources after logging is necessary in order to qualify for the exemption. Therefore, not all timbering would be exempt from Clean Water Act permitting. The November 28, 1995 USACE/EPA Memorandum to the Field for Silviculture Mechanical Site Preparation Activities also clarified that best management practices for mechanical silvicultural site preparation activities recognize that certain wetlands should not be subject to unpermitted mechanical silvicultural site preparation activities, including permanently flooded, intermittently exposed, and semi-permanently flooded wetland communities such as cypress-gum swamps. More information about the potential for exempt silvicultural activities in proposed mitigation areas should be provided to support the analysis of threat of adverse modifications to these wetlands, and determine whether preservation mitigation credit is appropriate for this area.

Section 8.3 also discusses future development (e.g. filling wetlands in order to construct homes and businesses) as a threat to bottomland hardwood wetlands in Area 161. Because such impacts would require a Clean Water Act Section 404 permit and compensatory mitigation for unavoidable impacts, the degree of threat is likewise potentially lower for these wetlands. The Final IFR/EIS would be strengthened by further analysis of the threat of destruction for these wetlands, in order to determine whether preservation mitigation credit is appropriate for this area.

The mitigation plan evaluated the value of the proposed preservation of forested wetlands using the Wetland Value Assessment (WVA), based on a Future Without Project (FWOP) and Future with Project (FWP). While this type of analysis may be used to calculate the value of restoration, enhancement and creation of wetlands, USACE Headquarters has recently determined during a dispute resolution process for a proposed mitigation bank that this approach to calculating preservation value is not supported by the CWA404(b)(1) Guidelines. Rather, higher acreage-based ratios should be used when calculating preservation mitigation, when preservation is deemed an appropriate form of compensatory mitigation for an impact (40 CFR 230.93(h)(v)(2)).

According to Table 8-1 (Appendix O), Orange 3 would directly impact 44.3 acres of BH wetlands and indirectly impact 12.7 acres, for a total of 57 acres. Up to 112.4 acres of BH wetlands would be preserved in Area 161 and up to 155.7 acres of BH wetlands would be preserved in Area 11. If the maximum proposed preservation of BH wetlands were achieved, this is still only a 4.7:1 ratio. This preservation ratio appears low in comparison to preservation ratios previously used in the Galveston District Regulatory Program. To account for the use of preservation, which does not increase wetland functions, the Orange 3 Alternative should propose additional mitigation for impacts to bottomland hardwood wetlands, either increasing proposed preservation that meets the requirements of the Mitigation Rule at 40 CFR 230.93(h), or proposing additional mitigation that increases wetland functions.

Mitigation credit calculations should be based upon functional lift between pre- and post-project (actual) site conditions, based on 40 CFR 230.98(o)(3), in the Mitigation Rule, not calculated

based on a future theoretical loss in the absence of preservation. According to Appendix O, the bottomland hardwood wetlands in Area 161 have Chinese tallow infestation scattered throughout the site and visible on autumn satellite imagery. If portions of Area 161 are in need of enhancement or restoration, it should not be eligible for preservation credits, as restoration is a higher priority according to the Mitigation Rule, and as when preservation is used as compensatory mitigation, it shall be done in conjunction with aquatic resource restoration, establishment and/or enhancement to the degree practicable (40 CFR 230.93(h)(2)). Table 8-4 shows that enhancement of Area 161 through Chinese tallow control and removal would generate 6.4 AAHU. Additional information should be provided about the extent of the Chinese tallow infestation and baseline wetland conditions within Area 161, to demonstrate whether preservation or enhancement is the most appropriate type of mitigation.

"Best Buy Plan" Approach and Preservation

The "Best Buy Plan" approach, which emphasizes the cost per unit of various mitigation alternatives, favors preservation of aquatic resources over restoration or enhancement, because using the WVA in the manner proposed (evaluating potential future losses of wetland functions versus future wetland function gains), preservation is consistently the less expensive mitigation type since no active restoration of wetlands is required This approach is not in line with the national goal of achieving a no net loss of wetlands, or with the preference given to restoration in the CWA 404(b)(1) Guidelines (40 CFR 230.93(a)(2)). The Guidelines consider practicability, of which cost is a factor. However, mitigation plans that are not the least expensive plan may still be considered practicable compensatory mitigation options.

Site Protection Instrument

A perpetual site protection instrument should be required for all mitigation sites, including preservation sites (40 CFR 230.93(h)(v)). Specifically, we recommend that a conservation entity such as a certified land trust hold the Conservation Easement for any non-public mitigation lands that are acquired, as opposed to the non-federal sponsor (NFS). This is standard practice for mitigation banks and permittee-responsible mitigation projects in the Galveston District.

Temporal Losses

Proposed performance standards for forested wetlands require that acquisition of mitigation areas occur by Year 7 after the commencement of the project construction. To reduce temporal losses, acquisition of all mitigation areas should occur as soon as possible, preferably before or shortly after commencement of construction. The performance standards also propose for baseline surveys of all forested mitigation areas, and implementation of Chinese tallow control as necessary, to begin by Year 10 of the mitigation implementation period. Likewise, these activities should be conducted as soon as possible to reduce temporal losses.

The document states up to 5 acres of forest within Mitigation Areas 11 or 161 could be sold without replacement, if sale or release is approved by the agency owner, determined to be in the public interest, and reported to USACE. This would appear to be contrary to the proposal to perpetually preserve wetlands as mitigation lands under a Conservation Easement.

Monitoring and Adaptive Management

Appendix P, Section 3.1.1.2, proposes that a minimum of 87 acres of BH forest in Area 161 and 241 acres of cypress swamp in Area 11 would be required to be maintained in perpetuity, to

achieve a minimum WVA-based mitigation ratio of 1:1. However, for BH wetlands this would achieve less than a 2:1 ratio based on acres of wetlands preserved. The acreage ratio for cypress swamp is significantly higher, at approximately 19:1, which is likely adequate if it is determined that preservation is appropriate based on the existence of threat to high quality wetlands. However, if preservation is determined to be appropriate mitigation for the Orange 3 impacts, we recommend removal of this language that only requires long-term maintenance of a portion of the wetland acreage within the proposed preservation areas. In particular, this proposed adaptive management trigger results in a preservation mitigation ratio that is too low for BH wetlands.

The proposed trigger for adaptive management through Chinese tallow control is if over 40% of existing swamp or bottomland hardwood acreage in monitored blow-down areas or gaps is infested with Chinese tallow (a majority of midstory or overstory canopy). If 40% of gaps are dominated by Chinese tallow, this represents a significant infestation that may be difficult to control. Mitigation banks in the Galveston District consistently achieve 0% Chinese tallow in the overstory and less than 1% in the understory in forested mitigation areas. This will remove the seed source for Chinese tallow and reduce its ability to colonize new gaps that may occur on the property.

Success Criterion CEM 5 proposes that in Year 8, a minimum of 90% of invasive and nuisance vegetation in the restored marsh be removed. Mitigation banks in the Galveston District typically maintain less than 5% invasive vegetation in herbaceous strata, which may better ensure that nuisance and invasive vegetation remains under control.

United States Department of the Interior
Office of the Secretary
Office of Environmental Policy and Compliance
1849 C Street, NW - MS 5538 - MIB
Washington, D.C. 20240

JUL 1 1 2017

9043.1
PEP/NRM

ER 15/0508

Theodore A. Brown, P.E.
Chief, Planning and Policy Division
Directorate of Civil Works
U.S. Army Corps of Engineers
CECW-P (SA)
7701 Telegraph Road
Alexandria, VA 22315-3860

Re: Sabine Pass to Galveston Bay Coastal Storm Risk Reduction and Ecosystem Restoration – Draft Chief of Engineers' Report and Final Environmental Impact Statement

Dear Mr. Brown:

The Department of the Interior (Department) has reviewed the U.S. Army Corps of Engineers' draft Chief of Engineers' Report (Chief's Report) and the Final Environmental Impact Statement (FEIS) regarding the Sabine Pass to Galveston Bay Coastal Storm Risk Reduction and Ecosystem Restoration. The Department has no comments on the documents.

For questions or further information regarding this response, please contact Cheryl Kelly on my Natural Resources Management Team, at 202-208-7565 or at cheryl_kelly@ios.doi.gov.

Thank you for the opportunity to review and comment on this Chief's Report and the FEIS.

Sincerely,

Michaela E. Noble
Director, Office of Environmental Policy
and Compliance

Electronic distribution: Sabine-Pass-chiefs-report@usace.army.mil;
SabinePassToGalvestonBay@usace.army.mil

cc: Stephen Spencer, REO Albuquerque, stephen_spencer@ios.doi.gov
Patricia Bee, USACE: patricia.l.bee@usace.army.mil
Scott Nicholson, USACE: Scott.R.Nicholson@usace.army.mil

TRANSMITTED ELECTRONICALLY – NO HARDCOPY TO FOLLOW

U. S. Department of Homeland Security
FEMA Region 6
800 North Loop 288
Denton, TX 76209-3698

FEMA

FEDERAL EMERGENCY MANAGEMENT AGENCY
REGION VI
MITIGATION DIVISION

RE: Sabine Pass to Galveston Bay, Texas, Coastal Storm Rish Management and Ecosystem Restoration Project

NOTICE REVIEW/ENVIRONMENTAL CONSULTATION

☐ We have no comments to offer. ☒ We offer the following comments:

WE WOULD REQUEST THAT THE COMMUNITY FLOODPLAIN ADMINISTRATOR BE CONTACTED FOR THE REVIEW AND POSSIBLE PERMIT REQUIREMENTS FOR THIS PROJECT. IF FEDERALLY FUNDED, WE WOULD REQUEST PROJECT TO BE IN COMPLIANCE WITH EO11988 & EO 11990.

Michael Shannon
County Engineer/FPA
Galveston County
722 Moody Avenue
Galveston, TX 77550
Michael.Shannon@co.galveston.tx.us
(409) 770-5453

Jesse Morales
Permits Manager
Harris County
10555 Northwest Freeway
North Entry – Suite 120
Houston, TX 77092
Jesse.Morales@hcpid.org
(713) 274-3752

Joe Ripple
Floodplain Administrator
Brazoria County
451 North Velasco Street
Suite 210
Angleton, TX 77515
JoeR@brazoria-county.com
(979) 864-1272

Rex Tunze
Environmental Health and Permitting Director
Chambers County
P.O. Box 1180
Anahuac, TX 77514
RTunze@co.chambers.tx.us
(409) 267-2703

Don Rao
Director of Engineering/FPA
Jefferson County
Jefferson County Courthouse
1149 Pearl Street, 5th Flood
Beaumont, TX 77701
DRao@co.jefferson.tx.us
(409) 835-8584

Lisa Roberts
Floodplain Administrator
11475-C FM 1442
Orange, TX 77630
LRoberts@co.orange.tx.us
(409) 745-1410

REVIEWER:

Lauren H Fulton
Floodplain Management and Insurance Branch
Mitigation Division
(940) 898-5127

DATE: June 28, 2017

17-6-3962

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
441 G STREET, NW
WASHINGTON, DC 20314-1000

JUN 15 2017

Date Rec'd: 6/16/17		
Rec'd by: dho		
	Action	Info
RA		✓
Deputy RA		✓
XA		
Analyst		
RES		
REC		
MIT	✓	
MSD		
NP		
Grants		
File		✓
Suspense Date: 6/30/17		

Federal Emergency Management Agency
Attn: Mr. Tony Robinson
Regional Administrator, Region 6
FRC 800 North Loop 288
Denton, Texas 76209

Dear Mr. Robinson:

Enclosed for your review and comment are two copies of the proposed report of the Chief of Engineers and the final report of the district engineer on the Sabine Pass to Galveston Bay, Texas, Coastal Storm Risk Management and Ecosystem Restoration Project. Included with the report of the district engineer is a Final Environmental Impact Statement (FEIS) prepared in accordance with Section 102(2)(C) of the National Environmental Policy Act of 1969 (Public Law 91-190).

In accordance with established coordination procedures on water resources reports, please furnish your comments and recommendations on any aspect of the report, and FEIS, for which your agency has jurisdiction by law or has special expertise. In order to facilitate processing of this document in a timely manner, you are requested to provide any comments or recommendations within 30 days. Please send your reply to me via email at Sabine-Pass-chiefs-report@usace.army.mil or to the following address:

Headquarters
U. S. Army Corps of Engineers
CECW-P (SA)
7701 Telegraph Road
Alexandria, VA 22315-3860

I appreciate your assistance with this review. Any questions on the proposed project or this request can be addressed to Scott Nicholson at (202) 761-7770.

Sincerely,

Theodore A. Brown

Theodore A. Brown, P.E.
Chief, Planning and Policy Division
Directorate of Civil Works

Enclosures

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
441 G STREET, NW
WASHINGTON, DC 20314-1000

OCT 2 0 2017

Ms. Lauren H. Fulton
Floodplain Management & Insurance Branch
Mitigation Division
Federal Emergency Management Agency
800 North Loop 288
Denton, TX 76209-3698

Dear Ms. Fulton,

This letter is in response to your letter of June 28, 2017, providing review comments on the U.S. Army Corps of Engineers (USACE) draft Chief of Engineers Report and the Final Integrated Feasibility Report and Environmental Impact Statement (FIFR-EIS) for the Sabine Pass to Galveston Bay, Texas feasibility study. In regard to the FIFR-EIS, you indicated a request that the local community floodplain administers be contacted regarding the environmental coordination.

Thank you for providing the list of community floodplain administators that we will notify for review and identification of any possible permit requirements for this project. In addtion, we acknowledge your request for this project to be in compliance with EO11988 and EO11990.

We appreciate the cooperative role that FEMA has played in facilitating the development of this project. Thank you for your comments and I look forward to future coordination with your agency.

Sincerely,

Theodore A. Brown, P.E.
Chief, Planning and Policy Division
Directorate of Civil Works

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
441 G STREET, NW
WASHINGTON, DC 20314-1000

OCT 2 0 2017

Mr. Ryan Vise
Intergovernmental Relations Division Director
Texas Commission on Environmental Quality
P.O. Box 13087
Austin, Texas 78711-3087

Dear Mr. Vise,

This letter is in response to your letter of June 16, 2017, providing review comments on the U.S. Army Corps of Engineers (USACE) draft Chief of Engineers Report and the Final Integrated Feasibility Report and Environmental Impact Statement for the Sabine Pass to Galveston Bay, Texas feasibility study. Your letter confirmed the results of previous coordination with the Texas Commission on Environmental Quality (TCEQ) regarding the General Conformity review of air quality impacts and water quality impacts.

We note that General Conformity rules do not apply to most of the project area, and that a General Conformity Determination is not required for the portion of the project in Brazoria County and we appreciate your concurrence. Water quality certification for all project areas was provided during prior coordination. As requested, USACE will ensure that construction and waste disposal activities are completed in accordance with applicable local, state and federal environmental laws and regulations.

We appreciate the cooperative role that TCEQ has played in facilitating development of this project. Thank you for your comments and I look forward to future coordination with your agency.

Sincerely,

Theodore A. Brown, P.E.
Chief, Planning and Policy Division
Directorate of Civil Works

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
441 G STREET, NW
WASHINGTON, DC 20314-1000

OCT 2 0 2017

Ms. Rebecca Hensley
Regional Director, Ecosystem Resources Program
Texas Parks and Wildlife Department
4200 Smith School Road
Austin, Texas 78744-3291

Dear Ms. Hensley,

This letter is in response to your letter of June 23, 2017, providing review comments on the U.S. Army Corps of Engineers (USACE) draft Chief of Engineers Report and the Final Integrated Feasibility Report and Environmental Impact Statement (FIFR-EIS) for the Sabine Pass to Galveston Bay (S2G), Texas feasibility study. Texas Parks and Wildlife Department (TPWD) requests that USACE consider including restoration within the Blue Elbow Swamp/Tony Houseman State Park and Wildlife Management Area (WMA) in the S2G mitigation plan.

TPWD actively participated in developing the S2G mitigation plan presented in the FIFR-EIS, which includes three mitigation measures that would restore 490 acres of marsh within the Lower Neches WMA. We welcome your stated willingness to continue engagement in mitigation planning and implementation of the S2G project. As we finalize project design, we will continue coordination with your agency to finalize details of the mitigation plan. However, including restoration work on the WMA to demonstrate for educational purposes does not meet USACE standards set by Congress for mitigation and the additional cost would not be justified.

We appreciate the cooperative role that the Texas Parks and Wildlife Department has played in facilitating development of this project. Thank you for your comments and I look forward to future coordination with your agency.

Sincerely,

Theodore A. Brown, P.E.
Chief, Planning and Policy Division
Directorate of Civil Works

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
441 G STREET, NW
WASHINGTON, DC 20314-1000

OCT 2 0 2017

Mr. Jason Hull
Director of Engineering
Port Freeport
1100 Cherry Street
Freeport, Texas 77541

Dear Mr. Hull,

This letter is in response to your letter of June 23, 2017, providing review comments on the U.S. Army Corps of Engineers (USACE) draft Chief of Engineers Report and the Final Integrated Feasibility Report and Environmental Impact Statement for the Sabine Pass to Galveston Bay, Texas feasibility study. Your letter expresses concern over the reported depth of the "bench" area, breakout of the Operation, Maintenance, Repair, Replacement, and Rehabilitiation (OMRR&R) costs by element, that the Sabine Pass to Galveston Bay project construction may impact vessel traffic, questions the need for improving the floodwall on the Port Freeport wharf, and requests continued coordination during final design preparations.

You referenced Table 6-10 when questioning the depth of the "bench" area. The 55 ft. depth in that table is referencing the potential of having a 55 ft. channel exacerbating the stability issue, not the existing depth of the "bench" area. You also asked if the stability issue was a design deficiency. As discussed in Table 6-10, the slope stability issue was to be resolved during construction by creating the previously mentioned "bench" area. In addtion, this area is being further studied under the Freeport Harbor feasibility study and the project sponsor, Port Freeport, is moving forward with a Section 408 request to modify the existing structure.

With respect to the breakout of the OMRR&R costs, and as discussed in the Chief's Report and study report, the OMRR&R estimates per year for Orange County, Jefferson County, and Brazoria County are $4,565,000, $195,000, and $708,000 respectively.

We want to assure you, as USACE proceeds with final design and construction, that coordination with your agency and other affected parties will continue to ensure that impacts to port operations are minimized, operational needs are met, and the specific questions regarding project details identified above and in your letter are addressed. We look forward to a continued cooperative relationship with Port Freeport in implementing this project. Thank you for your comments and I look forward to future coordination with your agency.

Sincerely,

Theodore A. Brown

Theodore A. Brown, P.E.
Chief, Planning and Policy Division
Directorate of Civil Works

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
441 G STREET, NW
WASHINGTON, DC 20314-1000

OCT 2 0 2017

Mr. David Montagne
General Manager and Executive Vice President
Sabine River Authority of Texas
P.O. Box 579
Orange, Texas 77631

Dear Mr. Montagne,

This letter is in response to your letter of June 23, 2017, providing review comments on the U.S. Army Corps of Engineers (USACE) draft Chief of Engineers Report and the Final Integrated Feasibility Report and Environmental Impact Statement for the Sabine Pass to Galveston Bay, Texas feasibility study. Your letter requests that the Orange 3 Plan include a closure structure on the Sabine River to protect freshwater supplies managed by the Sabine River Authority of Texas (SRA).

While USACE understands that protection of upstream freshwater intakes is a key public concern, our recommendation must to be consistent with the Water Resources Planning Act of 1965 (Pub. L. 89-80). The structural plan recommended by SRA was included in our evaluation but after a detailed analysis it was determined that it is not consistent with Pub. L. 89-90. Therefore it is not included in the recommended plan which reasonably maximizes net national economic development benefits consistent with protecting the Nation's environment.

Responsibility for flood risk management in the United States is a shared responsibility between multiple Federal, state, and local government agencies with a complex set of programs and authorities. USACE will continue to coordinate with SRA and other Federal and State agencies to address risk to drinking water supplies. This coordination could include participation in programs such as the Silver Jackets program to assist states and communities in reducing flood damages and promoting sound flood risk management.

We look forward to a continued cooperative relationship with SRA. Thank you for your comments and I look forward to future coordination with your agency.

Sincerely,

Theodore A. Brown, P.E.
Chief, Planning and Policy Division
Directorate of Civil Works

DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
441 G STREET, NW
WASHINGTON, DC 20314-1000

OCT 2 0 2017

Mr. Robert Houston
Chief, Special Projects Section
U.S. Environmental Protection Agency
Region 6
1445 Ross Avenue, Suite 1200
Dallas, TX 75202-2733

Dear Mr. Houston,

This letter is in response to your letter of July 7, 2017, providing review comments on the U.S. Army Corps of Engineers (USACE) draft Chief of Engineers Report and the Final Integrated Feasibility Report and Environmental Impact Statement (FIFR-EIS) for the Sabine Pass to Galveston Bay (S2G), Texas feasibility study. In regard to the FIFR-EIS, you indicated that USACE has addressed many of the concerns described in your agency's comments on the draft S2G report, dated October 30, 2015, however the United States Environmental Protection Agency (EPA) continues to have concerns with the bottomland hardwood mitigation plan.

We have carefully considered each of your comments, and detailed responses for each are provided in Enclosure 1. EPA specifically asserts that the plan does not comply with the Compensatory Mitigation for Losses of Aquatic Resources; Final Rule – Federal Register, Volume 73, No. 70 (April 10, 2008), referred to as the 2008 Mitigation Rule. The first paragraph of the 2008 Mitigation Rule specifies that it applies to USACE Clean Water Act (CWA) Section 404 permits. USACE Civil Works construction projects authorized by the U.S. Congress do not require Section 404 permits.

The S2G mitigation plan for this Civil Works project complies with all appropriate and relevant regulations, policies and guidance. Specifically, the bottomland hardwood mitigation is in compliance with the USACE Planning Guidance Notebook (ER 1105-2-100), Section 906(d) of the Water Resources Development Act (WRDA) 1986, Section 2036(a) of WRDA 2007 – Mitigation for Fish and Wildlife and Wetlands Losses," and associated implementation guidance. In addition to other requirements, WRDA 2007 requires mitigation plans, developed in compliance with the Civil Works guidance described above, to be consistent with CWA 404(b)(1) Guidelines and the 2008 Mitigation Rule. The mitigation plan complies with the WRDA 2007 Section 2036(a) implementation guidance and therefore is consisent with the 2008 Mitigation Rule. In addition, the S2G mitigation plan for this Civil Works project was developed in consultation with numerous Federal and state resource agencies, including EPA. As documented in the Coordination Act Report, the U.S. Fish and Wildlife Service supports the proposed mitigation plan and all of the other resouces agencies are supportive of the plan.

We appreciate the cooperative role that EPA has played in facilitating the development of this project. Thank you for your comments and I look forward to future coordination with your agency.

Sincerely,

Theodore A. Brown, P.E.
Chief, Planning and Policy Division
Directorate of Civil Works

USACE Detailed Response to EPA Region 6 State and Agency Review Comments (dated 7 July 2017)
Sabine Pass to Galveston Bay, Texas, Final Integrated Feasibility Report and Environmental Impact Statement
10 August 2017

The U.S. Environmental Protection Agency (EPA), by letter dated July 7, 2017, notified USACE that it has completed its review of the Sabine Pass to Galveston Bay (S2G) Final Integrated Feasibility Report and Environmental Impact Statement (FIFR-EIS). EPA noted that while the FIFR-EIS has addressed many of the concerns described in their comments on the draft S2G report, EPA continues to have some concerns, especially in regard to the bottomland hardwoods mitigation plan. Detailed responses to the seven EPA comments are provided below.

1) Clean Water Action Section 404 Guidelines

USACE Response:

Identification of a "least environmentally damaging practicable alternative" (LEDPA) is a requirement for evaluation of Department of Army Section 404 permits but it is not required for Civil Works projects. Regulatory-unique evaluation procedures including LEDPA, are necessitated by the unique nature of a private application for disposal of dredge and fill material. USACE, as was demonstrated here, considered and disclosed in the S2G FIFR-EIS all of the same impacts and mitigation considerations that a Department of Army permit would be subjected to for similar non-Federal impacts.

More specific information describing efforts to avoid and minimize impacts to aquatic resources is provided in an appendix to the Main Report. Appendix O "Wetland Value Assessment Modeling" describes several iterations of alignment modifications that were conducted in coordination with appropriate resource agencies, including EPA. Section 2 and Figure 2-4 present the full alignment originally considered and evaluated in the S2G DIFR-EIS. The Orange alignment originally included Reaches 1-3, and screenings utilizing economic, cost and environmental criteria resulted in the elimination of Reaches 1 and 2 from further consideration. Orange 3 was retained for further evaluation. Figure 2-5 presents the Orange 3 alignment that was evaluated as the Tentatively Selected Plan (TSP) in the DIFR-EIS. Figures 5-2 through 5-13 present the ultimate Orange 3 alignment that was included in the Recommended Plan. Section 6.0 explained that specific areas of divergence between the TSP and the Recommended Plan were mapped and described in this section. As stated in paragraph 6.4, the overall percentage of floodwalls was increased from about 20 percent in the TSP to about 40 percent in the Recommended Plan in order to avoid and minimize impacts to wetlands, and to avoid impacts to residences and pipelines. Figures 6-1 through 6-4 provide a comparative illustration of the changes made to the alignments to avoid and minimize wetland and other impacts. The additional information and maps provided in Appendix O clearly demonstrate that the Recommended Plan minimizes impacts to the greatest extent practicable. As described in the Main Report, the alignment was positioned at

the edge of the uplands, on the upland/wetland margin, and specifically situated to avoid wetlands to the greatest extent practicable. Floodwalls were recommended instead of levee systems wherever needed to reduce impacts to aquatic resources, producing a least environmentally damaging environmental plan.

2) No Net Loss of Wetlands

USACE Response: The S2G mitigation plan is in compliance with ER 1105-2-100 and implementation guidance for Section 2036(a) of the "Water Resources Development Act (WRDA) 2007 – Mitigation for Fish and Wildlife and Wetlands Losses." In addition to other requirements, WRDA 2007 requires that mitigation plans comply with mitigation standards and policies of the USACE regulatory program and contain specific mitigation plan components. The implementation guidance states that Civil Works studies will continue to use the mitigation planning process described in ER 1105-2-100, as supplemented by the Section 2036(a) implementation guidance. Specific mitigation plan components were added to the implementation guidance to ensure consistency with regulatory guidance contained in "Compensatory Mitigation for Losses of Aquatic Resources; Final Rule – Federal Register, Volume 73, No. 70 (April 10, 2008) which is also known as the 2008 Mitigation Rule . Thus, mitigation plans developed in compliance with the Civil Works guidance described above are consistent with Clean Water Act (CWA) 404(b)(1) Guidelines.

ER 1105-2-100, paragraph C-3(d)(3)(1) requires that damages to all significant resources be avoided and minimized to the extent practicable and that unavoidable damages be compensated to the extent possible. Furthermore, ER 1105-2-100, paragraph C-3(e) requires the use of a habitat-based methodology to evaluate impacts and identify mitigation needs. In this case, S2G Recommended Plan impacts and mitigation needs for bottomland hardwoods were determined using the Wetland Value Assessment (WVA) Bottomland Hardwood and Cypress-Tupelo Swamp models. These WVA models were certified for use through the USACE Planning Model Certification process; they produce habitat-based assessments that evaluate changes in aquatic ecosystem function and provide outputs in average annual habitat units (AAHU). As required by USACE guidance, this output was used to determine mitigation requirements using a cost-effectiveness/incremental cost analysis. The total AAHU . bottomland hardwood impacts of -42.7 AAHUs were used as a minimum target to incrementally evaluate several different mitigation measures. Mitigation plans producing a total of 62.5 AAHUs were recommended, thereby ensuring that losses to wetland function were more than fully compensated and thus, there would be no net wetland loss.

3) Final IFR/EIS: Appendix O and Appendix P; Mitigation Plan

USACE Response: Mitigation planning for the S2G project was performed in conformance with ER 1105-2-100, paragraph C-3(e), Section 906(d) of the Water Resources Development Act (WRDA) 1986, and the implementation guidance for Section 2036(a) of WRDA 2007. As described in Section 6.4.2.1 of the Main Report,

preservation was evaluated as potential mitigation for forested wetlands because extensive interagency evaluation found very limited opportunities for forested wetland restoration in the study area. Large areas in both the Neches and Sabine River bottomlands are already preserved by Federal or state agencies. Large stands of second growth forest on private property have experienced little disturbance since virgin growth timber stands were harvested in the late 19th and early 20th century. Most of these stands are located in bottomlands with good hydrologic connectivity and overland flow, limiting opportunities for hydrologic restoration. Tallow infestation is generally limited to small areas on the margins. Other areas, especially in the Sabine River watershed, have been converted to silviculture and are actively managed as mono-culture stands.

The S2G resource agency team discussed types of mitigation that could be implemented in this project area, identifying the following general types of mitigation: 1) marsh restoration using dredged material from navigation channels in the area; 2) hydrologic restoration of marsh or forested wetland areas; 3) preservation of forested wetlands areas in perpetuity, either with conservation easements or transference to a state conservation agency; and 4) preservation of forested wetland sites and restoration activities on these sites, such as Chinese tallow or other invasive plant control, or establishment of new or restoration of forested wetlands. All of the agencies were encouraged to identify specific sites of interest, including EPA. These proposed mitigation sites were selected by the S2G resource agency team based upon knowledge of the study area and close examination of Google Earth imagery. In addition, a two-day boat trip was conducted in 2016 to observe potential areas; reference site data was also collected from Texas Parks and Wildlife Department (TPWD)-owned properties. Screening of the measures for inclusion in the final array was done by the USACE and resource agency team as a group. The interagency team was provided an opportunity to comment on draft versions of Appendices O (WVA Modeling) and P (Monitoring and Adaptive Management Plan). No written or oral comments were provided by the EPA representative on this interagency team, who retired at the end of 2016. However, EPA and other agency suggestions were adopted wherever practicable in developing the final mitigation plans.

All of the resource agencies were active in this evaluation, but two were especially involved in the planning efforts. TPWD identified specific areas where they would like to see mitigation implemented, to offset impacts from project construction to property under their control. EPA conducted an exhaustive aerial image search and identified more than 100 additional sites for analysis. All of the proposed sites are listed in Attachment 5 of Appendix O, along with reasons why they were eliminated from further consideration or advanced for further screening. In total, 161 mitigation measures were evaluated, including about 50 bottomland hardwood measures. Eight bottomland hardwood measures were advanced into the final screening and four of these included restoration components. The other four areas were in good condition and no restoration needs were identified other than potential losses to silviculture or development. Three areas were identified that could benefit from hydrologic restoration. These areas are located in the Blue Elbow Mitigation Bank, on property co-managed with by Texas

Department of Transportation (TXDOT) and TPWD. TXDOT did not express support for the proposed hydrologic restoration activities in these areas, making implementation of the measures highly unlikely. The WVA future without-project assessment of the bottomland hardwood areas included an evaluation of the ecological effect of tallow growth in the areas where their presence was suggested by aerial imagery. Therefore, net mitigation benefits were lower than for areas with no indications of tallow. As noted in the EPA comment, restoration was evaluated in conjunction with one preservation measure in Mitigation Area 161. The ecological benefits of a tallow control measure were modeled, and the additional benefits of this costly measure were found to be very modest, adding a lift of 6.4 AAHUs to the preservation only lift of 49.3 AAHUs.

Following a recommendation from the EPA representative on the resource agency team, the preservation mitigation plans were developed to compensate for bottomland hardwoods under threat of destruction or adverse modification. The analysis of this threat, presented in Section 8.3.1 of Appendix O, is sufficient to adequately demonstrate this threat and to justify acceptance of the preservation only mitigation plans. A GIS analysis of forested wetlands in the lower Sabine River watershed compared indicators of logging disturbance (i.e. clearcutting or linear plantation plantations) between 1989 and 2015 aerial images of the area. This analysis found that an average of 3.28 percent of the forested wetlands has been disturbed prior to 1989 and an average of 4.27 percent had been disturbed between 1989 and 2015. Based on this analysis, the future without-project condition in the WVA modeling assumed a 3.28 percent loss of bottomland hardwoods for the years TY5 through TY31 and a 4.37 percent loss from TY 32 through TY61. Preservation does provide a functional lift because it maintains the bottomland hardwood as a functional part of the wetland ecosystem, as opposed to loss of a small percentage of the area to clear-cutting or conversion to mono-culture pine plantations.

ER 1105-2-100, paragraph C-3(e) and the implementation guidance for Section 2036(a) of WRDA 2007 require that mitigation planning for USACE Civil Works studies establish mitigation need by measuring the with-project condition against the future without-project condition. Mitigation credit calculations based upon functional lift between pre- and post-project (actual) site conditions, as required by 40 CFR 230.98(o)(3), do not apply to Civil Works studies, and mitigation ratios applied for mitigation of recent permitted activities in this region similarly do not apply. Civil Works guidance on the appropriate amount of mitigation requires the use of a habitat-based methodology to evaluate functional changes associated with impacts and mitigation needs. As described above, approved models and mitigation planning methods were used in selecting mitigation measures for the Orange 3 Recommended Plan. The appropriate amount of mitigation was not determined using a ratio of compensatory mitigation acreage to impacted acres. However, in the interest of transparency, the ratio of proposed mitigation for bottomland hardwoods acres impacted by the Orange 3 project would be 8.1:1, calculated for all of the bottomland hardwoods affected by the project, inclusive of cypress-tupelo swamp hardwoods.

4) "Best Buy Plan" Approach and Preservation

USACE Response: As discussed above, mitigation planning for Civil Works projects complies with ER 1105-2-100 (Planning Guidance Notebook) and implementation guidance for Section 2036(a) of WRDA 2007. This guidance does not require the selection of the lowest cost Best Buy Plan. Higher cost plans can be recommended if the additional lift provided by the higher cost plan can be justified and HQ-USACE approves. In this case, the additional lift provided by the tallow control plan for Mitigation Measure 161 provided a small amount of lift for a significant additional cost. This was discussed with resource agencies in a meeting on the mitigation plan recommendation. The minor lift was not considered worth the considerable increased cost of implementation. All of the other resource agencies have concurred with the final mitigation recommendations.

5) Site Protection Instrument

USACE Response: USACE Real Estate will ensure that the appropriate legal instruments are utilized to preserve the mitigation sites in perpetuity.

6) Temporal Losses.

USACE Response: Implementation timing for the mitigation plans presented in the construction monitoring performance standards (Appendix P) complies with the following USACE guidance. ER 1105-2-100 paragraph 2-3 (c) (6) "Mitigation measures determined to be appropriate should be planned for concurrent implementation with other major project features, where practical," and (9) "Timing of Implementation. For all water resources development projects, on which construction has not commenced as of 17 November 1986, authorized ecological resource mitigation features, including the acquisition of lands or interest in lands to mitigation losses to ecological resources, shall be undertaken or acquired either: (a) Before any construction of the projection (other than such mitigation land acquisition) commences; or (b) Concurrently with the acquisition of lands and interests in lands for project purposes (other than mitigation of fish and wildlife losses); whichever the Secretary determines is appropriate, except that any physical construction required for the purpose of mitigation may be undertaken concurrently with the physical construction of the project..." The timing was developed to ensure that all mitigation measures would be complete and functioning concurrently with completion of project construction. The timing is meant as a minimum standard and provides sufficient time for the acquisition of mitigation property which can be a lengthy process. The period of analysis utilized in the WVA modeling was designed to account for all temporal losses associated with the project construction period.

The O&M Phase standards allow for a maximum of a 5 acres of forested wetland to be sold without replacement. This will allow a small degree of flexibility to mitigation land managers. The actual AAHU loss associated with these acres would be small. For Mitigation Area 11, the loss of 5 acres equates to 0.225 AAHU from a total of 13.2 AAHUs provided to compensate for the loss of 7.3 AAHUs. For Mitigation Area 161, the

loss of 5 acres equates to 2.2 AAHUs from a total of 49.3 AAHUs provided to compensate for the loss of 35.4 AAHUs. Clearly, sufficient lands would be maintained to ensure the appropriate amount of mitigation in perpetuity.

7) Monitoring and Adaptive Management

USACE Response: As discussed in other responses above, the S2G mitigation plans (including monitoring and adaptive management) for Civil Works projects were developed in conformance with ER 1105-2-100, paragraph C-3(e) and the implementation guidance for Section 2036(a) of WRDA 2007. These regulations and guidance do not utilize ratios to determine appropriate mitigation, nor are they required to conform to standards or criteria applied to mitigation banks in this district. The appropriate amount of mitigation was determined with a habitat-based assessment that evaluated changes in aquatic ecosystem function. EPA was provided an opportunity to informally review the monitoring/adaptive management plan in draft form before the FIFR-EIS was released; no comments were provided.

As described in Section 2.0 of Appendix P, if monitoring reports indicate that if mitigation success is threatened, significant corrective actions can be taken as described in the Adaptive Management Plan. The monitoring and adaptive management plans can be modified, as needed, if monitoring results and continuing consultation with the resource agencies determine that the objectives of the mitigation plans are not being achieved.

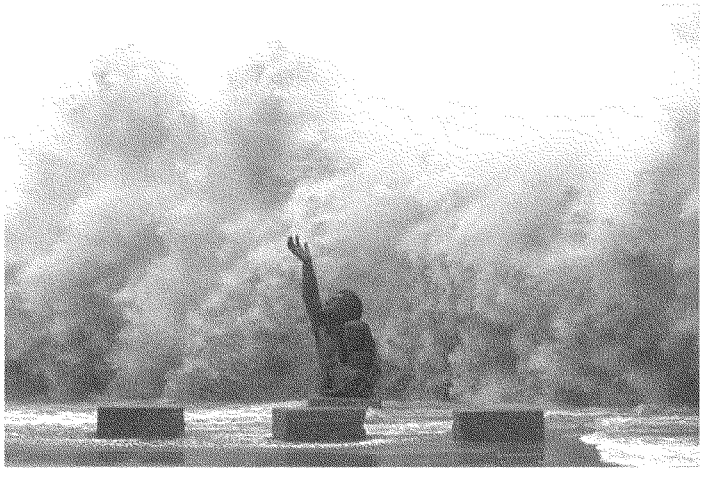
U.S. Army Corps
of Engineers

Galveston District
Southwestern Division

Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration

Volume 1

Final Integrated Feasibility Report – Environmental Impact Statement and Appendix A and B



May 2017

DEPARTMENT OF THE ARMY
GALVESTON DISTRICT, CORPS OF ENGINEERS
P. O. BOX 1229
GALVESTON, TEXAS 77553-1229

Sabine Pass to Galveston Bay, Texas
Coastal Storm Risk Management
and Ecosystem Restoration

Final Integrated Feasibility Report – Environmental Impact Statement

May 2017

**FINAL ENVIRONMENTAL IMPACT STATEMENT
FOR THE PROPOSED SABINE PASS TO GALVESTON BAY, TEXAS
COASTAL STORM RISK MANAGEMENT
AND ECOSYSTEM RESTORATION PROJECT**

The U.S. Army Corps of Engineers, Galveston District (USACE), under the authority of, a resolution from the Committee on Environmental and Public Works dated June 23, 2004, entitled "Coastal Texas Protection and Restoration Study" proposes to reduce the risks of tropical storm surge impacts by constructing the new Orange 3 coastal storm risk management (CSRM) system in Orange County, and increasing the level of risk reduction and resiliency of the existing Port Arthur and Vicinity and Freeport and Vicinity Hurricane Flood Protection (HFP) systems in Jefferson and Brazoria Counties, Texas. The Orange 3 CSRM project would consist of a 26.7-mile long levee/floodwall system along the edge of the Sabine and Neches River floodplains from Orange to the vicinity of Orangefield, Texas. The Port Arthur and Freeport CSRM Projects would raise or reconstruct 11.6 miles and 18.2 miles of existing levees/floodwalls for each system respectively, replace vehicular closure structures, construct navigable surge gate structures, and increase resiliency by installing erosion protection. The Orange 3 project would result in the loss of 69.5 acres of forested wetlands and 203.0 acres of estuarine marsh, as well as functional impacts to 2,137.2 acres of estuarine marsh. These impacts would result in the loss of 43 average annual habitat units (AAHUs) for forested wetlands and 143 AAHUs for estuarine marsh. A mitigation plan is proposed that restores 453 acres of estuarine marsh and preserves 559.5 acres of forested wetlands in perpetuity, providing 263 AAHUs to fully compensate for these impacts. The total first cost of the project is estimated to be $3,248,607,000.

This Final Integrated Feasibility Report and Environmental Impact Statement (FIFR- EIS) was prepared as required by the National Environmental Policy Act to present an evaluation of potential impacts of the proposed project. The FIFR-EIS addresses the potential impacts of the proposed project on the human environment, as identified during the public interest review, including potential effects on life and safety, economic benefits, air, water and sediment quality, forested wetlands and coastal marsh, protected species, hazardous and toxic materials, historic properties, energy needs, and, in general, the welfare of the people. Public and agency comments received during the public comment period were addressed. The public and agency comments on the findings of the FIFR-EIS will be addressed in the Record of Decision.

Comments on this FIFR-EIS must be postmarked by: June 26, 2017

Comments may be submitted by email at: SabinePassToGalvestonBay@usace.army.mil
or at the following address:

U.S. Army Corps of Engineers, Galveston District
Attention: Sabine Pass to Galveston Bay, Texas, Study
P.O. Box 1229
Galveston, Texas 77553-1229

EXECUTIVE SUMMARY (*NEPA Required)

STUDY DESCRIPTION

This is a Final Integrated Feasibility Report and Environmental Impact Statement (FIFR-EIS) examining coastal storm risk management (CSRM) and ecosystem restoration (ER) problems and opportunities within six counties of the upper Texas coast (Orange, Jefferson, Chambers, Harris, Galveston, and Brazoria Counties). The study has identified and screened alternatives to address CSRM and ER problems, and is presenting a Recommended Plan. This FIFR-EIS has undergone public review, policy review, Agency Technical Review (ATR), and Independent External Peer Review (IEPR). Final public and agency comments on the findings of the FIFR-EIS will be addressed in the Record of Decision (ROD).

STUDY PURPOSE AND SCOPE

The purpose of this report is to present the final findings of the feasibility investigations and analyses conducted to determine if there is a Federal interest in potential CSRM and ER projects within the coastal areas of the six-county study area. The scope of the study was the subject of multiple vertical team meetings with Headquarters USACE (HQUSACE) in the early stages of formulation. This study is recognized as a critical effort that encompasses six counties (Orange, Jefferson, Chambers, Harris, Galveston, and Brazoria) along 120 miles of the upper Texas coast (Figure ES-1). Multiple options for study scope were considered for this extensive geographic area. It became apparent as the study team identified alternatives, that a feasibility-level evaluation of all the potential alternatives in the entire six-county study area would be difficult to accomplish and maintain compliance with the 3x3x3 Rule. This rule applies to feasibility studies and requires completion within 3 years and under $3 million, unless an exemption is approved by HQUSACE. A Feasibility-level evaluation of all of the potential alternatives in the six-county study in three years introduced risk that was too high and not acceptable for decision making. An exemption request was approved in a CECW-SWD memorandum dated February 25, 2014. The approval was granted to pursue a scope for this study that would take 3.9 years and cost $4.4 million, and address only feasibility-level evaluation of CSRM projects in two of the three regions originally identified for the study (Sabine, Galveston, and Brazoria). The exemption approved evaluation of the Sabine region, focusing on Orange and Jefferson Counties, and the Brazoria region, focusing on the Freeport area in Brazoria County. Because of cost and complexity, the decision was made to include only a comprehensive assessment of potential CSRM projects in the Galveston region (Galveston, Harris, and Chambers Counties) and potential ER projects throughout the entire six-county study area. The comprehensive assessment is a listing of future studies that have high potential for recommending CSRM and ER projects with Federal interest. For example, one of the

ongoing studies, the USACE Coastal Texas CSRM and ER Feasibility Study is addressing issues in the Galveston Bay Region.

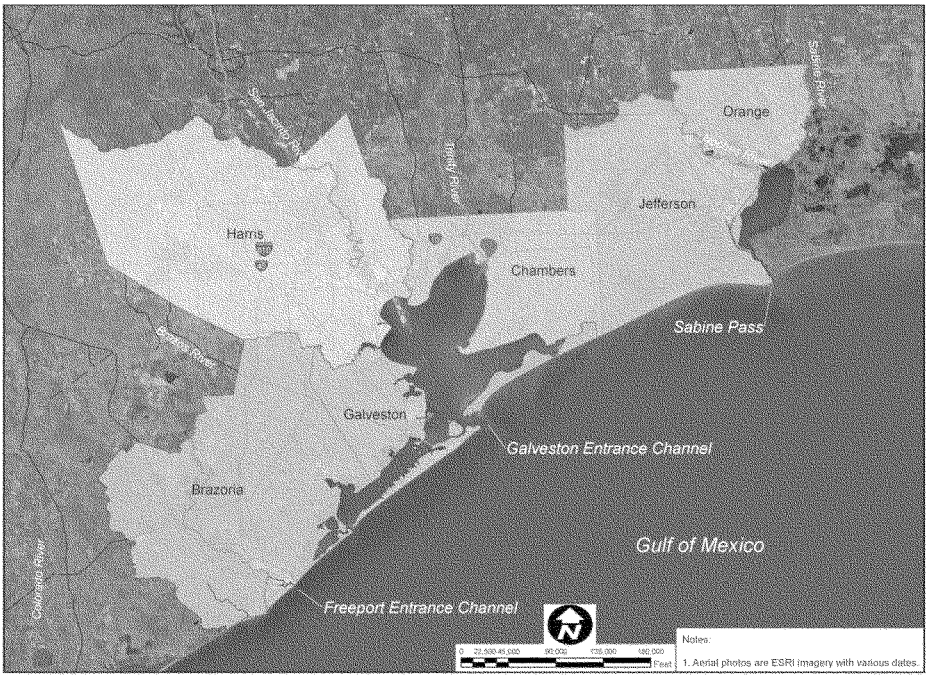


Figure ES-1: Sabine Pass to Galveston Bay Study Area

PROJECT PURPOSE AND NEED

The study area has seen several major historical surge events in the past 120 years. The most notable is the 1900 Storm, which inundated most of the island city of Galveston, Texas, and adjacent areas on the mainland. The storm was responsible for over 8,000 deaths and up to $30 million in property damage. Most recently, Hurricane Rita in 2005 resulted in storm surge of 9.24 feet in Port Arthur, Texas, and just over eight feet in Sabine Pass. Hurricane Ike in 2008 produced storm surges from 14 feet near Sabine Pass with 11 to 12 feet across Sabine Lake. Port Arthur was spared the storm surge thanks to its 14- to 17-foot seawall. However, the remaining southern half of Jefferson County was inundated, with estimated high water marks reaching 18 to 19 feet to the south and east of High Island.

Both hurricanes resulted in significant impacts on coastal shorelines, marsh, and forested wetlands. Shorelines eroded in some areas, while others were covered with several feet of sediment. Thousands of acres of coastal marsh were inundated with high salinity Gulf waters, scouring and killing marsh types that were not tolerant of the higher salinity. In addition to inundating marshes near the coast, tidal surges resulted in significantly increased salinities in large areas of swamp and freshwater marsh in the Sabine region for months after the storms.

Specific Problem and Opportunity statements were developed to address the need to reduce coastal storm risks in the study area, and these are described in the main body of this FIFR-EIS, in Chapter 4. This study identifies a Recommended Plan for implementation to address the storm surge flooding in the study area. Considering the recent damages from Hurricane Ike, the population and infrastructure of the region, and the national significance of the economic and environmental resources within the region, there is a Federal interest for implementing a project. A variety of alternatives were analyzed in the study, including the "No Action Alternative." The "No Action Alternative" is synonymous with the terms "future without-project" or "future without-project condition". These terms are used interchangeably throughout the FIFR-EIS and provided for a baseline comparison of all alternatives. The without-project condition describes the condition that is expected to prevail in the planning area in the future if the No Action Alternative is selected as the best thing to do. The alternatives were also measured against planning criteria developed for the study that align with USACE policies.

PLANNING OBJECTIVES

The objectives listed below were developed from problem and opportunity statements and used to guide the plan formulation for the Recommended Plan. The alternatives were measured throughout the study using the measuring criteria and in greater detail as the alternative screening progressed. The planning objectives were developed to align with the "four accounts" listed in the Economic and Environmental Principles for Water and Related Land Resources Implementation Studies. These "principles" were established pursuant to P.L. 89-80, as amended. The four accounts are established to facilitate evaluation and display of effects of alternative plans. The four accounts are: 1) National Economic Development (NED); 2) Environmental Quality (EQ); 3) Regional Economic Development (RED); and 4) Other Social Effects (OSE).

- Objective 1: Reduce economic damages to business, residents, and infrastructure for the Sabine and Brazoria regions for the 50-year period of analysis.
- Objective 2: Reduce risk to human life from storm surge impacts for the Sabine and Brazoria regions for the 50-year period of analysis.

- Objective 3: Maintain and/or restore coastal habitat that contributes to storm surge attenuation where feasible for the 50-year period of analysis.
- Objective 4: Enhance energy security and reduce economic impacts of petrochemical supply-related interruption for the Sabine and Brazoria regions for the 50-year period of analysis.
- Objective 5: Reduce risk to critical infrastructure (e.g., medical centers, ship channels, schools, transportation) for the Sabine and Brazoria regions for the 50-year period of analysis.
- Objective 6: Identify opportunities to enhance functionality of existing hurricane protection systems including evaluation of impacts due to sea level rise for the 50-year period of analysis.

Alternative plans were formulated to reduce the risk of damages from coastal storms, minimize impacts to floodplains, and avoid environmentally significant resources. Where impacts could not be avoided, environmental impacts were quantified and a mitigation plan was formulated.

The following constraint was developed from the problem and opportunity statements and used to guide the plan formulation for this study. Reducing life-safety risk is a primary objective of the study; however, careful evaluation of alternatives is required to ensure that structural plans do not increase risk. As such, features that increase risk to human life from storm surge impacts in the Sabine and Brazoria regions for the 50-year period of analysis were not considered with the development of the Recommended Plan.

FORMULATION OF ALTERNATIVE PLANS

Nonstructural and structural measures were considered as part of the study analysis and were developed to address study objectives. The nonstructural measures considered include buyouts or relocations, as well as identification of conservation areas. Floodplain management and emergency planning were also considered. The structural measures include new coastal and inland structural barriers, reconstruction of existing and construction of new regional hurricane risk reduction systems, local surge risk reduction systems, raising roads as surge or overwash risk reduction barriers, Gulf shoreline protection (beach and dune restoration, nearshore breakwaters, chenier ridge restoration), Gulf Intracoastal Waterway (GIWW) erosion protection, marsh restoration, and salinity/water control structures.

Through the initial scoping, and performance of a SMART Planning Charette (Charette), the full Vertical Team (USACE District, Division, Headquarters, and Office of Water Project Review) with participation with the local sponsor, worked through an abbreviated version of the six-step planning process, considering a full array of measures and alternatives, and then formulated

comprehensive (regional) plans to include in the "Initial Alternative Plans Array." This resulted in a list of about 75 initial measures that served as the building blocks of alternative plans. These nonstructural and structural measures were considered as part of the study analysis and were developed to address study objectives.

The initial measures were screened to determine if they adequately addressed the problems and objectives of this study. The remaining measures were then formed into arrays of alternatives plans, which were screened in three distinct iterations (increasing in level of detail as the screening progressed) to determine the most effective alternatives including:

- Initial Array of Alternatives;
- Evaluation Array of Alternatives; and
- Final Array of Alternatives.

In the Initial Array of Alternatives phase, comprehensive alternative plans were formulated for each of the three regions in the six-county study area. The Initial Array of Alternatives included eleven alternatives for the Sabine Region, nine alternatives for the Galveston Region and five alternatives for the Brazoria Region, for a total of 25 alternatives considered in the Initial Array of Alternatives. The Initial Array of Alternatives were screened using three quantitative criteria (economic benefits, environmental benefits, and implementation costs) and one qualitative criterion (environmental impacts). The screening process led to the identification of the Evaluation Array of Alternative Plans, which is comprised of ten alternatives (three from Sabine Region, four from Galveston Region, and three from Brazoria Region) to be evaluated in more detail.

The Evaluation of Alternatives was used as a decision point to determine whether the data collected and utilized for this analysis are sufficient to make the determination of which alternative "Gate" or "No-Gate" in the Sabine Region to carry forward for detailed analysis. It was estimated the plans would provide roughly the same amount of benefits. Consideration was given to a variety of factors including engineering, economics, costs, and environmental impacts for the Gate and No-Gate Alternatives; however, cost of the Gate Alternative was approximately $865 million more expensive than the No-Gate Alternative. The Gate Alternative also include significant Operation, Maintenance, Repair, Replacement and Rehabilitation (OMRR&R) concerns associated with crossing the Neches River. Therefore, the Gate Alternative was dropped from further consideration in the study.

As discussed above, the final recommendation was to pursue a $4.4 million comprehensive assessment of the six-county study area and focus the current evaluation on two sub-regions, Sabine and Brazoria for CSRM project implementation. This feasibility study will be followed by future studies recommending CSRM projects in the Galveston region, as well as ER opportunities

throughout the entire six-county region. In accordance with the exemption request approval, the Sabine and Brazoria CSRM alternatives were carried forward into detailed feasibility analysis. The Final Array of Alternatives is presented in Table ES-1. This list presents the project area for the final array. The "Optimization Alternatives" embedded in the project areas listed in Table ES-1 are the actual final array evaluated, compared and presented in the DIFR-EIS released in Sept 11, 2015.

Table ES-1: Final Array of Separable Elements presented in DIFR-EIS

Initial Array Alternative Name	Final Array of Separable Elements / Description
No Action	No Action or Future Without Project (FWOP)
S5	Orange-Jefferson CSRM
S5	Port Arthur and Vicinity CSRM
B2	Freeport and Vicinity CSRM
S11 & B5	Brazoria and Sabine Nonstructural

The DIFR-EIS presented the results of the alternatives analysis and selection of the TSP through an iterative process based on economic, environmental, regional economic, social, and engineering factors (i.e. the four accounts – 1) National Economic Development; 2) Environmental Quality; 3) Regional Economic Development; and 4) Other Social Effects). From evaluation of 59 Optimization Alternatives within 20 Alternative Reaches, the performance of Final Array of Alternatives was measured, then evaluated and compared against each other to determine a TSP. The evaluation included a comparison of the future without-project condition (FWOP) and the with-project condition. Since the release of the TSP, the USACE conducted a detailed feasibility analysis of the elements listed in Table ES-1.

AFFECTED ENVIRONMENT

The affected natural environment is a large and complex region that includes approximately 6,865 square miles and two environmentally sensitive and economically important bay systems (Sabine Lake and Galveston Bay), and the coastal portions of several large watersheds (Sabine, Neches, Trinity, San Jacinto and Brazos Rivers). It covers about 120 miles of the Texas coast. Diurnal tidal ranges are small, ranging from 1.3 to 2.0 feet. The study area lies within the Western Gulf Coastal Plain ecoregion, which extends along the Texas Gulf Coast from the Sabine River south to the Rio Grande. The prominent features of this coastal ecosystem include fresh, intermediate, brackish and saline marshes; bays and lagoons that support extensive seagrass beds, tidal flats, and reef complexes; barrier islands; tallgrass prairie with small depressional wetlands, riparian forests, oak mottes, and dense brush habitats. The Sabine and greater Galveston Bay estuaries and extensive coastal wetlands in the coastal Brazos River region are a vital habitat for 75 percent of

the fish and shellfish species found in the Gulf of Mexico. The marshes and rice fields over the entire study area are a major wintering area for waterfowl of the central flyway. On average, 1.3 to 4.5 million ducks, or 30 to 71 percent of the total flyway population, winter annually on the Texas Gulf coast. On average, 180,000 pairs of colonial-nesting waterbirds nest annually in Texas coastal habitats. Near coastal forests are critically important for the nation's songbird resources, as the vast majority utilize this habitat during their trans- and circum-Gulf migrations. A string of refuges and wildlife management areas (WMAs) along the coast serve as critical staging areas for waterfowl migrating to and from Mexico.

The affected human environment encompasses six coastal counties of the upper Texas coast. Over five million people reside in the six counties, which includes the fourth largest U.S. city (Houston), and three other metropolitan areas (Beaumont/Port Arthur/Orange, Galveston/Texas City, and Freeport/Surfside). In addition to the population at risk, three of the nine largest oil refineries in the world, 40 percent of the nation's petrochemical industry, 25 percent of the nation's petroleum-refining capacity, and three major U.S. seaports based on tonnage (Port of Houston, Port of Beaumont, and Texas City) are also located in the study area. The growing population, communities, and nationally significant industries are severely vulnerable to risks from coastal storm events. Approximately 2.26 million people across the study area live within storm-surge inundation zones, and estimates for a one-month closure of the Houston Ship Channel alone are upwards of $60 billion in damages to the national economy.

NO ACTION/FUTURE WITHOUT-PROJECT CONDITION

Before the Final Array of Alternatives were evaluated, additional details of the future without-project conditions were gathered for the project areas. Based on the evaluation of the No Action/FWOP conditions, there is the potential for significant economic damages in the Orange-Jefferson CSRM, Port Arthur and Vicinity CSRM, and Freeport and Vicinity CSRM project areas. There are also concerns for life-safety, damages to critical infrastructure, sea level changes, and impacts on significant environmental resources. Storm surge associated with Hurricane Rita flooded much of southern Orange County, causing significant damages in Bridge City, Rose City and the City of Orange. While the existing Port Arthur and Vicinity Hurricane Flood Protection Project (HFP) prevented surge from entering that city, it was nearly overtopped. Changing conditions associated with relative sea level change would result in increasing risks of loss of life and surge damages in the areas currently served by the Port Arthur and Freeport HFP projects. Opportunities to provide life-safety benefits, and other non-traditional secondary or ancillary economic benefits were identified, including preventing disruptions in business and increases in reducing disruption to significant industrial and manufacturing facilities located in the project areas.

FINAL ARRAY EVALUATION RESULTS

As described in the DIFR-EIS the alternatives in each project area were evaluated in detail, then compared against each other to identify which plan contributes most to the objectives. This process continued throughout the detailed feasibility analysis. The alternatives were again evaluated for the NED objectives. Life-safety, critical infrastructure, and consideration of RSLC were also evaluated qualitatively. The decision criteria for selecting a Recommended Plan at this point in the study was based on building a plan for each project area that reasonably maximized net benefits (Objective 1 for the study) consistent with the Federal objective of protecting the Nation's environment. In addition, separable elements of each project area had to be incrementally justified to be included in the final plan. The table below shows how the TSP has been further optimized since the DIFR-EIS was released in Sept 11, 2015.

Table ES-2: Overview of changes since release of DIFR-EIS

Project Area	Elements presented in Sept 11, 2015 DIFR-EIS	Elements in Final Recommendation
Orange-Jefferson CSRM	Orange 3 New Levee (11-foot)	**Included in Final Recommended Plan**
	Beaumont A New Levee (12-foot)	Removed due to limited net benefits, and recently constructed risk reduction improvements.
	Jefferson Main New Levee (11-foot)	Removed due to limited net benefits
Port Arthur and Vicinity CSRM	8-10 ft I-Wall Raise (1-foot)	**Included in Final Recommended Plan**
	Closure Structure Raise (1-foot)	**Included in Final Recommended Plan**
	I-Wall Raise Near Valero (1-foot)	**Included in Final Recommended Plan**
	I-Wall Raise Near Tank Farm (1-foot)	**Included in Final Recommended Plan**
	-------	**Final Recommended Plan included an additional 1,830 LF of new levee added to Existing Port Arthur and Vicinity HFPP to address flanking of surges**
Freeport and Vicinity CSRM	Dow Barge Canal Gate Structure	**Included in Final Recommended Plan**
	Oyster Creek Levee Raise (1-foot)	**Included in Final Recommended Plan**
	East Storm Levee Raise (1-foot)	**Included in Final Recommended Plan**
	Freeport Dock Floodwall Raise (1-foot)	**Included in Final Recommended Plan**
	Old River Levee Raise at Dow Thumb (1-foot)	**Included in Final Recommended Plan**
	Tide Gate I-Wall Raise (1-foot)	**Included in Final Recommended Plan**
Brazoria and Sabine Nonstructural	-------	Buyouts were considered ancillary to the implementation of new levees/floodwalls in Orange and Jefferson Counties and to the enhancement of features in the Port Arthur and Freeport CSRM project areas. Buyout opportunities in Brazoria were virtually non-existent and very limited in both

		Orange and Jefferson Counties. A quantitative analysis was conducted to determine the viability of any proposed nonstructural buyout. The analysis showed the nonstructural buyouts had negative net benefits and any potential buyouts were screened from the analysis. There were also OSE concerns with leaving communities exposed. Improvements to risk reduction system near these communities could potentially induce stages in the local communities.

RECOMMENDED PLAN

The Recommended Plan was developed in conformance with decisions resulting from the Agency Decision Milestone (ADM) based on responses from public, policy, and technical reviews of the DIFR-EIS. The Recommended Plan consists of three elements – construction of the new Orange 3 CSRM levee/floodwall system, and levee raising/floodwall improvements in the Port Arthur and Freeport CSRM Plans. A region wide systems approach for construction of Orange 3, Port Arthur and Freeport CSRM Plan, is being recommended to ensure that all of the benefits would be achieved. Construction and completion of a region wide risk reduction system would help to lessen the financial and social impacts that tropical storms and hurricanes can cause by reducing the risk of property damage that displaces residents, shuts down commercial and industrial services, and disrupts livelihoods. The risk reduction system has been designed to provide a risk reduction against a 1% probability storm based on the 2080 intermediate relative sea level rate (RSLR) forecast condition within current data and modeling capabilities. The current design elevations varies across the system but utilizes the 2080 intermediate RSLR forecast condition to obtain a 1% level of risk reduction throughout the length of the system. It is important to note that the system should be monitored on a frequent basis to determine if there have been any changes from the initial level of risk reduction stated. The total first cost of the project is estimated to be $3,248,607,000.

- The Orange 3 CSRM Plan would add approximately 15.6 miles of new levees, at elevations ranging from 12.0 to 17.5 feet NAVD88 and approximately 10.7 miles of new floodwalls and gates at elevations ranging from 13.5 to 16 feet NAVD88. New pump stations, a total of 7, would be constructed to mitigate interior flooding during surge events, and navigable sector gates would be constructed in Adams and Cow Bayous to reduce surge penetration. A mitigation plan is included that fully compensates for all impacts of this plan, and a monitoring and adaptive management plan has been developed to ensure that mitigation outcomes are consistent with performance standards, and corrective actions are taken as needed. The total first cost of project construction and mitigation is estimated to be

$1,926,224,000 and the average annual cost of OMRR&R (including mitigation monitoring costs) is $4,565,000.

- The Port Arthur and Vicinity CSRM Plan would raise approximately 5.5 miles of the existing 27.8 miles of earthen levee to elevations ranging from 14.4 to 17.2 feet NAVD88, and construct or reconstruct about 5.7 miles of floodwall to elevations ranging from about 14.4 to 19.4 feet NAVD88. A separate 1,830 feet of new earthen levee would be constructed in the Port Neches area northwest of the existing northern terminus. Numerous vehicle closure structures would be replaced and erosion protection would be added. Environmental impacts of this plan are negligible and no mitigation is needed. The total first cost of project construction is estimated to be $729,069,000 and the average annual cost of OMRR&R is $195,000.
- The Freeport and Vicinity CSRM Plan would raise approximately 13.1 miles of the existing earthen levee system and construct or reconstruct about 5.5 miles of floodwall, improving approximately 43 percent of the existing 43-mile long system. Final elevations would range from 15.8 to 23.8 feet NAVD88. Navigable sector gates would be installed in the Dow Barge Canal to reduce surge penetration in that area. Numerous vehicle closure structures would be replaced and erosion protection would be added. Other project features include raising and reconstructing the Highway 332 crossing, installation of a drainage structure at the head of the Dow Barge Canal, and raising the floodwall at Port Freeport's Berth 5 dock. Environmental impacts of this plan are negligible and no mitigation is needed. The total first cost of project construction is estimated to be $593,313,000 and the average annual cost of OMRR&R is $708,000.

The Recommended Plan is the environmentally preferable alternative. Because the Port Arthur Freeport and Vicinity CSRM Plan is generally the lowest height of all action alternatives that were evaluated and because the Orange 3 CSRM Plan follows the wet/dry interface of the marsh in the area, it would result in the narrowest footprint and the fewest environmental impacts, while reasonably maximizing coastal storm risk reduction to the affected communities. The No Action Alternative would provide no coastal storm risk reduction to the vulnerable populations and infrastructure of the study area.

ENVIRONMENAL CONSEQUENCES

The Orange 3 CSRM element of the Recommended Plan would have significant environmental impacts and, therefore, an EIS has been prepared and integrated with the feasibility report. The Port Arthur and Vicinity and Freeport and Vicinity CSRM Plans would result in only negligible impacts. The Recommended Plan has been determined to be the least environmentally damaging practicable alternative. The Orange 3 project would result in the loss of 69.5 acres of forested

wetlands (cypress-tupelo swamp and bottomland forest) and 203.0 acres of estuarine emergent marsh, as well as indirect functional impacts to 2,137.2 acres of estuarine marsh. Ecological modeling of the Orange 3 project impacts has determined that 143 average annual habitat units (AAHUs) would be lost due to direct and indirect impacts to fresh, intermediate and brackish marsh, and 43 AAHUs would be lost due to direct and indirect impacts to cypress-tupelo swamp and bottomland hardwood forests, over the 50-year period of analysis. A $19,635,000 mitigation plan is proposed that restores 453 acres of estuarine marsh in four proposed areas and preserves 559.5 acres of forested wetlands in perpetuity in two proposed areas, providing 263 AAHUs to fully compensate for these impacts. A monitoring and adaptive management plan has also been prepared to determine if the mitigation outcomes are consistent with performance standards and to take corrective actions in case monitoring demonstrates that mitigation measures are not achieving ecological success. The monitoring plan identifies the ecological success criteria for the mitigation, and describes the cost and duration of the monitoring. Orange County, the non-Federal sponsor, would be responsible for the monitoring, resource agency coordination and adaptive management. All monitoring reports prepared by the NFS would be provided to USACE for upward reporting.

ENVIRONMENAL COMPLIANCE

Project impacts were assessed and the mitigation plan was developed in consultation with numerous Federal and state resource agencies. The U.S. Fish and Wildlife Service (USFWS) actively participated in the impacts evaluation and environmental modeling, and has prepared a Final Fish and Wildlife Coordination Act Report (Appendix K). Their recommendations have been incorporated into this proposed project to the greatest extent possible. Formal consultation with the National Marine Fisheries Service regarding impacts to essential fish habitat (EFH) have been concluded, and the mitigation plan has been accepted as providing appropriate compensation for functional losses to fisheries habitat associated with construction of navigable sector gates in Adams and Cow Bayous (Appendix G). The USACE prepared a Biological Assessment (BA) that determined that the Recommended Plan would have no effect on listed species that may occur in the project area (Appendix J) and this assessment was accepted by USFWS and NMFS. The Texas Coastal Management Program has conducted a Federal consistency review and determined that the proposed project is consistent with the Coastal Management Plan goals and policies (Appendix M). The Texas Commission on Environmental Quality (TCEQ) has reviewed the proposed project for general conformity and has determined that the general conformity rules do not apply to the project elements located in Orange and Jefferson Counties, as this area is currently in attainment with National Ambient Air Quality Standards. The proposed Freeport and Vicinity CSRM Plan is located in a current nonattainment area. However, projected emissions are below the threshold that would require a general conformity analysis (Appendix I). USACE has prepared a Clean Water Act §404(b)(1) evaluation of the proposed action, (Appendix H) and TCEQ has provided

water quality certification. The U.S. Department of Agriculture has confirmed that the proposed project site need not be given further consideration for protection of prime farmland soils in the area (Appendix G). USACE has executed a Programmatic Agreement among USACE, the Texas State Historic Preservation Officer (SHPO), and non-Federal implementation sponsors to address the identification and discovery of cultural resources that may occur during the construction and maintenance of proposed or existing facilities (Appendix L). There is a potential for new construction and improvements to existing structures to cause effects on historic properties; however, the numbers of properties that may be affected are not extensive. Intensive cultural resources investigations to identify and evaluate any historic properties within proposed construction areas will be conducted prior to construction. Coordination with Federal and state resource agencies will continue throughout the study process as required by the National Environmental Policy Act (NEPA) and Fish and Wildlife Coordination Act.

PUBLIC COORDINATION

Extensive public scoping, stakeholder communication, and resource agency coordination have been maintained throughout development of the Recommended Plan. Four scoping meetings were held in early 2012, which assisted identifying CSRM problems and ER opportunities in the original six-county study area. Two stakeholder briefings were held in the spring of 2014 that focused primarily on communicating the goals and progress of the study with local governments and agencies. Resource agency meetings were held in 2013 and 2014 to update agencies on the progress of the study, and intensive WVA modeling meetings were held through 2015 and the first half of 2016 to model impacts and mitigation associated with the Orange 3 CSRM Plan. Continuous contact has been maintained with outside organizations that have been working to address the same problems as those addressed by this study. In particular, close communication has been maintained with the team at Texas A&M Galveston, which has been working to develop the Ike Dike proposal, the Severe Storm Prediction, Education and Evacuation from Disasters (SSPEED) Center (a consortium of several universities headquartered at Rice University in Houston) which has been assessing a number of other CSRM, ER and recreation initiatives for the Galveston Bay region, and the Gulf Coast Community Protection and Restoration District (GCCPRD) which is preparing a report evaluating CSRM opportunities in the six-county study area.

The majority of the public and agency scoping comments pertained to the Galveston Bay Region and to ecosystem restoration opportunities in general, and are summarized in the report. In the Sabine region, the majority of comments pertained to the need for storm surge risk reduction in Orange County. Industrial interests and the general public emphasized the need to protect petro-chemical facilities in the area. The general public was also concerned about maintaining or

improving evacuation routes during storm emergencies. County governments, non-governmental organizations (NGOs), and the public were interested in maintaining and restoring marsh systems in the area. In the Brazoria region, the majority of comments related to the need to address hydrologic/erosion impacts of existing navigation projects, and the need for restraint in the construction of structural systems that would encourage more development. Resource agencies and NGOs urged restoration of natural coastal shoreline features and working with nature and natural processes, as well as protecting shoreline features that provide natural erosion protection.

Public comments on the DIFR-EIS focused on the potential for construction to interfere with port, municipal or industrial operations, and the need for a detailed, final mitigation plan. While supportive of the project, individuals and companies expressed concerns over impacts to their properties or operations during construction, or maintaining access through the structures after construction. One organization requested that the report provide additional explanations regarding screening of structural and non-structural alternatives, induced impacts, cumulative impacts, operations and maintenance concerns, and effect of relative sea-level rise on the proposed project. Changes to the TSP subsequent to public review of the draft report were not significant enough to require a second NEPA review. Additional information on these topics has been included, as appropriate, in this final report.

NON-FEDERAL SPONSOR SUPPORT

The existing Port Arthur and the Freeport HFPPs local sponsors have expressed interest in cost sharing for the Recommended Plan identified for the Port Arthur and Vicinity CSRM and the Freeport and Vicinity CSRM plans. The local sponsors responsible for OMRR&R are the Jefferson Country Drainage District No. 7 and the Velasco Drainage District (VDD), respectively. The local sponsor for Orange 3 CSRM Plan would be Orange County. They have also expressed interest in cost share for construction.

AREAS OF CONTROVERSY AND UNRESOLVED ISSUES

There are no known controversies regarding the Recommended Plan at this time. This study's comprehensive treatment of CSRM concerns for Galveston Bay and ER concerns for the entire study area, which was questioned by some comments on the DIFR-EIS, is being superseded by the ongoing USACE Coastal Texas CSRM and ER Feasibility Study, which is addressing all of these issues.

There are several unresolved issues that will require resolution during Preconstruction Engineering and Design (PED) or construction phases.

- Fill material for levee system construction was assumed to come from approved, commercial borrow sources. If new borrow areas are identified during PED, review of potential environmental impacts would be required.
- Some of the construction areas in all three project elements are located in or immediately adjacent to industrial sites that have a history of generating, handling or storing hazardous or toxic materials. Because of this proximity, additional hazardous, toxic and radioactive waste (HTRW) risk information would be collected with Phase I HTRW assessments during the PED phase to determine if there is potential for construction to disturb previously unknown contaminated sediments or groundwater. In addition, submerged water bottoms to be disturbed by construction of the Adams and Cow Bayou sector gates would be tested for contaminants prior to construction.
- The USACE would evaluate the results of O&M sediment testing of the Neches River Channel maintenance material, and if warranted based upon the results of this testing and evaluation, conduct additional sediment testing prior to construction to confirm the suitability of SNWW sediments for use in marsh mitigation features. The risk of identifying insufficient quantities of suitable sediment for the mitigation features is considered to be low based on the large quantity of shoaled sediments available in adjacent navigation channels, routine O&M water and sediment testing results, and the acceptability of this material for several recent Neches River beneficial use projects.
- Design and construction of the Adams and Cow Bayou sector gates should adopt "fisheries friendly design considerations" provided by NMFS, and the final design of the sector gates should result in no more than a 50 percent constriction of each. If the constriction exceeds this amount, additional impact analysis and resource agency consultation would be required.
- Intensive cultural resource investigations of the Orange 3 CSRM Plan alignment must be completed prior to construction and coordinated with the Texas SHPO.
- The Recommended Plan would impact a total of 80.1 acres of property owned by the Texas Parks and Wildlife Department (TPWD). TPWD has agreed that the feasibility-level impact analysis is sufficient at this time, pending additional study and consultation during the PED phase as planned by USACE. Final approval or concurrence by TPWD cannot occur until requirements of Chapter 26 of the Parks and Wildlife Code are met, and that process cannot be initiated until after the FIFR-EIS is complete and the project is authorized. At this time, no significant obstacles to this approval have been identified. Two of the mitigation areas identified as Best Buy Plans and selected as part of the overall mitigation plan are located on TPWD property. TPWD would consider accepting any and possibly all of the private properties acquired for mitigation purposes, as long as the properties are readily accessible to TPWD staff and the public, and practically manageable. USACE anticipates that these conditions could be met.

MAJOR FINDINGS AND CONCLUSIONS

A diligent effort was made to coordinate and collaborate with resource agencies, local industry, and environmental interests throughout the study process and public meetings. Environmental resource concerns were addressed throughout the study process to ensure that adverse impacts were avoided to the maximum extent practicable. The recommendations contained herein reflect the information available at this time. To ensure that all applicable laws and policies are addressed for the Recommended Plan, this FIFR-EIS will undergo a final state and agency review. The study team will address any outstanding issues raised during this review and confirm the Recommended Plan in the Record of Decision.

TABLE OF CONTENTS

EXECUTIVE SUMMARY (*NEPA REQUIRED) **1**

1 STUDY INFORMATION **1-1**

1.1 INTRODUCTION 1-1
1.2 STUDY AUTHORITY 1-1
1.2.1 General Authority 1-1
1.2.2 Additional Study Guidelines 1-2
1.3 STUDY PURPOSE AND SCOPE* 1-2
1.4 NON-FEDERAL SPONSOR 1-3
1.5 STUDY AREA 1-3
1.6 PROJECT AREA 1-4
1.7 PROJECT DATUMS 1-5
1.8 MAJOR HISTORICAL SURGE EVENTS IN THE STUDY AREA 1-5
1.9 HISTORY OF THE INVESTIGATION 1-6
1.10 PRIOR STUDIES AND EXISTING USACE WATER PROJECTS 1-7
1.10.1 Existing Coastal Storm Risk Management Projects 1-7
1.10.2 Navigation Projects in the Study Area 1-8

2 EXISTING CONDITIONS/AFFECTED ENVIRONMENT* **2-1**

2.1 GENERAL 2-1
2.2 PHYSICAL DESCRIPTION OF THE EXISTING AREA 2-1
2.2.1 Tides 2-1
2.2.2 Currents and Circulation 2-5
2.2.3 Relative Sea Level Change 2-6
2.3 ENVIRONMENTAL AND HISTORIC RESOURCES 2-7
2.3.1 Description of the Ecological Region 2-7
2.3.2 Storm Surge Effects on the Study Area 2-8
2.3.3 Attenuation of Storm Surge Impacts by Coastal Wetlands 2-9
2.3.4 Protected Lands in the Study Area 2-10
2.3.5 Physical and Hydrological Characteristics of the Study Area 2-14
2.3.6 Biological Communities in the Study Area 2-15
2.3.7 Essential Fish Habitat 2-17
2.3.8 Threatened and Endangered Species 2-18
2.3.9 Water and Sediment Quality 2-19

2.3.10 Air Quality 2-19
2.3.11 Hazardous, Toxic, and Radioactive Waste Concerns 2-20
2.3.12 Cultural Resources 2-20
2.3.13 Energy and Mineral Resources 2-21
2.3.14 Socioeconomic Considerations 2-21

3 NO ACTION ALTERNATIVE (FUTURE WITHOUT-PROJECT CONDITIONS)* 3-1

3.1 PROJECT AREA 3-1
3.2 ECONOMIC CONDITIONS 3-7
3.2.1 Initial and Evaluation Array of Alternatives 3-7
3.2.2 Final Array of Alternatives 3-7
3.3 ENVIRONMENTAL CONDITIONS 3-13
3.4 LIFE SAFETY 3-14
3.5 CRITICAL INFRASTRUCTURE 3-16
3.6 RELATIVE SEA LEVEL CHANGE (RSLC) 3-18
3.7 FUTURE WITHOUT-PROJECT CONDITIONS SUMMARY 3-20

4 PROBLEMS AND OPPORTUNITIES 4-1

4.1 PROBLEMS AND OPPORTUNITIES/NEED FOR ACTION* 4-1
4.1.1 Problem Statements 4-1
4.1.2 Opportunity Statements 4-2
4.2 PLANNING GOALS AND OBJECTIVES 4-3
4.2.1 Planning Goals 4-3
4.2.2 Public Concerns 4-3
4.2.3 Planning Objectives 4-3
4.2.4 Planning Constraints 4-7
4.3 RELATED PROJECT DOCUMENTS 4-7

5 FORMULATION AND EVALUATION OF ALTERNATIVE PLANS* 5-1

5.1 PLAN FORMULATION RATIONALE 5-1
5.2 MANAGEMENT MEASURES 5-2
5.3 SUMMARY OF ALTERNATIVES ANALYSES 5-4
5.3.1 Initial Array of Alternatives 5-4
5.3.2 Evaluation Array of Alternatives 5-5
5.3.3 Scoping of Study under 3x3x3 Guidelines 5-7
5.3.4 Final Array of Alternatives 5-7
5.4 COMPARISON OF FINAL ARRAY OF ALTERNATIVE PLANS AND DECISION CRITERIA 5-8

5.4.1 Final Screening Criteria 5-9
5.4.2 Final Array Evaluation Results 5-10
5.4.3 Comparison of Alternative Plans 5-21
5.4.4 Identifying a Tentatively Selective Plan (TSP) 5-27
5.4.5 Selection of the TSP for the DIFR-EIS 5-27
5.4.6 Comparison of Environmental Impacts for Final Array of Alternatives .. 5-32
5.5 CHANGES TO TSP AND SELECTION OF THE RECOMMENDED PLAN SUMMARY 5-41
5.5.1 Removal of Beaumont A New Levee (12-foot) and Jefferson Main New Levee (11-foot) from Recommended Plan 5-43
5.5.2 Reevaluation of Orange 3 as a component of the Recommended NED Plan 5-43
5.5.3 Confirmation of Orange 3 as a component of the Recommended NED Plan 5-47

6 RECOMMENDED PLAN 6-1

6.1 PLAN COMPONENTS 6-1
6.2 DESCRIPTION OF THE RECOMMENDED PLAN 6-5
6.2.1 Orange CSRM Project Area 6-5
6.2.2 Port Arthur and Vicinity CSRM Project Area 6-7
6.2.3 Freeport and Vicinity CSRM Project Area 6-9
6.3 SEPARABLE ELEMENTS 6-11
6.4 FISH AND WILDLIFE MITIGATION 6-12
6.4.1 Summary of Environmental Impacts 6-12
6.4.2 Mitigation Plan 6-14
6.4.3 Historic Properties Mitigation 6-24
6.5 COST ESTIMATE 6-24
6.6 PROJECT SCHEDULE AND INTEREST DURING CONSTRUCTION 6-25
6.7 DESIGN AND CONSTRUCTION CONSIDERATIONS 6-25
6.8 DEFERRED MAINTENANCE CONSIDERATIONS 6-25
6.9 VALUE ENGINEERING (VE) 6-27
6.10 SEA LEVEL AND CLIMATE CHANGE 6-27
6.11 REAL ESTATE CONSIDERATIONS 6-28
6.11.1 Lands, Easements, and Rights-of-Way 6-29
6.11.2 Facility Removals/Utility Relocations 6-29
6.12 OPERATION AND MAINTENANCE, REPAIR, REHABILITATION AND REPLACEMENT (OMRR&R) 6-30

6.13 ECONOMIC ANALYSIS FOR RECOMMENDED PLAN 6-30
6.13.1 Summary of Accounts 6-30
6.14 RISK AND UNCERTAINTY 6-32
6.14.1 Engineering Data and Models 6-32
6.14.2 Economic and Life Safety Risks 6-34
6.14.3 Environmental Data and Analyses 6-36
6.15 CONSISTENCY WITH OTHER STATE AND FEDERAL LAWS 6-36
6.15.1 Clean Air Act 6-37
6.15.2 Clean Water Act 6-37
6.15.3 Endangered Species Act 6-38
6.15.4 Magnuson-Stevens Fishery Conservation and Management Act 6-38
6.15.5 Coastal Zone Management Act 6-40
6.15.6 Fish and Wildlife Coordination Act 6-40
6.15.7 Marine Mammal Protection Act of 1972 6-44
6.15.8 National Historic Preservation Act 6-44
6.15.9 Federal Water Project Recreation Act 6-44
6.15.10 Farmland Protection Policy Act of 1981 and the CEQ Memorandum Prime and Unique Farmlands 6-44
6.15.11 Executive Order 11988, Floodplain Management 6-45
6.15.12 Executive Order 11990, Protection of Wetlands 6-45
6.15.13 Coastal Barrier Improvement Act of 1990 6-46
6.15.14 Executive Order 12898, Environmental Justice 6-46
6.15.15 Executive Order 13186, Responsibilities of Federal Agencies to Protect Migratory Birds and the Migratory Bird Treaty Act 6-46
6.15.16 Executive Order 13045, Protection of Children from Environmental and Safety Risks 6-47
6.15.17 Hazardous Wildlife Attractants On or Near Airports 6-47
6.15.18 Consultation with Federally-recognized Indian Tribes 6-47

7 ENVIRONMENTAL CONSEQUENCES* 7-1

7.1 PROTECTED LANDS 7-1
7.1.1 Orange 3 CSRM Plan 7-1
7.1.2 Port Arthur and Vicinity CSRM Plan 7-2
7.1.3 Freeport and Vicinity CSRM Plan 7-2
7.2 PHYSICAL AND HYDROLOGICAL CHARACTERISTICS 7-2
7.2.1 Orange 3 CSRM Plan 7-2
7.2.2 Port Arthur and Vicinity CSRM Plan 7-8
7.2.3 Freeport and Vicinity CSRM Plan 7-8

7.3 COASTAL PRAIRIE 7-9
7.3.1 Sabine Region CSRM Plans 7-9
7.3.2 Freeport and Vicinity CSRM Plan 7-9
7.4 COASTAL MARSH 7-10
7.4.1 Orange 3 CSRM Plan 7-10
7.4.2 Port Arthur and Vicinity CSRM Plan 7-11
7.4.3 Freeport and Vicinity CSRM Plan 7-11
7.5 FORESTED WETLANDS 7-11
7.5.1 Orange 3 CSRM Plan 7-11
7.5.2 Port Arthur and Vicinity CSRM Plan 7-12
7.5.3 Freeport and Vicinity CSRM Plan 7-13
7.6 IMPACTS TO FISH AND WILDLIFE AND THEIR HABITATS 7-13
7.6.1 Fish and Wildlife Impacts 7-13
7.6.2 Essential Fish Habitat Impacts 7-17
7.6.3 Threatened and Endangered Species Impacts 7-18
7.7 WATER AND SEDIMENT QUALITY IMPACTS 7-19
7.7.1 No Action Alternative 7-19
7.7.2 Recommended Plan 7-20
7.8 AIR QUALITY IMPACTS 7-23
7.8.1 No Action Alternative - All CSRM Plans 7-23
7.8.2 Recommended Plan 7-23
7.9 NOISE IMPACTS 7-28
7.9.1 No Action Alternative for all CSRM Plans 7-28
7.9.2 Recommended Plan 7-29
7.10 HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE IMPACTS 7-30
7.10.1 Orange CSRM Plan 7-31
7.10.2 Port Arthur and Vicinity CSRM Plan 7-32
7.10.3 Freeport and Vicinity CSRM Plan 7-33
7.11 CULTURAL RESOURCE IMPACTS 7-34
7.11.1 No Action Alternative – All CSRM Plans 7-34
7.11.2 Recommended Plan – All CSRM Plans 7-36
7.12 PRIME AND UNIQUE FARMLANDS 7-37
7.12.1 Orange 3 CSRM Plan 7-37
7.12.2 Port Arthur and Vicinity CSRM Plan 7-38
7.12.3 Freeport and Vicinity CSRM Plan 7-39
7.13 FLOODPLAIN IMPACTS 7-39
7.13.1 EO 11988 7-39
7.13.2 EO 11988 Eight-Step Analysis 7-40

7.14 SOCIOECONOMIC IMPACTS (ENVIRONMENTAL JUSTICE) 7-43
7.14.1 No Action Alternative – All CSRM Plans 7-44
7.14.2 Recommended Plan – All CSRM Plans 7-44
7.15 PROTECTION OF CHILDREN FROM ENVIRONMENTAL AND SAFETY RISKS 7-44
7.15.1 No Action Alternative – All CSRM Plans 7-44
7.15.2 Recommended Plan – All CSRM Plans 7-45
7.16 HAZARDOUS WILDLIFE ATTRACTANTS ON OR NEAR AIRPORTS 7-45
7.16.1 No Action Alternative 7-45
7.16.2 Recommended Plan 7-46
7.17 CUMULATIVE IMPACTS 7-46
7.17.1 Sabine Region 7-47
7.17.2 Brazoria Region 7-52
7.18 ANY ADVERSE ENVIRONMENTAL IMPACTS THAT CANNOT BE AVOIDED SHOULD THE RECOMMENDED PLAN BE IMPLEMENTED 7-56
7.19 ANY IRREVERSIBLE OR IRRETRIEVABLE COMMITMENTS OF RESOURCES INVOLVED IN THE IMPLEMENTATION OF THE RECOMMENDED PLAN 7-56
7.20 RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY 7-56
7.21 ENERGY AND NATURAL OR DEPLETABLE RESOURCE REQUIREMENTS AND CONSERVATION POTENTIAL OF VARIOUS ALTERNATIVES AND MITIGATION MEASURES 7-56

8 IMPLEMENTATION REQUIREMENTS 8-1

8.1 DIVISION OF PLAN RESPONSIBILITIES AND COST-SHARING REQUIREMENTS 8-1
8.2 COST FOR THE RECOMMENDED PLAN 8-3
8.3 VIEWS OF NON-FEDERAL SPONSOR AND OTHERS 8-4
8.4 IMPLEMENTATION PLAN 8-4
8.5 COST-SHARING APPORTIONMENT 8-5
8.6 RECOMMENDED PLAN AND RECENT USACE INITIATIVES 8-6
8.6.1 USACE Campaign Plan 8-6
8.6.2 Environmental Operating Principles 8-6

9 PUBLIC INVOLVEMENT 9-1

9.1 PUBLIC INVOLVEMENT ACTIVITIES 9-1

9.2 SUMMARY OF NOTICE OF INTENT COMMENTS 9-1
9.3 COMMENTS ON THE DIFR-EIS 9-3
9.3.1 Summary of Public Comments 9-3
9.3.2 Summary of Resource Agency Comments 9-4
9.4 DISTRIBUTION LIST* 9-5

10 RECOMMENDATIONS 10-1

10.1 OVERVIEW 10-1
10.2 RECOMMENDATIONS 10-1

11 REFERENCES 11-1

12 INDEX* 12-11

APPENDICES*

A – Measure Information Sheets
B – Plan Formulation Appendix
C – Economic Analysis
D – Engineering Design, Cost Estimates and Cost Risk Analysis
E – Real Estate Plan
F – Public Coordination: 1) Scoping; 2) Comments on Draft IFR-EA*
G – Agency and Tribal Coordination
H – Clean Water Act Section 404(b) (1) Evaluation
I – Clean Air Act Emissions Modeling
J – Endangered Species Act – Biological Assessment
K – Fish and Wildlife Coordination Act – Final Coordination Action Report
L – National Historic Preservation Act Coordination – Programmatic Agreement
M – Coastal Zone Management Act Coordination – Consistency Determination
N – Hazardous, Toxic and Radioactive Waste Assessment
O – Wetlands Value Assessment Ecological Modeling Report
P – Monitoring and Adaptive Management Plan
Q – Wetlands Value Assessment Coastal Marsh Model Sensitivity Analysis
R – Demographic Analysis Appendix
S – List of Preparers
T – Distribution List

FIGURES

Page

Figure 1-1: Sabine Pass to Galveston Bay, Texas Study Area 1-4
Figure 2-1: Geopolitical Map of Sabine Region (Orange County) 2-2
Figure 2-2: Geopolitical Map of Sabine Region (Jefferson County) 2-3
Figure 2-3: Geopolitical Map of Brazoria Region (Freeport) 2-4
Figure 3-1: Orange-Jefferson CSRM and Port Arthur and Vicinity CSRM Project Areas 3-2
Figure 3-2: Freeport and Vicinity CSRM Project Areas 3-3
Figure 3-3: Existing Floodwall in the Orange-Jefferson CSRM Project Areas 3-4
Figure 3-4: Port Arthur and Vicinity CSRM Failure Locations 3-5
Figure 3-5: Existing HFPP in Freeport and Vicinity CSRM 3-6
Figure 3-6: Orange-Jefferson CSRM Alternative Reaches 3-9
Figure 3-7: Port Arthur and Vicinity Failure Locations 3-11
Figure 3-8: Freeport and Vicinity CSRM Failure Locations 3-12
Figure 5-1: Location of Optimization Alternatives in the Orange-Jefferson CSRM Project Area 5-11
Figure 5-2. Optimization Alternatives – Port Arthur and Vicinity CSRM Project Area 5-14
Figure 5-3: Location of Optimization Alternatives in the Freeport CSRM Area 5-16
Figure 5-4: Orange County Critical Infrastructure 5-30
Figure 5-5: Jefferson County Critical Infrastructure 5-31
Figure 5-6: Ring Levee Review 5-47
Figure 6-1: Orange-Jefferson CSRM Plan 6-2
Figure 6-2: Port Arthur and Vicinity CSRM Plan 6-3
Figure 6-3: Freeport and Vicinity CSRM Plan 6-4
Figure 6-4. Swamp and Bottomland Hardwood Mitigation Area 11 6-18
Figure 6-5. Bottomland Hardwood Mitigation Area 161 6-18
Figure 6-6. Fresh Marsh Mitigation Area 52 6-20
Figure 6-7. Intermediate Marsh Mitigation Area 6-20
Figure 6-8. Brackish Marsh Mitigation Areas 6-21
Figure 7-1: Sabine Regions Sub-basins and Drainages 7-4

TABLES

Page

Table 2-1: Diurnal tide ranges within the StudyArea 2-1
Table 2-2: Estuarine EFH for Gulf Managed Species in S2G Study Area 2-18
Table 3-1: Expected Annual Damages 3-10
Table 3-2: Expected Annual Damages 3-11

Table 3-3: Expected Annual Damages 3-13
Table 3-4: Population at Risk by Project Area and Alternative Reach 3-15
Table 3-5: Estimated RSLC over the first 20 years of the project life (2030-2050) 3-19
Table 3-6: Estimated RSLC over the first 50 years of the project life (2030-2080) 3-19
Table 3-7: Estimated RSLC over the first 100 years of the project life (2030-2130) 3-19
Table 4-1: Sabine Pass to Galveston Bay, Texas Planning Objectives and Measurements 4-5
Table 5-1: Summary of Management Measures and Initial Screening of Measures 5-3
Table 5-2: Criteria for Screening Initial Array of Alternatives 5-5
Table 5-3: Evaluation Array of Alternatives 5-6
Table 5-4: Final Array of Alternatives 5-8
Table 5-5: Relationship with Project Area, Alternative Reaches and Optimization Alternatives 5-8
Table 5-6: Net benefits of Optimization Alternatives for the Orange-Jefferson CSRM project area 5-12
Table 5-7: Net Benefits of Optimization Alternatives for the Port Arthur and Vicinity CSRM Project Area 5-15
Table 5-8: Net Benefits of Optimization Alternatives for the Freeport and Vicinity CSRM Project Area 5-20
Table 5-9: Average Recommended Relative Sea Level Change (RSLC), Feet NAVD 5-23
Table 5-10: Comparison of Final Array of Alternative by Planning Objectives 5-25
Table 5-11: Cost Analyses Comparison for Optimization Alternatives in the Orange-Jefferson Project Area 5-28
Table 5-12: Ranges for RSLC for the Orange-Jefferson CSRM Project Area 5-32
Table 5-13: Total Wetland Impacts of Jefferson Main and Beaumont Alternatives (All RSLC Scenarios) 5-35
Table 5-14: Direct and Indirect Wetland Impacts of Orange 1, 2, and 3 Alternatives (All RSLC Scenarios) 5-36
Table 5-15: Overview of changes since release of DIFR-EIS 5-42
Table 5-16: Planning Review of "gate" alternative 5-44
Table 5-17 Evaluation of Orange Ring Levees 5-46
Table 6-1: Orange 3 Reach – Features of Work 6-6
Table 6-2: Orange 3 Levee and Floodwall Elevations Recommended Elevations (NAVD88) 6-7
Table 6-3: Port Arthur and Vicinity CSRM Project Area - Features of Work 6-8
Table 6-4: Port Arthur Levee and Floodwall Recommended Elevations (NAVD88) 6-8
Table 6-5: Freeport and Vicinity CSRM - Features of Work 6-9
Table 6-6: Freeport and Vicinity CSRM Levee and Floodwall Recommended Elevations (NAVD88) 6-10

Table 6-7: Direct and Indirect Impacts (Intermediate RSLC)- Recommended Plan 6-13
Table 6-8. Mitigation Best Buy Plans 6-16
Table 6-9. TPCS Overview 6-25
Table 6-10. Deficiency Tabulation from the Freeport and Vicinity Hurricane Flood Protection System (HFPS) System Wide Improvement Framework (SWIF) 6-26
Table 6-11. Economic Performance of Recommended Plan Overview 6-31
Table 6-12. Equivalent Annual Residual Damages - By Components of Recommended Plan 6-35
Table 6-13. USFWS Final CAR Recommendations 6-40
Table 7-1: Impacts on TPWD Property 7-2
Table 7-2: Air Quality Impacts in the BPA AQCR 7-24
Table 7-3: Air Quality Impacts in the HGB AQCR 7-24
Table 8-1: Estimate of Total First Costs of the Recommended Plan 8-4
Table 8-2: Cost Apportionment of Recommended Plan 8-5

List of Acronyms

AAHU	Average Annualized Habitat Units
ACE	Annual Chance Exceedance
ADCIRC	Advanced Circulation
ADM	Agency Decision Milestone
APE	Area of Potential Effects
AQCR	Air Quality Control Region
BA	Biological Assessment
BCR	Benefit-to-cost ratio
BiOp	Biological Opinion
BPA	Beaumont-Port Arthur
BUDM	Beneficial Use of Dredged Material
CAA	Clean Air Act
CAR	Coordination Act Report
CBBEP	Coastal Bend and Bays Estuary Program
CBRA	Coastal Barrier Resources Act
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIP	Channel Improvement Project
CR	Conservation Recommendation
cfs	Cubic feet per second
CO2	Carbon dioxide-equivalent
CO2e	Carbon dioxide-equivalent
CR	Conservation Recommendation
CSRM	Coastal Storm Risk Management
CWA	Clean Water Act
CY	Cubic yards
CY/YRr	Cubic yards per year
dBA	Logarithmic A-weighted decibel
DIFR-EIS	Draft Integrated Feasibility Report and Environmental Impact Statement
DOE	Department of Energy
EC	Engineer Circular
EFH	Essential fish habitat
EIS	Environmental Impact Statement
EJ	Environmental Justice
ETN	Emergency Tracking Network
EOP	Environmental Operating Principles

EO	Executive Order
EPA	U.S. Environmental Protection Agency
EQ	Environmental quality
ER	Ecosystem Restoration
ERDC	Engineer Research and Design Center
ESA	Endangered Species Act
°F	Degrees Fahrenheit
FCSA	Feasibility Cost Sharing Agreement
FEMA	Federal Emergency Management Agency
FIFR-EIS	Final Integrated Feasibility Report and Environmental Impact Statement
FPPA	Farmland Protection Policy Act
FM	Farm to Market Road
FWCA	Fish and Wildlife Coordination Act
FWOP	Future Without-Project
FY	Fiscal year
GHG	Greenhouse Gases
GIWW	Gulf Intracoastal Waterway
GLO	General Land Office
HCD	Habitat Conservation Division
H&H	Hydraulics and Hydrology
HFPP	Hurricane Flood Protection Project
HGB	Houston, Galveston and Brazoria Airshed
HPTRM	High performance turf reinforcement mattress
HSC	Houston Ship Channel
HTRW	Hazardous, Toxic and Radioactive Waste
HQUSACE	Headquarters U.S. Army Corps of Engineers
IDC	Interest during construction
IPCC	Intergovernmental Panel on Climate Change
LERRs	Lands, easements, rights-of-way, and relocations
LF	Linear Feet or Foot
LNG	Liquid Natural Gas
MBTA	Migratory Bird Treaty Act
MCACES	Micro Computer Aided Cost Engineering System
MCY	Million cubic yards
MLLW	Mean lower low water
MLT	Mean low tide
MOVES	Motor Vehicle Emissions Simulator
MPRSA	Marine Protection, Research, and Sanctuaries Act
MSA	Metropolitan Statistical Area

MSL	Mean Seal Level
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NAVD	North American Vertical Datum
NED	National Economic Development
NEPA	National Environmental Policy Act
NFS	Non-Federal Sponsor
NGO	Non-Governmental Organizations
NMFS	National Marine Fisheries Service
NPL	National Priority List
NRHP	National Register of Historic Places
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrous oxides
NNBF	Natural and nature-based features
NRC	National Research Council
NRCS	Natural Resource Conservation Service
NSI	National Structure Inventory
NWR	National Wildlife Refuge
O&M	Operation and Maintenance
OMRR&R	Operation, Maintenance, Repair, Replacement and Rehabilitation
OSE	Other social effects
P&G	Principles and Guidelines
PA	Placement area
PCB	Polychlorinated biphenyl
PDT	Project Delivery Team
PED	Preconstruction Engineering and Design
PGL	Planning Guidance Letter
P.L.	Public Law
PMP	Project Management Plan
PSD	Prevention of Significant Deterioration
RCRA	Resource Conservation and Recovery Act
RED	Regional economic development
RSLC	Relative sea level change
RSLR	Relative sea level rate
RSM	Regional Sediment Management
SIP	State Implementation Plan
SAV	Submerged aquatic vegetation
SHPO	State Historic Preservation Officer
SOC	Species of Concern

SPR	Strategic Petroleum Reserve
SNWW	Sabine-Neches Waterway
SWL	Still Water Level
TCEQ	Texas Commission on Environmental Quality
TCMP	Texas Coastal Management Program
TEEX	Texas Engineering Extension Service
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
TxDOT	Texas Department of Transportation
US	United States
USACE	United States Army Corps of Engineers
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VDD	Velasco Drainage District
VE	Value Engineering
VOC	Volatile organic compounds or
WMA	Wildlife management areas
WRRDA	Water Resources and Reform Development Act

1 STUDY INFORMATION

1.1 INTRODUCTION

This is a Final Integrated Feasibility Report and Environmental Impact Statement (FIFR-EIS) examining coastal storm risk management (CSRM) and ecosystem restoration (ER) opportunities within six counties of the upper Texas coast (Orange, Jefferson, Chambers, Harris, Galveston, and Brazoria Counties). Report sections required for compliance with the National Environmental Policy Act (NEPA) are indicated with an asterisk following the section heading. The Feasibility Cost Sharing Agreement (FCSA) for this study was signed on January 10, 2013, with the non-Federal sponsor, the Texas General Land Office (GLO). The study has identified and screened alternatives to address CSRM and ER problems in the study area. A Draft Integrated Feasibility Report and Environmental Impact Statement (DIFR-EIS) presenting a tentatively selected plan (TSP) was released in Sept 11, 2015. Since the DIFR-EIS the report has undergone public review, policy review, Agency Technical Review (ATR), and Independent External Peer Review (IEPR). This FIRR-EIS documents revisions to the detailed feasibility design, analysis and impacts analyses of the Recommended Plan on significant resources. Revisions from the Revised Integrated Draft Feasibility Report and Environmental Impact Statement are present at the end of Chapter 5.

1.2 STUDY AUTHORITY

1.2.1 General Authority

Authorization for the study is derived from a resolution from the Committee on Environmental and Public Works dated June 23, 2004, entitled "Coastal Texas Protection and Restoration Study".

> *By resolution dated June 23, 2004 entitled "Coastal Texas Protection and Restoration Study", the Committee on Environment and Public Works, U.S. Senate has requested that in accordance with Section 110 of the Rivers and Harbors Act of 1962 the Secretary of the Army develop a comprehensive plan for severe erosion along coastal Texas for the purposes of shoreline erosion and coastal storm damages, providing for environmental restoration and protection, increasing natural sediment supply to coast, restoring and preserving marshes and wetlands, improving water quality, and other related purposes to the interrelated ecosystem along the coastal Texas area.*

The study fits into the overall concept of the authorization to conduct an integrated and coordinated approach to locating and implementing opportunities for CSRM and ER. The purpose of the study is to recommend for Congressional approval a regional CSRM and ER project that encompasses the six coastal counties of the upper Texas coast between Sabine Pass and Galveston Bay. Pursuant to NEPA, an EIS was be integrated into the report.

1.2.2 Additional Study Guidelines

The request for re-scoping the Sabine Pass to Galveston Bay Shoreline Erosion Feasibility Study was granted November 21, 2011. A Planning Charette was performed in August 2012. Memorandums were prepared for In-Progress Reviews (IPR) throughout the study to document discussions with the vertical team and for input into the decision log and decision management plan. The documents provided guidance to the study team as the study progressed. Most importantly, an exemption approval to the 3x3x3 Rule was provided in a CECW-SWD memorandum, dated February 25, 2014. The memorandum provided guidance on the scope of the study. This is discussed further in the next section, "Study Purpose and Scope."

1.3 STUDY PURPOSE AND SCOPE*

The purpose of this report is to present the findings of the feasibility investigations and analyses conducted to determine if there is a Federal interest in potential CSRM and ER projects within the coastal areas of the six-county study area. This study is an interim response to the "Coastal Texas Protection and Restoration Study," authority. Originally, the study was intended to develop recommendations for regional CSRM and ER projects for Congressional approval across a study area encompassing six counties along the upper Texas coast between Sabine Pass and Galveston Bay. The 3x3x3 Rule exemption approved February 25, 2014, approved a revision to the study scope to focus full feasibility planning efforts on CSMR projects in the northern (Orange and Jefferson) and southern (Brazoria County) parts of the study area. Accordingly, the feasibility study effort described here has focused on CSRM recommendations for the Sabine Region (Orange and Jefferson Counties) and the Brazoria Region (the Freeport metropolitan area in southern Brazoria County). An FCSA amendment was executed on March 9, 2015, to modify the scope of the study.

In the exemption approval, it was agreed that this report would present a comprehensive overview of CSRM problems and opportunities in the central Galveston region (Galveston, Harris, and Chambers Counties) and a comprehensive assessment of ER opportunities for the entire six-county study area. Using work already accomplished to date, the comprehensive assessment is a listing and screening of alternatives identified as having high potential to demonstrate Federal interest and result in successful CSRM and ER projects. Potential CSRM and ER measures are described

and illustrated in individual measure sheets presented in Appendix A. The measures were evaluated, combined into potential alternatives, and screened as explained in Appendix B. The alternatives evaluated include an extensive list of CSRM alternatives for Galveston Bay and ER alternatives for the entire six-county area. Future feasibility studies, including the ongoing coastal Texas comprehensive study, will leverage this work and ongoing work by others to develop and recommend future CSRM or ER projects. In addition, these alternatives will be used to develop projects that could be completed under other existing authorities. This EIS will also serve as a vehicle from which future Environmental Assessments of the evaluated alternatives could be tiered.

1.4 NON-FEDERAL SPONSOR

The USACE Galveston District was responsible for the overall management of the study and the report preparation. As the non-Federal sponsor of the study, the GLO was actively involved throughout the study process. As this time GLO is not expected to be the implementation sponsor. The existing Port Arthur and the Freeport HFPPs local sponsors have expressed interest in cost sharing for the Recommended Plan identified for the Port Arthur and Vicinity CSRM and the Freeport and Vicinity CSRM. The local sponsors responsible for operation, maintenance, repair, replacement and rehabilitation (OMRR&R) are the Jefferson Country Drainage District No. 7 and the Velasco Drainage District (VDD), respectively. The local sponsor for Orange 3 CSRM Plan would be Orange County. They have also expressed interest in cost share for construction.

1.5 STUDY AREA

The study area encompasses six coastal counties of the upper Texas coast (Figure 1-1). Over five million people reside in the six counties, which includes the fourth largest U.S. city (Houston), and three other metropolitan areas (Beaumont/Port Arthur/Orange, Galveston/Texas City, and Freeport/Surfside). The population of the counties is projected to increase to over nine million within the next 50 years. In addition to the population at risk, three of the nine largest oil refineries in the world, 40 percent of the nation's petrochemical industry, 25 percent of the nation's petroleum-refining capacity, and three major U.S. seaports based on tonnage (Port of Houston, Port of Beaumont, and Texas City) are also located in the study area. The growing population, communities, and nationally significant industries are severely vulnerable to risks from coastal storm events. Approximately 2.26 million people across the study area live within storm-surge inundation zones, and estimates for a one-month closure of the Houston Ship Channel (HSC) alone are upwards of $60 billion in damages to the national economy. All of these characteristics of the study area are important to note from a planning and environmental setting perspective; however, the six-county study area was refined in the study process, which ultimately focused on direct damages to structures in an economic evaluation.

The study area was broken down into regions. The Sabine region includes the Sabine Lake system and Gulf shoreline from Sabine Pass to High Island and the Sabine-Neches Waterway, serving the Ports of Beaumont, Port Arthur, and Orange. The Galveston region includes all of the Galveston Bay system including the Gulf shoreline from High Island to San Luis Pass and Bolivar Peninsula. The Houston-Galveston Navigation System provides access to the Ports of Galveston, Texas City, and Houston. The Brazoria region includes the Brazos River system and the Gulf shoreline in Brazoria County, as well as the Freeport Harbor Channel (FHC), serving Port Freeport. The major landmarks listed above are noted in Figure 1-1 to show general locations of the regions. All three regions include heavily industrialized areas of strategic importance to the nation, as well as navigation channels, including the Gulf Intracoastal Waterway (GIWW), that are critical infrastructure.

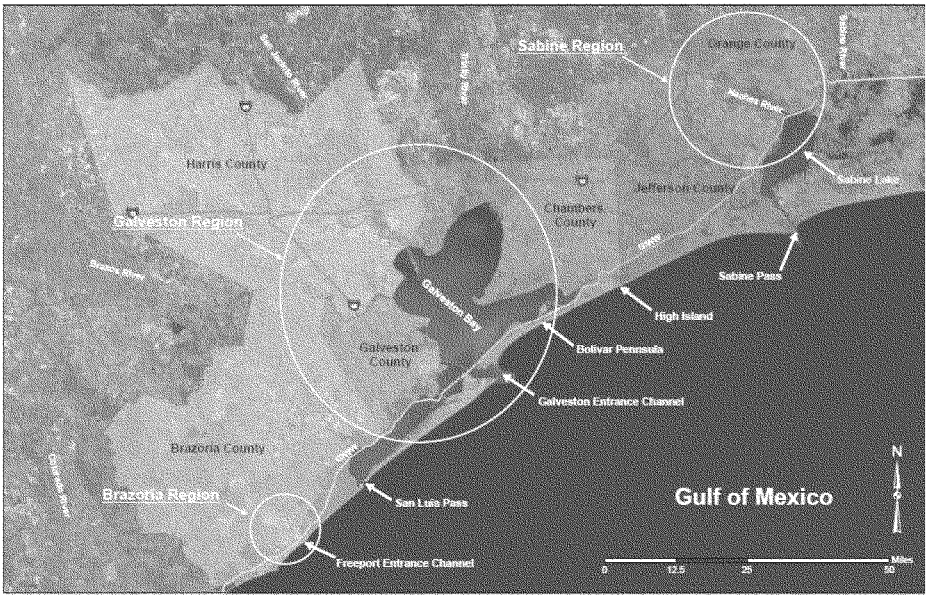


Figure 1-1: Sabine Pass to Galveston Bay, Texas Study Area

1.6 PROJECT AREA

The regions were refined in the study within the Sabine and Brazoria regions located in Orange, Jefferson, and Brazoria Counties into project areas. These project areas are focal points where the

study team identified alternatives. The geographical extent of the study was large at the beginning of the study. The project areas were not defined until the "Final Array of Alternatives" was developed; therefore, the project areas are defined in the future without-project (FWOP) section where important details of resources were investigated to define the FWOP. The following represent the project areas: Senators John Cornyn and Ted Cruz, and Representatives Randy Weber (District 14), Sheila Jackson Lee (District 18), Pete Olson (District 22), Gene Green (District 29), and Brian Babin (District 36).

1.7 PROJECT DATUMS

All elevations referred to in this report, unless specifically noted otherwise, are based on the North American Vertical Datum of 1988 (NAVD 88). All depths used in this report are at Mean Lower Low Water (MLLW) datum unless otherwise specified.

1.8 MAJOR HISTORICAL SURGE EVENTS IN THE STUDY AREA

The study area has seen several major historical surge events in the past 120 years. The storm surge levels in this section are presented in Mean Sea Level (msl). The most notable is perhaps the 1900 Storm, which inundated most of the island city of Galveston, Texas, and adjacent areas on the mainland. The storm was responsible for over 8,000 deaths and up to $30 million in property damage. Storm surge values for Jefferson and Orange Counties are not available (Weems).

Other major events include the 1915 Storm, which made landfall across western Galveston Island and, due to its large size, resulted in storm surge of 16 feet in Galveston, partially ameliorated by the newly built 17-foot Galveston Seawall, and a surge of 9 to 11 feet across coastal areas of Jefferson and Orange Counties. Hurricane Audrey made landfall from Sabine Pass to Cameron in June 1957. Storm surge heights exceeded 6 feet in coastal areas north of Galveston, with storm surge of 8 to 10 feet recorded across eastern Jefferson and Orange Counties. Hurricane Carla (1961) made landfall across the Central Texas coast and caused 7- to 8-foot storm surge across coastal Jefferson and Orange Counties.

In 1983 during Hurricane Alicia, Baytown, Texas, had 10- to 12-foot tides, with Morgan Point, Texas, seeing the highest tides at 12.1 feet. Hurricane Bonnie (1986) was a very small Category 1 hurricane that made landfall between High Island and Sea Rim State Park in Jefferson County. Storm surge was 6 to 7 feet across Jefferson County. Hurricanes Chantal and Jerry (1989) were very small Category 1 hurricanes that made landfall at High Island and Galveston, respectively, and caused storm surge values of 4 to 5 feet across Jefferson County.

Tropical Storm Frances in 1998 made landfall across the central Texas coast. Nearly every road in Sabine Pass was underwater. Highway 87 flooded south of Port Arthur to Sabine Pass, and north of Port Arthur to Bridge City. Many locations further inland across western Jefferson County were also underwater. The extensive flooding was due to tides running 3.5 to 5 feet for 2.5 days.

Hurricane Rita in 2005 resulted in storm surge of 9.24 feet in Port Arthur, Texas, and just over 8 feet in Sabine Pass. Hurricane Ike in 2008 produced storm surges from 14 feet near Sabine Pass with 11 to 12 feet across Sabine Lake. Port Arthur was spared the storm surge thanks to its 14- to 17-foot seawall. However, the remaining southern half of Jefferson County was inundated, with estimated high water marks reaching 18 to 19 feet to the south and east of High Island (Southeast 2013).

Hurricane Ike was the third-costliest storm in U.S. history, causing an estimated $29 billion in property damage. Storm surges of 15-20 feet above normal tide levels occurred along the Bolivar Peninsula of Texas and in much of the Galveston Bay area. Impacts on an eight-county region's economy have been estimated at $142 billion over the four yearly quarters following the storm.

1.9 HISTORY OF THE INVESTIGATION

Investigation of surge damage impacts in the Galveston and Jefferson County region began in 2004 after the initiation of a Feasibility Study with the intent of evaluating plans to develop CSRM and ER features. The team had completed the development of the expected condition of the area if no action were taken over a 50-year period. Almost immediately after completion of that effort, the region was impacted by Hurricane Ike. At the request of local study sponsors the study was put on hold until the determination was made in late 2011 to rescope the study to include surge reduction measures for a six-county region to include Orange, Jefferson, Chambers, Galveston, Harris, and Brazoria Counties.

This re-scoped study began under the 3x3x3 guidelines developed under the recent USACE planning modernization. Under these guidelines, planning studies are limited to a duration of 3 years and cost of $3 million dollars, and are managed through a 3-tier vertical team (VT). These planning guidelines were revised to emphasize risk-based decision-making and early vertical team engagement while further developing and enhancing our planning capability.

Four scoping meetings were held in early 2012. A total of 285 distinct ideas were collected, collated and screened by the Project Delivery Team (PDT) to a detailed list of measures. These measures were considered during the SMART (Specific, Measurable, Attainable, Risk Informed, and Timely) Planning Charette held August 6 through 10, 2012.

At the Charette, the full Vertical Team (USACE District, Division, Headquarters, and Office of Water Project Review) including the local sponsor worked through an abbreviated version of the six-step planning process, considering a full array of measures and alternatives, and then formulated comprehensive (regional) plans to include in the Initial Alternative Plans Array. After the Charette, a Project Management Plan was developed and a FCSA with the GLO (non-Federal sponsor) was executed on January 10, 2013.

In February 2014, an exemption request to allow the study to continue outside of the 3x3x3 guidelines was approved by HQUSACE, resulting in a $4.4 million study, which focused on the Brazoria and Sabine area CSRM problems and opportunities. The Notice of Intent to prepare an EIS was published in the Federal Register on November 24, 2014.

1.10 PRIOR STUDIES AND EXISTING USACE WATER PROJECTS

1.10.1 Existing Coastal Storm Risk Management Projects

The following studies and projects were reviewed as part of the feasibility study investigations. These reports provided information on previous Federal and local evaluation of CSRM problems in the study area.

1.10.1.1 Port Arthur HFPP, Texas

The existing Port Arthur and Vicinity, Texas Hurricane Flood Protection Project (HFPP) was authorized by the Flood Control Act of 1962, Public Law 87-874. Construction began in March 1966, and was completed in April 1982. The system protects the Port Arthur region from coastal storm surge events coming from the Gulf of Mexico. It also protects from flooding from the Sabine River. The levee system consists of 27.8 miles of earthen embankment and 6.6 miles of floodwall. This includes 3.5 miles of coastal cantilever I-wall. There is also a wave barrier on Pleasure Island. The system was designed and constructed for a 1% Annual Chance Exceedance (ACE) storm event. It is operated by Jefferson County Drainage District No. 7.

1.10.1.2 Texas City HFPP, Texas

The Texas City and Vicinity, Texas HFPP was authorized by the Flood Control Act of July 3, 1958, Public Law 85-500, substantially in accordance with recommendations of the Chief of Engineers in the House Document No. 347, 85th Congress, 2nd Session. Construction began in 1962. Authorized modifications to the project were approved in the Flood Control Act of 1968, House Document No. 187, 90th Congress, 1st Session. Authorized modifications included an extension of the levee risk reduction system to protect the City of Hitchcock and La Marque. Construction was completed in April 1987. The Texas City, Texas HFPP is located on the southwest shore of Galveston Bay about nine miles northwest of Galveston, Texas. The system

was designed and constructed for a 1% ACE event. The levee system consists of earthen embankment and floodwalls protecting an area of approximately 36 square miles. The levee consists of 21.85 miles of earthen embankment and floodwall. There are approximately 1.32 miles of floodwall on the system, consisting of nearly 0.92 mile of I-wall (0.64 mile of Braced Cantilever I-wall and 0.28 mile of Cantilever I-wall) and 0.4 mile of T-wall. One section of earthen embankment was constructed in 1930 and enlarged in the authorized project. There is a section of levee on the northwest side of the system which was constructed by local interests in 1947 and is also included as part of the system.

1.10.1.3 Freeport HFPP, Texas

The Freeport and Vicinity, Texas Hurricane Flood Protection Project (HFPP), was authorized by the Flood Control Act of 23 October 1962, Public Law 87-874, substantially in accordance with House Document No. 495, 87th Congress, 2nd Session. The authorization provides for construction of improvements at Freeport and Vicinity, Texas, for risk reduction against storm tides caused by tropical cyclones along the Gulf Coast of magnitudes up to and including the standard project hurricane. The Freeport and Vicinity HFPP is located in the coastal plains in southern Brazoria County, about 48 miles southwest of Galveston, Texas. The system was designed and constructed for a 1% ACE event. The VDD, a subdivision of the State of Texas, is the local sponsor of the Freeport and Vicinity HFPP. The system consists of approximately 43 miles of levees and wave barriers, seven pump stations and multiple gates, culverts and related appurtenances. Additionally, the line of risk reduction includes multiple structures that also serve as control structures and docks for the DOW Chemical Co., BASF, Conoco Philips, Exxon and Port Freeport. As a part of this Project, the USACE upgraded and incorporated existing levees into the HFPP in addition to extending and constructing a new levee reach northward along Oyster Creek to the high bank of Oyster Creek just east of the City of Clute, Texas. This created a coherent HFPP extending from the 7-mile "river system", which connects to the HFPP at Brazos River mile 11, and extends to the high bank on Oyster Creek just east of the City of Clute, Texas.

1.10.2 Navigation Projects in the Study Area

There are multiple deep-draft navigation channels in the study area including: the Sabine-Neches Waterway (SNWW), the Houston Ship Channel (HSC), the Texas City Channel (TCC), the Galveston Ship Channel (GSC) and the Freeport Ship Channel (FSC). Additionally there are shallow-draft channels in the area including the Gulf Intracoastal Waterway (GIWW), Chocolate, Cow, and Adams Bayous.

The SNWW is an approximately 64-mile Federally authorized and maintained waterway located in Jefferson and Orange Counties in southeast Texas and Cameron Parish, Louisiana. The deep-draft portion of the authorized Federal project generally provides for a channel 42 feet deep and

800 feet wide at the entrance to the Gulf of Mexico, a channel 40 feet deep and 500 feet wide to Port Arthur, and a channel depth of 40 feet MLLW and 400 feet wide to Beaumont by way of the Neches River. Authorization for deepening the SNWW to 48 feet MLLW was included in the Water Resources and Reform Development Act (WRRDA) of 2014.

The FSC provides deepwater access from the Gulf of Mexico to Port Freeport. In 1929, the Brazos River was diverted to control excessive dredging requirements in Port Freeport, resulting in the jettied channel entrance being separated from the river mouth. The waterway extends from deep water in the Gulf through a 0.83-mile jettied channel to the Lower Turning Basin, then westerly approximately 1.5 miles to and including the Brazosport Turning Basin, then westerly approximately 2.2 miles through the Upper Turning Basin to and including a turning basin at Brazos Harbor. The Stauffer Channel extends 1.15 miles from the Upper Turning Basin to the Stauffer Turning Basin. Authorized project widths of the channel range from 400 feet from the Gulf to the Brazosport Turning Basin to 200 feet for the Brazos Harbor Channel. The majority of the Freeport channel has been constructed of a depth of 46 feet MLLW. Brazos Harbor Channel and Turning Basin are 37 feet MLLW. The deauthorized Stauffer Channel measures 200 feet wide with a depth of approximately 19 feet MLLW. Authorization for deepening Freeport Channel varying depths of 56 feet, 51 feet, and 26 feet MLLW was included in the WRRDA of 2014.

2 EXISTING CONDITIONS/AFFECTED ENVIRONMENT*

2.1 GENERAL

The six-county study area is a large and complex region that includes approximately 6,865 square miles and two environmentally sensitive and economically important bay systems (Sabine Lake and Galveston Bay), and several large watersheds (Sabine, Neches, Trinity, San Jacinto and Brazos Rivers). It covers approximately 120 miles of the Texas coast. The following description provides a brief overview of existing conditions (i.e. affected environment) for the entire six-county area. However, since the study scope was revised to focus full feasibility planning efforts on CSMR projects in the northern (Orange and Jefferson Counties) and southern (Brazoria County) parts of the study area only, geopolitical maps are provided for the general project areas in each county as Figures 2-1, 2-2, and 2-3 respectively.

2.2 PHYSICAL DESCRIPTION OF THE EXISTING AREA

2.2.1 Tides

NOAA's Center for Operational Oceanographic Products and Services also provides tide data for the Texas coastline. The datum for these tide levels is MLLW.

Table 2-1: Diurnal tide ranges within the StudyArea

Station	Diurnal Range (feet)
Texas Point NWR, Sabine Pass, Texas	1.98
Galveston Pleasure Pier, Texas	2.04
Pier 21, Galveston, Texas	1.41
Morgan's Point, Texas	1.31
U.S. Coast Guard (USCG) Freeport, Texas	1.80

In both the Port Arthur area and Galveston, there are tide gages on both the Lake/Bay side of the coast and on the Gulf side. At Port Arthur/Sabine, tides must travel up miles of Sabine Pass and across Sabine Lake to get to the Port Arthur tide gage. Likewise, tides at Galveston have to travel through Bolivar Pass and halfway along Galveston Island to get to the Pier 21 gage on the Bay side of Galveston Island. Thus tides at these two interior gages (Port Arthur and Pier 21) are subject to reduction in both amplitude and phase, compared to the open-coast gages (Sabine Pass and Pleasure Pier). Their magnitude/range is less, and the timing lags that of the gages on the open coast of the Gulf.

Figure 2-1: Geopolitical Map of Sabine Region (Orange County)

Figure 2-2: Geopolitical Map of Sabine Region (Jefferson County)

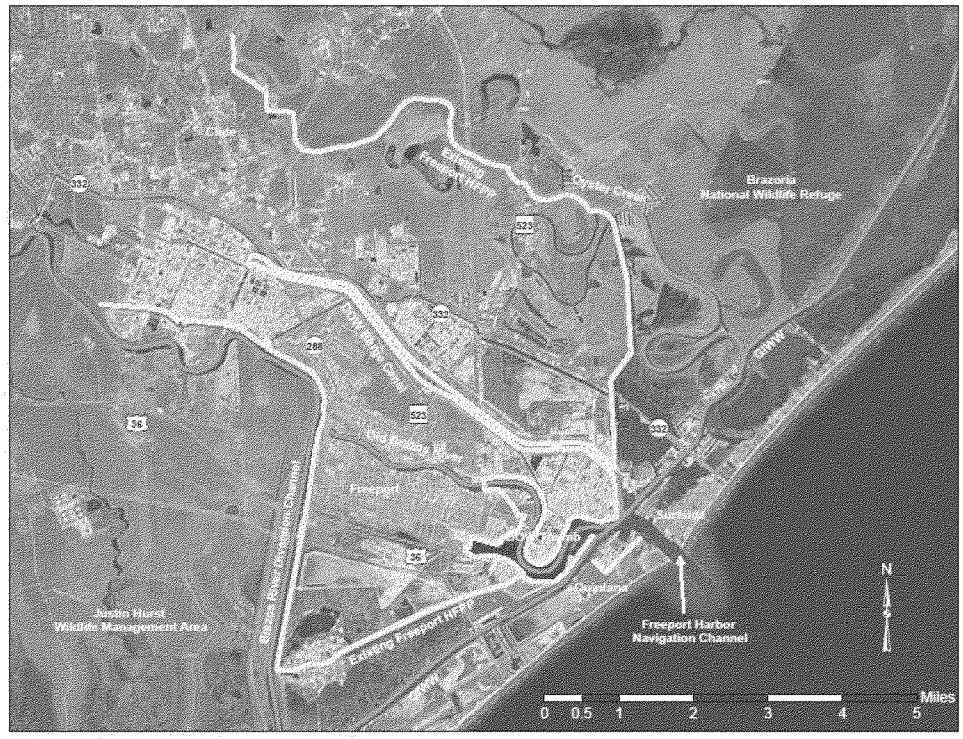


Figure 2-3: Geopolitical Map of Brazoria Region (Freeport)

2.2.2 Currents and Circulation

There are two major estuarine systems (Sabine Lake and Galveston Bay) and one major river system (the Brazos River) in the six county study area. Additionally, the GIWW passes through the entire study area adding additional complexity to the movement of water. Each of these systems, along with other waterways in the study area, is discussed in detail below.

2.2.2.1 Sabine Lake Estuary

The Sabine estuary's circulation and salinity patterns are complex. Fresh water enters the system through several tributaries, including the Sabine and Neches Rivers. The Sabine and Neches Rivers flow into Sabine Lake and into the Gulf of Mexico through Sabine Pass.

The Sabine-Neches Waterway (SNWW) Navigation Channel system serves as a pathway for both freshwater from the inflowing rivers and the saltwater wedge coming up the deep draft channel through Sabine Pass. This combination results in highly stratified conditions in the navigation channel, bringing saltwater up the SNWW and into the northwest corner of Sabine Lake and the lower reaches of the Neches River. As a result, the observed salinity in Sabine Lake is highest at both the southern end, where the lake connects to Sabine Pass, and the northern end, where the lake connects to the SNWW. The lowest salinities are observed in the central and eastern portions of the lake, which are furthest from sources of salt water (USACE 2009).

2.2.2.2 Galveston Bay Estuary

The San Jacinto River runs from its headwaters in several counties north of Harris County to Lake Houston and from there to Galveston Bay. Continuing southward, the river merges with Buffalo Bayou before the mouth of the bayou at Galveston Bay. The San Jacinto River drains an area of 3,976 square miles with almost 2 million acre-feet of runoff. Discharges into Galveston Bay vary considerably due to reservoirs, water supply constraints, and the complexity of the watershed.

The Trinity River is a 710-mile-long river that is the longest river flowing entirely within Texas. It rises in extreme north Texas, a few miles south of the Red River, and flows onward to the south, discharging into Trinity Bay, an arm of Galveston Bay, near the town of Anahuac east of Houston.

The Buffalo Bayou watershed is a 102-square-mile watershed primarily located in west-central Harris County with a small portion crossing into Fort Bend County. Near downtown Houston, White Oak Bayou flows into Buffalo Bayou. Just east of downtown Houston near the Turning Basin, Buffalo Bayou becomes the HSC. Buffalo Bayou and the HSC receive discharged water

from several major tributaries, such as White Oak, Brays, Greens, Halls, Sims, and Vince Bayous. Buffalo Bayou mean discharge varies considerably, and is estimated to be 20,000 cubic feet per second (cfs) at its outfall into the HSC.

The HSC, built in 1914 to link the Port of Houston with Galveston Bay and the Gulf of Mexico, runs through Buffalo Bayou and the lower course of the San Jacinto River into Galveston Bay. The San Jacinto River proper is navigable for about 20 miles above its mouth.

2.2.2.3 Brazos River System

The Brazos River watershed begins in the State of New Mexico and then runs approximately 840 miles across Texas to its mouth at the Gulf of Mexico, two miles south of Freeport in Brazoria County. It is the longest river in Texas and has one of the largest discharges. Discharges at the mouth have been recorded as high as 120,000 cfs (USGS).

2.2.2.4 GIWW

The GIWW spans the entire study area from Sabine Lake to Freeport (and beyond). The salinity of the water varies dramatically from reach to reach. Spans that are open to the Gulf of Mexico and to large bays like Galveston Bay tend to have a higher salinity. Spans of the GIWW more closed off and protected, like in Jefferson County and near Freeport, tend to have better access to freshwater sources, and therefore, a lower salinity.

2.2.2.5 Additional Waterways

In addition to the major waterways mentioned previously in this section, several other waterways exist within the study area. These include (but are not limited to) Oyster Creek, Taylors Bayou, Chocolate Bayou, Cedar Bayou, Cow Bayou, Adams Bayou, Little Cypress Bayou, Dickinson Bayou, Halls Bayou, Austin Bayou, and Bastrop Bayou.

2.2.3 Relative Sea Level Change

Relative Sea Level Change (RSLC) was calculated following USACE guidance provided in ER 1100-2-8162 "Incorporating Sea Level Change" dated 31 December 2013, and ETL 1110-2-1 "Procedure to Evaluated Sea Level Change Impacts, Responses and Adaptation" dated 30 June 2014. For the study area, all of the sea level rise is due to a combination of an eustatic component of ocean water rising and subsidence along the Gulf Coast. Projections of low, moderate, and high levels of RSLC at the end of the 50-year period of analysis are estimated to range from 1.26 foot to 4.51 feet within the study area. Detailed discussion on RSLC is included in Section 3.6.

2.3 ENVIRONMENTAL AND HISTORIC RESOURCES

2.3.1 Description of the Ecological Region

The study area lies within the Western Gulf Coastal Plain ecoregion, which extends along the Texas Gulf Coast from the Sabine River south to the Rio Grande (Griffith 2004). The prominent features of this coastal ecosystem include fresh, intermediate, brackish and saline marshes; bays and lagoons that support extensive seagrass beds, tidal flats, and reef complexes; barrier islands; tallgrass prairie with small depressional wetlands, riparian forests, oak mottes, and dense brush habitats. Wetland habitats provide several important functions, including flood storage, water quality maintenance, and fish and wildlife habitat and forage. The study area is an important wintering and migration stopover habitat for migratory birds, including the Central Flyway waterfowl, shorebirds, wading birds, and marsh and waterbirds. A string of refuges and wildlife management areas (WMAs) along the coast serve as critical staging areas for waterfowl migrating to and from Mexico (TPWD 2013; USFWS 2013).

Natural forces, which shape the system, include dominant south to southeast winds, tropical weather systems, and a substantial rainfall amount of roughly 45 to 60 inches per year. Flooding and freshwater inflows are key systemic processes, which buffer salinity and provide nutrients and sediments to extensive estuaries in the Sabine and Galveston regions. In contrast to these regions, the Brazos River discharges directly into the Gulf of Mexico, but deltaic and barrier island processes have formed extensive coastal wetlands along the coast in Brazoria County. While highly impacted by human activities, this ecosystem remains very productive for a wide variety of fish and wildlife.

The Sabine and greater Galveston Bay estuaries and extensive coastal wetlands in the coastal Brazos River region are a vital habitat for 75 percent of the fish and shellfish species found in the Gulf of Mexico. Marshes and rice fields over the entire study area are a major wintering area for waterfowl of the central flyway. On average, 1.3 to 4.5 million ducks, or 30 to 71 percent of the total flyway population, winter annually on the Texas Gulf coast (Stutzenbaker and Weller 1989). On average, 180,000 pairs of colonial-nesting waterbirds nest annually in Texas coastal habitats. Near coastal forests are critically important for the nation's songbird resources, as the vast majority utilize this habitat during their trans- and circum-Gulf migrations (USFWS 2008).

2.3.2 Storm Surge Effects on the Study Area

Storm surge has had both long-term positive and negative effects on the ecosystem of the region. Storm overwash deposits help shape and maintain coastal environments affected by relative sea level rates (RSLR). In some areas, storm surges cause shoreline accretion by depositing sediment on beaches and within marshes behind the shore. Hurricane Rita's surge resulted in shoreline accretion along some sections of Bolivar Peninsula of up to 170 feet (Andrews et al. 2006). Sediment carried on and over barrier islands such as Follets Island helps to maintain the natural transgressive development of this barrier island. In other areas, storm surges had erosive effects. Far more of the Gulf shoreline in southeast Texas suffered erosion as a result of Rita's surge than experienced accretion. In the Chenier Plain, Hurricane Ike caused the complete loss of a sand veneer between the low tide line and the slight dune ridge that bordered the shore from Sabine Pass to High Island, and even more importantly, removed much of this ridge which once protected the freshwater wetland and coastal prairie complex in the Texas Point NWR, J.D. Murphree WMA, and McFaddin NWR (Williams et al. 2009). On Bolivar Peninsula, Hurricane Ike removed nearly all traces of sand dunes, which had stood 4 to 5 feet in height, and exposed underlying Pleistocene mud deposits. Bolivar Peninsula is too wide at most locations for sand overwash to be deposited in marshes along the backside of the barrier island; most was deposited mid-island. On Galveston Island, marshes are rapidly shrinking due to RSLR and wave erosion. Hurricane Ike did not provide supplementary material to fill this accretion deficit. Instead, erosion rates 1.5 times greater than normal were recorded (Williams et al. 2009).

Coastal marshes and swamps in some parts of the study area were flooded with storm surge for weeks after Hurricanes Rita and Ike, while coastal marshes in the Galveston Bay area drained quickly, reducing the potential for long term-impacts (FEMA 2008). Coastal marshes around Galveston Bay contain salt-tolerant vegetation, are formed on mineral soils and are sloped toward the bay. However, it is expected that the Chenier Plain marshes surrounding Sabine Lake will experience significant, long-term impacts. These marshes are concave in shape, and under normal conditions, do not drain as rapidly as tidal fringe marshes. The drainage of these marshes is also impaired by numerous human-caused hydrologic modifications within and adjacent to these marshes, such as the GIWW, the SNWW, intentional and inadvertent marsh impoundments, numerous roads, and other infrastructure (FEMA 2008). In addition to inundating salt marshes near the coast, these surges resulted in significantly increased salinities in large areas of swamp and freshwater marsh in the Sabine system for months after the storms (Steyer et al. 2007; FEMA 2009). The marshes of Sabine Lake are composed of generally brackish and intermediate vegetation communities, which were not tolerant of the higher salinity of Ike's storm surge. Therefore, the high salinity water was either lethal to these plants or had sub-lethal effects ranging from reduced seed production, vegetative stress, and increased vulnerability to disease (Smart and

Barko 1980; Linthurst and Seneca 1981; Howard and Mendelssohn 1999). Further compounding the problem are the organic soils that are typical of these marshes, and when exposed to saline waters, can produce high amounts of hydrogen sulfide, which can lead to sulfide toxicity and death in marsh plants. Organic soils are also dependent on plant roots for cohesion; therefore, upon plant death, these soils are subject to rapid erosion and dissolution in normal marsh conditions (FEMA 2008).

In addition to significant marsh loss from shoreline erosion and saltwater stress, other direct impacts on coastal wetlands include scouring and compression, as well as downed trees from surge and winds (FEMA 2008). Oyster beds and fishing grounds were covered by sediment from the retreating storm surge in Galveston Bay, Trinity Bay, Sabine Lake, and the Chenier Plain. The loss of oyster reefs not only impacts the oyster fishery, but also can result in bay-wide ecological impacts.

2.3.3 Attenuation of Storm Surge Impacts by Coastal Wetlands

It is generally believed that coastal wetlands provide critical risk reduction against incoming hurricane storm surges, and that restoration of lost wetlands should be a key component of any strategy to protect vulnerable regions such as the Sabine Pass to Galveston Bay study area. However, few studies have evaluated the value of wetlands in protecting against storm surge in this area. Furthermore, studies of the attenuation effects of coastal marshes and forests in Louisiana and Mississippi have yielded mixed results (Barbier et al. 2013; Costanza et al. 2008; Fitzpatrick 2008, Resio and Westerink 2008, Wamsley et al. 2007; Wamsley et al. 2010).

Historically, many studies have relied upon a USACE estimate of the degree to which marshes and coastal forests slow inland surge penetration (USACE 1963). This report analyzed seven storms occurring between 1909 and 1957 throughout southern Louisiana, producing a widely cited rule of thumb that each 2.7 miles of marsh knocks down the storm surge by 1 foot (1-meter reduction per 14.5 km of marsh). However, the data from this study varied by about a factor of three; attenuation rates as high as 1 foot per 1.3 miles of marsh was seen in one storm, and as low as 1 foot per 3.8 miles of marsh in another (Masters n.d.).

More recent storm surge studies have found that the inland penetration of the storm surge is an extremely complicated function of storm track, speed, duration, size, and associated waves; the regional topography, geometry of the shore, presence of barrier islands, and slope of the ocean bottom; plus the type and thickness of vegetation, and presence or absence of levees. Wetlands will slow down the inland penetration of a storm surge, so the surge will not be able to advance very far inland before the winds die down if a region is exposed to strong winds for a short period

of time. One example of this was in western Louisiana during Hurricane Rita of 2005 (Resio and Westerink 2008). As the hurricane rapidly approached western Louisiana, Rita blew water away from the coast and then plunged water onto land as the eye of the storm passed rapidly. Maximum inland attenuation rates ranged from 1 foot per 2.1 miles to 1 foot per 3.6 miles of inland penetration, under conditions in which the coast was only subject to onshore winds for a few hours.

Hurricane Rita also provides an example of an opposite effect. For slow moving storms, or for portions of the coast subjected to strong winds for many hours, the wetlands may completely flood, and there would be no reduction of storm surge. During Rita, strong winds blew along the east side of the Mississippi for almost a full day, completely flooding the 25 miles of wetlands fronting the Mississippi River levee at English Turn. In fact, the model results show that the surge possibly increased in height, by 1 foot per 8.7 miles of inland penetration because the surge piled up against the levee (Resio and Westerink 2008).

Another storm surge simulation investigates what would happen if Louisiana wetlands were allowed to continue to deteriorate with no restorative efforts over the next 50 years (Wamsley 2007). Results suggest that storm surge heights would increase by 10 to 15 percent along Louisiana coastal areas to the east of New Orleans. These results held for both a severe Katrina-like hurricane, and a more modest hurricane. However, the authors cautioned that additional research is required because "the impact of landscape features on surge propagation is a relatively new application for surge models."

This summary indicates that the effect of wetlands in attenuating storm surge is situationally dependent. Wetlands can attenuate surge in many situations but may also be largely irrelevant in others. The effect of specific marsh restoration or preservation measures cannot be determined without studies and modeling based on fundamental underlying physics, forcing and dissipation mechanisms, adequate specification of the system geometry, and the evaluation of a wide array of storms, varying in direction, speed, and size (Resio and Westerink 2008).

2.3.4 Protected Lands in the Study Area

2.3.4.1 Sabine Region

McFaddin NWR covers about 58,861 acres in Jefferson and Chambers Counties (USFWS 2012 and 2013). Along with the J.D. Murphree WMA, it protects the largest expanse of remaining freshwater marsh on the Texas Coast and thousands of acres of intermediate marsh. The Refuge's southern boundary consists of over 15 miles of Gulf of Mexico shoreline. Remnant dune/beach systems exist along the coastline, although much has been lost through RSLC, erosion and shoreline retreat, leaving only a low-lying washover terrace (TPWD 2013).

J.D. Murphree WMA is 24,498 acres of fresh, intermediate and brackish marsh on the Chenier plain in Jefferson County (TPWD 2013). Extending north and south of the GIWW west of the Sabine-Neches Waterway, the WMA is highly diverse in coastal wetland communities.

Texas Point NWR in Jefferson County encompasses 8,952 acres of fresh to saline marshes and some wooded uplands and prairie ridges (USFWS 2012 and 2013). The Refuge's southern boundary consists of over 6 miles of Gulf of Mexico shoreline. The Chenier plain is characterized by relict beachfronts that form ridges paralleling the Gulf shore. The term derives from the French name for live oak trees (*chenier*), which typically are found growing atop these ridges.

Lower Neches River WMA has 7,998 acres located near Bridge City in Orange County (TPWD 2013). The WMA is composed of three separate units. The Nelda Stark and Old River units are located adjacent to the lower Neches River. The Nelda Stark Unit is primarily shallow open water, which resulted from the degradation of a former marsh system by subsidence and saltwater intrusion. The Old River Unit, near the mouth of the Neches River, is a mixture of intermediate marsh and open water. The Adams Bayou Unit is located on Adams Bayou, a tributary of the lower Sabine River. Formerly a meandering coastal stream and forested bottomland, it was channelized to allow oil field access but still contains a remnant of the Sabine River forested wetlands.

Tony Houseman WMA, managed as a cooperative effort between the Texas Department of Transportation (TxDOT) and TPWD, is located on the Sabine River at Interstate 10 (I-10) (TPWD 2013). A 600-foot boardwalk leads from the center into the swamp. Outdoor recreation includes public hunting opportunities, fishing, wildlife viewing, hiking, and canoeing. The WMA extends from the western bank of the Sabine River just north of the community of Echo down to the confluence of Little Cypress Bayou and the Sabine River south of I-10 at Orange. More than 80 percent is cypress-tupelo swamp.

Two USACE-approved mitigation banks are located on the Neches and Sabine rivers. The Neches River Cypress Swamp Preserve is located north of Interstate 10 below the Neches River Saltwater Barrier (USACE 2005a). Located north of Interstate 10 and west of the Sabine River, the 2,737-acre Blue Elbow Swamp Mitigation Bank is owned by the Texas Department of Transportation (TxDOT) and used to mitigate impacts of state highway projects.

2.3.4.2 Galveston Region

Anahuac NWR is located in Chambers County along the north shore of East Bay, within the Chenier plain region of southwestern Louisiana and southeastern Texas (USFWS 2013). The

Refuge's southern boundary consists of nearly 7 miles of Galveston Bay shoreline (TPWD 2013). Comprising 34,400 acres, it contains brackish and saline marshes, coastal prairie, and coastal woodlands (USFWS 2012).

Armand Bayou Nature Center and Preserve covers a total of 2,800 acres along Armand Bayou in southeastern Harris County (TPWD 2013). Armand Bayou, a tributary of Clear Lake, is a tidally influenced component of the Galveston Bay system. The Preserve is unique in that it is a remnant natural system still existing within a heavily developed, densely populated region. The brackish water bayou bounded by riparian hardwood forest is surrounded by 900 acres of remnant coastal prairie currently under restoration. The Armand Bayou Coastal Preserve is leased from the GLO by the TPWD.

Atkinson Island WMA is on the southern portion of Atkinson Island, a long, narrow island in the very northern tip of Galveston Bay, on the edge of Harris and Chambers Counties (TPWD 2013). The island was used as a case study for the construction of a wetland restoration project using dredged materials. Habitats on the island include a 40-acre woodlot and 90 acres of brackish marsh.

Candy Abshier WMA is located in Chambers County south of the community of Smith Point. This 209-acre WMA consists primarily of coastal prairie habitat with important coastal woodlot or oak mottes. Approximately 60 acres of the area are in this oak motte habitat with the remaining acreage in coastal prairie vegetation. It is owned and managed by TPWD.

Moody NWR is located on the north shore of East Bay (USFWS 2012). The refuge has approximately of 2 miles of bay shoreline and covers 3,517 acres. It took a direct hit and suffered extensive damages from Hurricane Ike. The USFWS holds a perpetual non-development conservation easement on the Moody NWR, which is otherwise entirely privately owned and managed.

North Deer Island Sanctuary is a 10-plus acre island in West Galveston Bay, one of the few natural islands left in this system. It is one of the most important colonial waterbird nesting islands on the upper Texas coast, used by 10,000 to 30,000 pairs of birds each year (TPWD 2013). Dredged material has been placed over approximately one-third of the island. Natural uplands are covered by a plant community unique on the upper Texas coast, composed of lime prickly ash, mesquite, paloverde, and mulberry trees, as well as lantana and cactus. High-quality salt marshes border the uplands on the southeast side of the island. The island is owned by three equal undivided interests the National Audubon Society, the Houston Audubon Society, and a private individual. It is a Houston Audubon/National Audubon Bird sanctuary.

The John O'Quinn Interstate 45 (I-45) Estuarial Corridor contains a wetland corridor gateway to Galveston Island and a mainland coastal prairie component at Virginia Point. The O'Quinn estuarial corridor runs along both sides of I-45 as it passes from the mainland to Galveston Island. This 900-acre area is composed of natural, undisturbed tidal marsh and about 70 acres that have been restored to historical marsh conditions. The 1,500-acre Virginia Point tract is predominantly coastal prairie with interspersed freshwater sloughs and ponds. Together, these tracts of land form a contiguous coastal preserve across the southern tip of the mainland from Jones Bay to the west, where the wetlands are adjacent to property across Highland Bayou managed by The Nature Conservancy and Galveston Bay Foundation, to Galveston Bay to the east. The preserve encompasses approximately 5 linear miles of Bay shoreline. Both areas are owned by Scenic Galveston.

2.3.4.3 Brazoria Region

The Brazoria NWR is a 44,414-acre wildlife conservation area along the coast in Brazoria County (USFWS 2012). It borders the GIWW, behind Follets Island in Brazoria County. Refuge habitats are made up of salt water, fresh water, and brackish wetlands. In addition, there are prairies, woody thickets, salt and mud flats, and lakes and streams. The refuge also contains 5,000 acres of rare, native bluestem prairie, representing one of the last coastal prairies in Texas. Brazoria NWR has a key location on the Texas Gulf, which helps Freeport draw one of the highest Audubon Christmas bird counts in the nation with more than 200 species.

Christmas Bay Coastal Preserve, in Brazoria County, encompasses a shallow 4,173-acre embayment in the southwestern portion of the Galveston Bay system (TPWD 2013). The preserve is one of the most ecologically productive bays of the Galveston complex and has not yet been greatly altered by human activity. The preserve totals approximately 5,700 acres in area. Nearly level prairies are contiguous to extensive fresh and saline marshes. Christmas Bay benefits from Brazoria NWR, a 42,000 acre protected wetland, which contributes to the preserve's productivity and helps protect its water quality. Owned by the GLO, the preserve is leased to TPWD and designated by the TPW Commission as a State Scientific Area.

Justin Hurst WMA (Bryan Beach Unit) is located on the Gulf shoreline on the eastern shore of the Brazos River Diversion Channel. The unit is 440 acres dominated by a 90 acre embayment, which is flooded by Gulf waters during high tides and storms. Large vegetated coastal dunes surround the embayment and separate it from the Gulf.

The Nannie M. Stringfellow WMA is comprised of approximately 3,664 acres in Brazoria County (TPWD 2013). Located in the floodplain of the San Bernard River, the dominant vegetation is coastal bottomland hardwood forest, which is subject to frequent flooding.

San Bernard NWR in Brazoria County serves as the end point of the Central Flyway for waterfowl in winter, and an entry point for neotropical migratory songbirds tired from a 600 mile Gulf crossing from the Yucatan Peninsula (USFWS 2012). The 57,698 acre refuge contains salt and freshwater marshes, sloughs, ponds, coastal prairies, and bottomland forest. Refuge bottomland forests and willow trees attract high numbers of warblers migrating north. Several remote islands in a sheltered bay between the GIWW and the Gulf come alive every nesting season with herons, egrets, terns, and gulls.

2.3.5 Physical and Hydrological Characteristics of the Study Area

The study area, situated in the Western Gulf Coastal Plain, can be divided into two distinct physiographic areas. The surface topography of the project area is mainly flat to gently rolling and slopes to the southeast toward the Gulf. The coastal areas of the eastern- and westernmost sections (Jefferson, Chambers and western Brazoria counties) are barrier headlands consisting of beach or eroding marsh shores, dune and supratidal habitats that naturally decrease in elevation toward fringing intertidal marshes, lakes, and ponds. On the east, Sabine Lake formed in the elongated drowned river valley of the Sabine River; it empties into the Gulf through a narrow constriction at Sabine Pass. The Sabine and Neches Rivers flow into Sabine Lake. On the west, the Brazos River flows directly into the Gulf through a diversion channel constructed by the USACE in 1929 (USACE 2012). A diversion dam about 7.5 miles above the original Brazos River mouth was constructed as part of this navigation improvement project, and the diversion channel rerouted the Brazos River from the dam to an outlet in the Gulf about 6.5 miles southwest of the original mouth. The San Bernard River, the westernmost river in the study area, meanders through a landscape of coastal marshes and lakes on its way to the Gulf (USACE 2008). Its mouth is now frequently closed due to sand accretion from the Diversion Channel delta.

In between, the coastal areas of Galveston, Harris, and eastern Brazoria counties are characterized by a nearly continuous series of marginal marine embayments separated from the Gulf by a system of barrier islands and peninsulas (Lankford and Rehkemper 1969). Coastline features are typically the result of several active, geologic processes including longshore drift, beach wash, wind deflation and deposition, tidal currents and waves, delta outbuilding, and river point bar and flood deposits. The Trinity and San Jacinto rivers, Clear Creek, and Chocolate Bayou are the largest inflows to the Galveston Bay system. Important tributaries in these watersheds include Buffalo, Cedar and Dickinson Bayous.

The coastal zone is underlain by sedimentary deposits that originated in ancient but similar coastal systems - Recent and Holocene-age alluvium containing thick deposits of clay, silt, sand, and gravel, overlying the Pleistocene Beaumont Formation (Barnes 1982, 1987; McGowen et al. 1976). These formations consist mainly of stream channel, point bar, natural levee, and back swamp deposits associated with former and current river channels and bayous.

Probably of most significance in relation to potential storm surge impacts, the widest part of the continental shelf in the northern Gulf of Mexico lies offshore of the study area. At its widest point, offshore of Sabine Pass, the bottom slope averages 6 feet per mile until roughly 1 mile offshore, after which it steadily decreases to an average of 1 foot per mile through roughly 10 miles offshore (White et al. 1987). Thus, for most of its extent the shelf is gently sloping and (with the exception of a few topographically high features such as the Sabine, Heald, and Shepard banks, and relict Sabine, Trinity, and Brazos river valleys) is relatively featureless. Sandy muds and clay muds predominate the surface inner shelf region; however, the surface of virtually the entire area is covered by a sheet of sand approximately 2 feet thick (Anderson and Wellner 2002; PBS&J 2004; White et al. 1988). Storm surges are strongly influenced by the geometry of the basin and continental shelf leading up to the coastal floodplain, especially the depth of water and shelf width. Shelves with a larger shallow-water area will produce larger surges than those with steep offshore slopes (Resio and Westerink 2008).

2.3.6 Biological Communities in the Study Area

2.3.6.1 Coastal prairies

Remnant tracts of tall grass and salty prairies are present in the study area, often interspersed within coastal marshes. Slightly higher in elevation, the grass and prairie tracts offer a different type of habitat (USFWS 2008). Wooly rosemallow, bushy bluestem, and gulf cordgrass thrive there and provide important nesting habitat for mottled ducks, dickcissels, and other species. Black rails, short-eared owls, and LeConte's sparrow find shelter and feed within these prairie habitats. Almost all of the region's historic native coastal tall grass prairie and its associated prairie wetlands have been lost through conversion to agricultural uses and urban development (USFWS 2008). This community is considered critically imperiled by the Texas Natural Heritage Program (USGS 2000).

2.3.6.2 Coastal marshes

Salt marsh is located close to the Gulf shoreline and higher salinity areas of the estuarine systems. Subjected to regular tidal inundation, low saline marsh is dominated by smooth cordgrass/oystergrass (*Spartina alterniflora*) and often accompanied by seashore saltgrass (*Distichlis spicata*), blackrush (*Juncus romerianus*), saline marsh aster (*Aster tenuifolius*), and

marsh hay cordgrass/wiregrass (*S. patens*). The dominant species in high salt marsh, which is subject to less-frequent tidal inundation, is glasswort (*Salicornia* spp.). Brackish marshes grade inland from salt marsh. The dominant species in low brackish marsh is saltmarsh bulrush (*Scirpus robustus*); seashore salt grass and marsh hay cordgrass are co-dominant species in high brackish marsh. Intermediate marshes are subjected to periodic pulses of salt water and maintain a year-round salinity in the range of 0.5 to 4 ppt. They grade inland from brackish marshes and dominate interior marshes of the Sabine and Galveston Bay systems. The diversity and density of plant species are relatively high with marsh hay cordgrass the most dominant species in high marsh. Co-dominant species in low marsh are seashore paspalum (*Paspalum vaginatum*), Olney bulrush (*S. americanus*), California bulrush/giant bulrush (*S. californicus*), and common reedgrass/roseau cane (*Phragmites australis*); bulltongue (*Sagittari lancifolia*) and sand spikerush (*E. montevidensis*) are also frequent. Freshwater marshes dominate in upstream reaches of the Sabine, Neches, Trinity, San Jacinto, and Brazos Rivers. They are heterogeneous, with local species composition governed by frequency and duration of flooding, topography, substrate, hydrology, and salinity. Co-dominant species in low marsh are maidencane (*P. hemitomen*), giant cutgrass (*Zizaniopsis milacea*), and bulltongue. Co-dominant species in high marsh are squarestem spikerush (*E. quadrangulata*) and marsh hay cordgrass. Other characteristic species include American lotus (*Nelumbo lutea*), watershield (*Brasenia screben*), duckweed (*Lemna* spp.), and fanwort (*Cabomba caroliniana*). Salinity rarely increases above 2 ppt, with a year-round average of approximately 0.5 to 1 ppt. Tidal fresh marshes support extremely high densities of wildlife, such as migratory waterfowl. Marsh serves as nursery areas for many important commercial and recreational fish and shellfish species including white and brown shrimp, blue crab, red drum, flounder, and speckled sea trout. Coastal marsh habitats provide important functions of improving water quality in the estuarine ecosystem, providing flood control benefits, and buffering inland habitats from tropical storm-generated tidal surges. In addition, marshes are extremely biologically productive and diverse and provide detrital input, which is the basis for the estuarine food chain (USFWS 2008).

2.3.6.3 Forested Wetlands

Upstream of the coastal marshes in Sabine, Neches, and Trinity estuaries, the study area is dominated by dense bottomland hardwood forests and cypress-tupelo swamps. These wetland forests cover an intricate network of sloughs and sandy ridges formed within the rivers' relict meander belts. Bald cypress (*Taxodium distichum*) – tupelo-gum (*Nyssa aquatica*) swamps grow in the inundated areas between the ridges, and floodplain hardwood forest of oaks (*Quercus nigra, Q. phellos, Q. alba, Q. lyrata*), sweetgum (*Liquidambar styraciflua*), hickories (*Carya* spp.), American elm (*Ulmus americanus*), maple (*Acer rubrum*), green ash (*Fraxinus pennsylvanica*), American holly (*Ilex opaca*), and loblolly pine (*Pinus taeda*) grow atop the sandier ridges and on the Pleistocene terrace uplands that border the floodplains. In general, these are healthy, stable

habitats. The hardwoods, and especially the cypress trees, have been logged repeatedly since the turn of the century and as recently, perhaps, as the 1950s (USACE 1998). Though much of the forest is secondary growth, the swamp and bottomland hardwood habitats have medium to high value for food and cover to resident and migratory fish and wildlife. Forested wetlands in the San Jacinto and Brazos River system are dominated by bottomland hardwood communities.

Oak woodlot habitats (also known as oak mottes) can be found on higher ridges and mounds scattered across coastal marshlands. They are vital for resident and migrant species of wildlife, especially neotropical migrant passerine species.

2.3.6.4 Other Aquatic Habitats

Extensive freshwater aquatic habitats are present in the upstream reaches of rivers and bayous in the study area. Large estuarine aquatic habitats are present in the Sabine Lake area and the greater Galveston Bay area; somewhat smaller estuarine aquatic habitats are present in Chocolate Bayou, and the San Bernard River delta area. Approximately 36,000 acres of oyster reefs are present in the Sabine and Galveston Bay systems. The Texas oyster fishery is the second largest in the country, with Galveston Bay accounting for approximately 18 percent of total oyster landings. The average annual catch value of Galveston Bay oysters for the period between 2005 and 2007 was in excess of $10.4 million (FEMA 2008). Sabine Lake is currently closed to commercial oyster harvesting (USACE 2011). In addition to supporting a large commercial fishery, oyster reefs provide important habitats for numerous commercially and recreationally important fishery species, such as red drum and brown shrimp. Oysters are also vital to maintaining the water quality of estuarine systems. Through their filter-feeding activities, oysters remove nutrients, pollutants, and algae from the water column. The shallow Gulf of Mexico waters, tidal flats, and beaches provide important shallow water feeding, breeding and nesting habitat utilized by killdeer, black-necked stilt, and willet (USFWS 2008). This transition from land to sea contains a combination of salt-tolerant marsh and beach plants, which are adapted to shifting sands, high winds, and rising waters and help protect the dunes from erosion.

2.3.7 Essential Fish Habitat

Essential fish habitat (EFH) consists of those habitats necessary for spawning, breeding, feeding, or growth to maturity of species managed by Regional Fishery Management Councils, as described in a series of Fishery Management Plans, pursuant to the Magnuson-Stevens Fishery Conservation and Management Act. Gulf of Mexico managed species and habitat types in the study area designated as EFH for each species' life stages are presented in Table 2-2.

Table 2-2: Estuarine EFH for Gulf Managed Species in S2G Study Area

Common and Species Name	Eggs	Larvae	Post Larvae	Early Juvenile	Late Juvenile	Adult
Estuarine Emergent Marsh						
Red drum (*Sciaenops ocellatus*)			•	•		•
Gray snapper (*Lutjanus griseus*)						•
Brown shrimp (*Penaeus aztecus)*				•		
White shrimp *(Penaeus setiferus*)				•		
Estuarine Submerged Aquatic Vegetation						
Red drum (*Sciaenops ocellatus*)		•	•		•	•
Lane snapper (*Lutjanus synagris*)			•	•	•	
Brown shrimp (*Penaeus aztecus)*				•		
Estuarine Mud/Soft Bottom						
Red drum (*Sciaenops ocellatus*)		•	•	•		•
Gray snapper (*Lutjanus griseus*)						•
Lane snapper (*Lutjanus synagris*)				•	•	
Brown shrimp (*Penaeus aztecus)*				•		
White shrimp *(Penaeus setiferus*)				•		

2.3.8 Threatened and Endangered Species

Federally-listed species potentially occurring within Orange, Jefferson and Brazoria Counties study area include wintering populations of the piping plover (*Charadrius melodus*), red knot (*Calidris canutus rufa*), whooping crane (*Grus americana*), West Indian manatee (*Trichechus manatus*) several species of whales (fin [*Balaenoptera physalus*], humpback [*Megaptera novaeangliae*], sei [*Balaenoptera borealis*], and sperm [*Physeter macrocephalus*]), swimming green, hawksbill, Kemp's ridley, leatherback, and loggerhead sea turtles (*Chelonia mydas, Eretmochelys imbricata, Lepidochelys kempii, Dermochelys coriacea, and Caretta caretta*), and Texas prairie dawn-flower (*Hymenoxys texana*) (USFWS 2013; NOAA 2013). National Marine Fisheries Service has also designated the following four species of corals as endangered for this area – lobed star (*Orbicella annularis),* mountainous star *(Orbicella faveolata),* boulder star *(Orbicella franksi),* and elkhorn (*Acropora palmata).* USFS has identified three Candidate species – Sprague's pipit (*Anthus spragueii*), the smooth pimpleback clam (*Quadrula houstonensis*) and the Texas fawnsfoot clam (*Truncilla macrodon*). Descriptions of these species and their habitats are provided in the Biological Assessment (Appendix J).

Critical habitat for wintering populations of the piping plover is present in Galveston and Brazoria Counties. In Galveston County, shoreline areas around Rollover Pass, near Fort Travis at the Galveston East Jetty, Big Reef at the Galveston West Jetty, and on the east side of San Luis Pass have been designated. In Brazoria County, critical habitat has been designated for the western Brazoria County shoreline, beginning at Bryan Beach State Park and extending west to beyond the county line.

2.3.9 Water and Sediment Quality

Water and sediment quality in the study area are generally of good quality, although some stream segments in each area are identified as impaired. Testing of water and sediments in conjunction with maintenance dredging of existing navigation channels and proposed modifications for the Sabine-Neches Waterway (USACE 2011), the GIWW from High Island to Brazos River (USACE 2003), the Houston-Galveston Navigation Channels and associated projects (USACE 2003, 2010, 2013), the Texas City Channel (USACE 2008), the Freeport Harbor Channel (USACE 2012), and the mouth of the San Bernard River (USACE 2008) have generally identified few causes for concern. The Galveston Bay Foundation has recently issued a grade of "A" for water quality in Galveston Bay, but an overall grade of "C" for toxins in the sediments (Galveston Bay Foundation and HARC 2016). This is related primarily to concerns with Houston Ship Channel sediments inland of Galveston Bay. In the Sabine region, freshwater stream segments are generally of good quality, but tidal segments of several streams have depressed levels of dissolved oxygen and undesirable levels of bacteria, due in large part to low tidal flows (TCEQ 2014). Contaminated sediments and edible fish tissues have been reported for a few segments in and near the Neches and Sabine Rivers. In the Brazoria region, only one stream has been classified as non-supporting for recreation use due to undesirable levels of bacteria. Additional information is provided for the No Action Alternative description in section 7.7.1.

2.3.10 Air Quality

The Galveston and Brazoria regions are located within the Houston-Galveston-Brazoria (HGB) Air Quality Control Region (AQCR), consisting of Harris, Montgomery, Liberty, Chambers, Galveston, Brazoria, Fort Bend, and Waller Counties. This AQCR meets all of the U.S. Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS), except for ozone. Exposure to ground level ozone in high concentrations can result in adverse effects on humans, plants, and animals. Urban areas typically have high levels of ground level ozone. The HGB AQCR is classified as marginal nonattainment for the 2008 ozone NAAQS, and severe nonattainment for the 1997 ozone NAAQS.

Jefferson and Orange counties are located in the Beaumont-Port Arthur (BPA) AQCR. On October 20, 2010, the EPA published a final rule in the *Federal Register* (75 FR 64675), effective November 19, 2010, approving a redesignation request and finalizing a determination that the BPA area is in attainment for the revoked one-hour ozone standard. The EPA's determination to redesignate signifies that the BPA area has met all of the applicable Federal Clean Air Act requirements for the purpose of redesignation to attainment.

2.3.11 Hazardous, Toxic, and Radioactive Waste Concerns

Hundreds of petrochemical plants, oil storage facilities, hazardous waste facilities, aboveground tanks, and underground storage tanks are located in storm surge-vulnerable regions of the numerous industrial centers in the study area (Orange, Beaumont, Port Arthur, Texas City, Pasadena/Deer Park, Houston, Baytown, Chocolate Bayou, and Freeport). In the Houston Ship Channel area alone, about 20,000 acres along lower Buffalo Bayou contain industrial facilities with potential for toxic environmental releases as a result of storm surge (Rifai and Burleson 2012). Hurricane Ike caused hundreds of localized oil and other toxic spills that threaten fish and wildlife throughout the affected area (FEMA 2008). As of Oct. 1, 2008, the multi-agency task force for spill response had assessed more than 200 pollution reports, which include more than 180 sites in the Houston-Galveston area and 47 in the area from Port Arthur to Lake Charles, Louisiana. The type and amount of pollution included oil and diesel from vessels, as well as industrial chemicals.

2.3.12 Cultural Resources

Numerous cultural resource surveys in the area have documented over 1,000 cultural resource sites in the study area, ranging from prehistoric shell middens to numerous historic sites including houses, buildings, bridges, tunnels, and lighthouses. The area includes several National Historic Landmarks, including the San Jacinto Battlefield, the Battleship Texas, the Tall Ship Elissa, and the Spindletop Oil Field, as well as National Historic Landmark Districts, such as the Galveston Strand Historic District and the Galveston East End Historic District. The Galveston Strand District contains many Victorian-era National Register structures from the city's historic heyday when Galveston's national prominence resulted in it being called "the Wall Street of the Southwest". There are over 100 National Register Properties within the study area. Sixty of the historic properties are located in the city of Galveston, and are primarily historic houses, commercial and government buildings. Other National Register sites and districts located throughout the area include the Apollo Mission Control Center, the Space Environment Simulation Laboratory, the Saturn V Launch Vehicle, the Point Bolivar and Sabine Pass Lighthouses, the Beaumont Commercial District, the Jefferson Historic District, the Port Arthur-Orange Bridge, the W. H. Stark House, the Old Wallisville Townsite, Fort Anahuac, and the Chambers and Jefferson

County Courthouses. The majority of these cultural resources are vulnerable to damage or destruction from hurricane storm surge.

2.3.13 Energy and Mineral Resources

Hundreds of pipelines cross the waterways and marshes of the study area. Pipelines crossing beneath the navigation channels are generally buried deeply enough that they would not be affected by storm surge scouring. However, it is likely that pipelines are present in many areas where storm surge barriers or ER measures such as marsh restoration or breakwaters have been proposed. In-depth research and surveys would be needed to identify pipelines for detailed preconstruction planning and design.

2.3.14 Socioeconomic Considerations

The Sabine Pass to Galveston Bay study area encompasses six coastal counties of the upper Texas coast. Over five million people reside in the six counties, which include the 4th largest U.S. city (Houston) and three other large metropolitan areas (Beaumont/Port Arthur/Orange, Galveston/Texas City and Freeport/Surfside). The population of these counties is projected to increase to over nine million within the next 50 years. In addition to the at risk population, three of the nine largest oil refineries in the world, 40 percent of the nation's petrochemical industry, 25 percent of the nation's petroleum-refining capacity, and three of the ten largest US seaports are also located in the study area. The growing population, communities and nationally significant industries are severely vulnerable to risks from coastal storm events. Approximately 2.26 million people across the study area live within a storm-surge inundation zone, and estimates for a one-month closure of the Houston Ship Channel alone are upwards of $60 billion in damages to the national economy.

Hurricane Ike is an example of the types of socioeconomic disruptions that could be expected when another major hurricane strikes the area. Numerous industries, including the petrochemical, health care, agriculture and forestry, fishing, tourism, nonprofit, and small business sectors would be adversely affected, both during and after the storm. Shipping would be disrupted and port facilities damaged in three of the four primary Texas ports (Kraus and Lin 2009). According to USACE records, in 2006 these four port areas cumulatively accounted for nearly 500 million short tons (454 million metric tons) of waterborne tonnage and handled 25 percent of all foreign (imports and exports) tonnage traveling on U.S. waterways. Crude petroleum tonnage was 35 percent of the national total. Other significant commodity totals include gasoline (19.8 percent of national coastwise total), distillate fuel oil (24.3 percent of national coastwise total), wheat (22.4 percent of national coastwise total), and benzene and toluene (72 percent of national coastwise total). Clearly, recovery of the coastal navigation channels and associated waterways was of national urgency

after Hurricane Ike (Tirpak 2009). During Hurricane Ike, hundreds of thousands of homes along the upper Texas coast were severely damaged or destroyed as a surge of up to 20 feet hit in conjunction with the high tide (FEMA 2008). It has been estimated that 75 percent of the 24,000 structures on Galveston Island flooded during Ike to a maximum height of 10 to 12 feet (Tirpak 2009). Entire cities were inundated with the mud and debris that accompanied the surge. In the small town of Bridge City, only 14 of its 3,400 homes were habitable after the storm. In Gilchrist, located on the Bolivar Peninsula, only one home was left standing when the winds stopped. Months after the storm, thousands of families across the region continued to struggle with finding places to live near their jobs and children's schools in an effort to restore some normalcy to their lives (FEMA 2008). Hurricane Ike also placed immediate and long-term strains on the ability of impacted communities to provide access to health care and specialty health services, and basic services, like childcare, public education, and public utilities.

3 NO ACTION ALTERNATIVE (FUTURE WITHOUT-PROJECT CONDITIONS)*

The USACE is required to consider the No Action Alternative during the planning process and assessment of impacts to comply with the NEPA and CEQ guidance (40 CFR §1502.14) as well as USACE regulations (ER 200-2-2) for implementing the NEPA. The No Action Alternative is a forecast of the future without-project (FWOP) conditions which provide the basis for plan formulation and eventual comparison to all other alternative plans. The terms "No Action Alternative", "future without-project" or "future without-project condition" is used synonymously or interchangeably throughout the FIFR-EIS. With the No Action Alternative, it is assumed that no project would be implemented by the Federal Government or by local interests to achieve the planning objective. The No Action Alternative forms the basis against which all other alternative plans are measured.

The No Action Alternative condition assumes the continuation of existing conditions for the resources listed above; no improvement of existing HFPPs at Port Arthur, Texas City, and Freeport; no intervention to reduce the impacts of storm surge on the vulnerable populations and infrastructure of the study area; and no large-scale ER efforts to improve the sustainability of fragile coastal systems and attenuate storm surge.

3.1 PROJECT AREA

The regions described in Section 1.5 were refined in the study within the Sabine and Brazoria regions located in Orange, Jefferson, and Brazoria counties into project areas. These project areas were defined to show more detail on the No Action Alternative conditions for storm surge flood risk. The project areas generally align with the 0.2% ACE (500-year floodplain) and locations of economic damages analyzed in the study. Figures 3-1 and 3-2 show the project areas. The Orange-Jefferson CSRM and Port Arthur and Vicinity CSRM projects areas are in the same general vicinity. In Figure 3-1, the highlighted areas shown in red are located on the Orange County side and structures in yellow on the Jefferson County side. The Orange-Jefferson CSRM focus on inundation of structure on the Orange and Jefferson County side, while the Port Arthur and vicinity focus on the Jefferson County side.

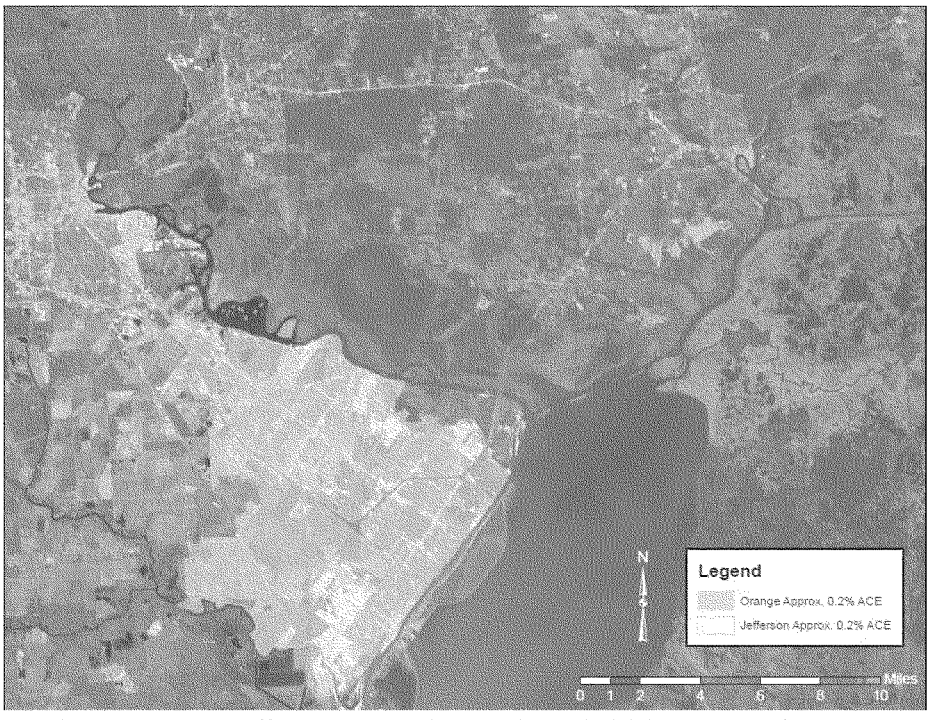


Figure 3-1: Orange-Jefferson CSRM and Port Arthur and Vicinity CSRM Project Areas

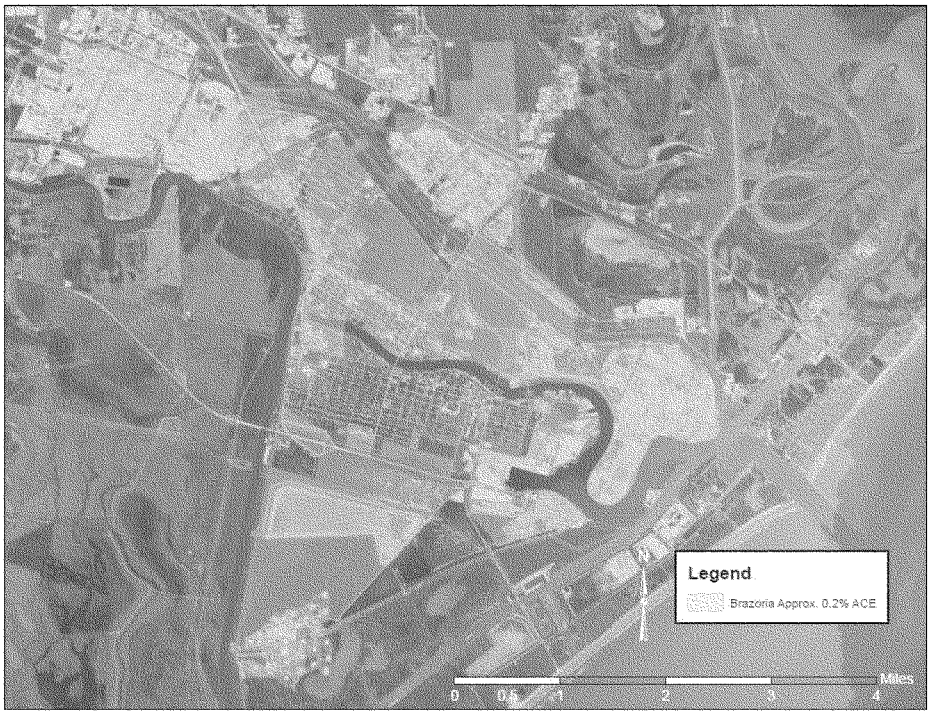


Figure 3-2: Freeport and Vicinity CSRM Project Areas

In order to define the No Action Alternative for life-safety, economic damages, and critical infrastructure, a description of the existing HFPPs is required. This includes a description of the existing facilities in place and the known vulnerabilities in those systems. The following is a brief description of the existing projects in place, including two Federal projects (Freeport HFPP and Port Arthur HFPP). Other projects in the vicinity are noted, but were not originally built by USACE. Additional detail of the existing projects is included in the engineering appendix (Appendix D).

As noted in Section 1.9 of this report, the Port Arthur and the Freeport HFPPs were constructed by USACE. The local sponsors responsible for operation and maintenance are the Jefferson Country Drainage District No. 7 and the Velasco Drainage District (VDD), respectively. There is no existing USACE HFPP in the Orange-Jefferson CSRM project area. The following describes the existing projects in place for each project area.

Orange-Jefferson CSRM Project Area

A known existing flood risk reduction facility located in the Orange-Jefferson CSRM project area is a wall surrounding the Exxon Mobil industrial facilities as indicated in Figure 3-3. This facility was constructed by local industry around the Exxon Mobil plant.

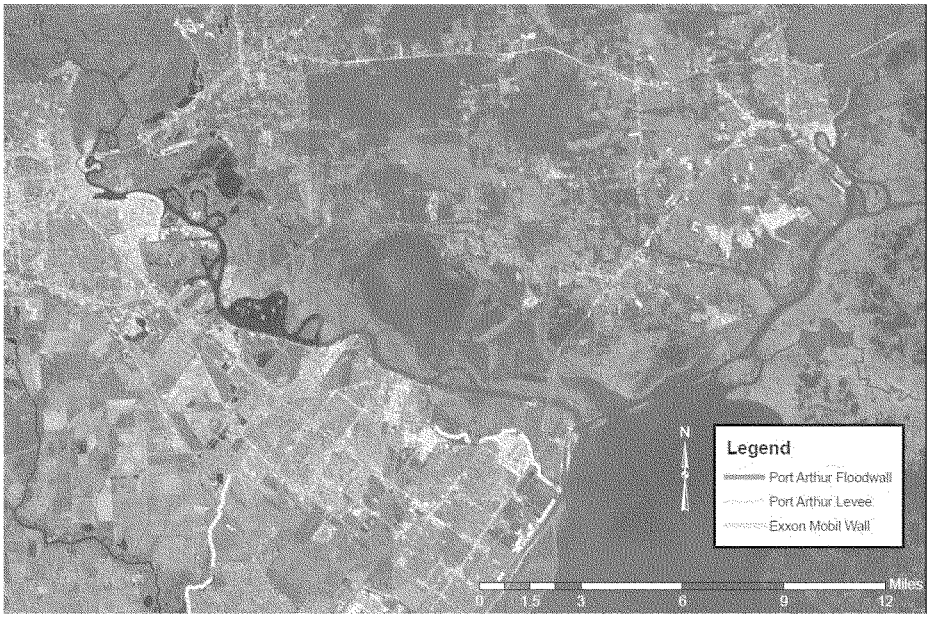


Figure 3-3: Existing Floodwall in the Orange-Jefferson CSRM Project Areas

Port Arthur and Vicinity CSRM Project Area

The existing HFPP protects the Port Arthur region from coastal storm surge events coming from the Gulf of Mexico. It also protects from flooding from the Sabine River. The levee system consists of 27.8 miles of earthen embankment and 6.6 miles of floodwall. This includes 3.5 miles of coastal cantilever I-wall (Texas Coastal I-Wall study). There is also a wave barrier on Pleasure Island. The system was designed and constructed for a 1% ACE.

The Port Arthur and Vicinity CSRM project area has an existing USACE HFPP with a preliminary Levee Safety Action Classification (LSAC) that has resulted in the RMC initiating a Semi-Quantitative Risk Assessment (SQRA) to better define the systems risk. This classification was primarily driven by three main risk factors (probability of load, probability of failure, and nature

of the consequences). The following lists the major engineering concerns for the Port Arthur and Vicinity CSRM:

- Potential failure due to I-wall stability (locations of concern shown in Figure 3-4); and
- Currently the system would suffer a catastrophic failure during a future hydraulic loading roughly equivalent to 0.6% ACE (150-year event).

The existing system at Port Arthur is considered "minimally acceptable" under the USACE's P.L. 84-99 program. A Periodic Inspection was completed for the Port Arthur system in 2012, and the sponsor was provided a list of items to correct. The sponsor is in the process of correcting these items. The potential failure issues addressed in this study are not considered an O&M responsibility. The existing Port Arthur HFPP is certifiable for FEMA accreditation under CFR 65.10, so the local sponsor has no current plans to address the risk drivers for the engineering concerns in the FWOP condition. It is assumed in the No Action Alternative that no other actions to reduce the risk will take place by others.

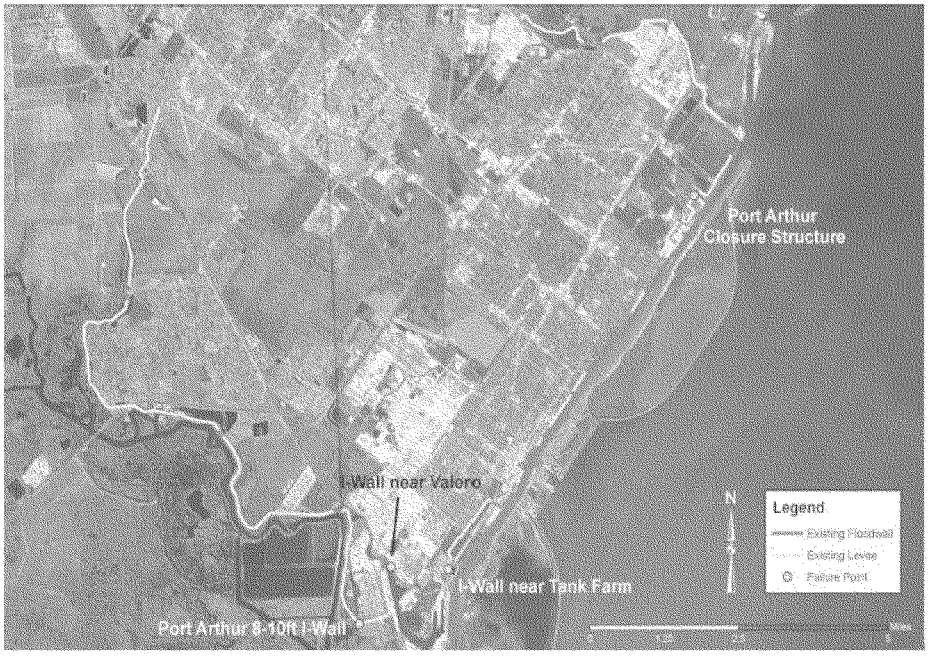


Figure 3-4: Port Arthur and Vicinity CSRM Failure Locations

Freeport and Vicinity CSRM Project Area

The existing HFPP at Freeport consists of approximately 43 miles of levees and wave barriers, seven pump stations and multiple gates, culverts, and related appurtenances, generally depicted in Figure 3-5. Additionally, the line of risk reduction includes multiple structures that also serve as control structures and docks for the DOW Chemical Co., BASF, Conoco Philips, Exxon, and Port Freeport.

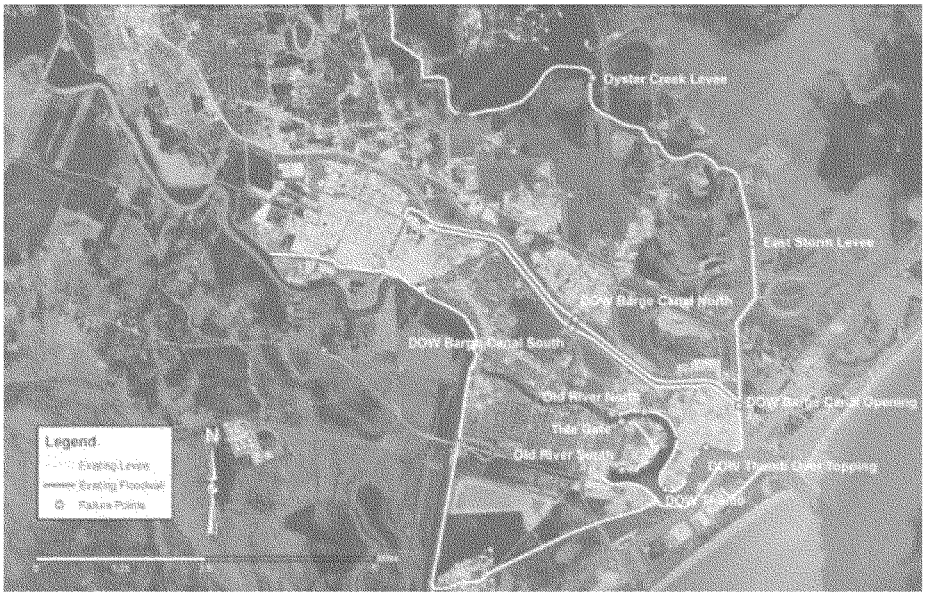


Figure 3-5: Existing HFPP in Freeport and Vicinity CSRM

The Freeport and vicinity system has a preliminarily LSAC that has resulted in the RMC conducting an SQRA to define the systems risk. This classification was driven by numerous factors. The primary structural factors that would have Federal interest are seepage/slope stability of "sandy" levees, I-wall stability, and a "low" level of risk reduction (i.e., high probability of overtopping):

- Steady state seepage analysis for the levees and foundation areas that have a high sand content show high potential for levee failure at top of levee loading;
- Potential failure of the I-wall at the tide gate due to stability; and

- System capacity corresponds to around a 0.7% ACE (130-year event) with significant consequences.

Currently the system is "unacceptable" in the PL 84-99 program and not certifiable for FEMA accreditation under CFR 65.10; therefore, the local sponsor has a System-Wide Improvement Framework (SWIF) plan in place to address the deferred maintenance issues and issues impeding CFR 65.10 accreditation. The sponsor has no current plans to address the structural risk drivers for the LSAC rating due to the performance concerns coming at a more significant hydraulic loading event than the requirements under CFR 65.10. The No Action Alternative would result in no action being undertaken to reduce the risk that the system would suffer a catastrophic failure during a future hydraulic loading roughly equivalent to 0.7% ACE event.

3.2 ECONOMIC CONDITIONS

The FWOP economic conditions were evaluated throughout plan formulation in greater levels of detail to screen measures and alternatives as the study progressed. It is important to note some level of detail regarding the plan formulation process used in this study to introduce how the FWOP economic conditions were estimated. First, management measures to address flood risk and ecosystem restoration were developed and screened. Then remaining measures were evaluated as stand-alone alternatives or in combination with each other and screened in an iterative process referred to as the Initial Array, Evaluation Array, and the Final Array of Alternatives. The economic screening performed during each iteration is described in detail in Appendix B (Plan Formulation) and summarized here for the all screening leading up to Final Array of Alternatives. More detail for the FWOP economic conditions for the Final Array Alternatives is described in this section.

3.2.1 Initial and Evaluation Array of Alternatives

For the Initial and Evaluation Array Alternatives, FWOP economic damages and benefits were estimated using the Hydrologic Engineer Center Flood Impact Analysis model (HEC-FIA) for the 1% ACE event (or 100-year). HEC-FIA is a software package developed by USACE that analyzes the consequences of flood events. The economic damage estimates are roughly equivalent to insured losses, and do not include damages to the economy as a whole. Economic and cost criteria were applied to screen the alternatives.

3.2.2 Final Array of Alternatives

This is a summary of the FWOP economic conditions for the Final Array of Alternatives. Structure files for the project areas were developed to determine the potential flood damages to properties based on estimated storm surge events. Estimated Annual Damages (EAD) under the FWOP

conditions were calculated using the risk and uncertainty within HEC-FDA version 1.2.5, through integration of frequency-damage data. Based on the characteristics of the floodplain, the project areas were split into damage reaches based on hydraulic, geotechnical, and environmental considerations. The EADs for the FWOP conditions are presented in detail in Appendix B for each alternative reach along with the engineering inputs and assumptions into the model. The results are summarized here. Tables displaying structure and content values by reach, detailed tables of the EAD calculations, and additional detail regarding development of the structure file is provided in Appendix C.

The effort for estimating EAD estimates for each damage reach used a different methodology than what was employed for the Initial Array and Evaluation Array Alternatives. This screening used HEC-FIA with 1% ACE depth grids in conjunction with HAZUS-MH data to determine FWOP economic damages as described previously in Section 3.1.1. This analysis incorporated a risk-based analysis in compliance with ER-1105-2-101.

Still water levels were used to determine the overall economic efficiency of the final array alternatives since low-probability wave run-up and/or overtopping do not incorporate a reliable means of determining high-level overall economic efficiency. Design considerations for wave run-up and overtopping was analyzed later and applied to specific locations where it is applicable. This includes along the levee/floodwall system and necessary interior drainage analysis on the final feasibility-level design of the Recommended Plan. Fragility curves were developed for use in the HEC-FDA model for specific locations along the Port Arthur and Freeport HFPP in order to account for the anticipated system performance at those locations, and were used to scope the reconstruction and resiliency features for the existing system. Additional detail of the fragility curve development for the economic evaluation for the FWOP condition is included in Appendix D, Geotechnical Section.

Orange-Jefferson CSRM

To estimate EADs, the system was set up with three major components based on their location. This was primarily due to initial configurations of new levees based on alignments from the Orange County Flood Protection Planning Study (Orange Report), completed in 2012. The following lists the Alternative Reaches:

- Orange 1, Orange 2 and Orange 3
- Jefferson Main
- Beaumont A, Beaumont B, Beaumont C

The Orange component runs along the north side of the Neches River and was divided into three sections: Orange 1 on the western end that primarily protects Rose City, Orange 2 that begins just east of Rose City and ends roughly halfway between Rose City and Bridge City, and Orange 3, which encompasses the remainder of the Orange County component. Figure 3-6 presents the Orange-Jefferson damage reaches. The "with-project" levee and floodwall alignments are included in this figure although this discussion is only supposed to present the No Action Alternative Reaches.

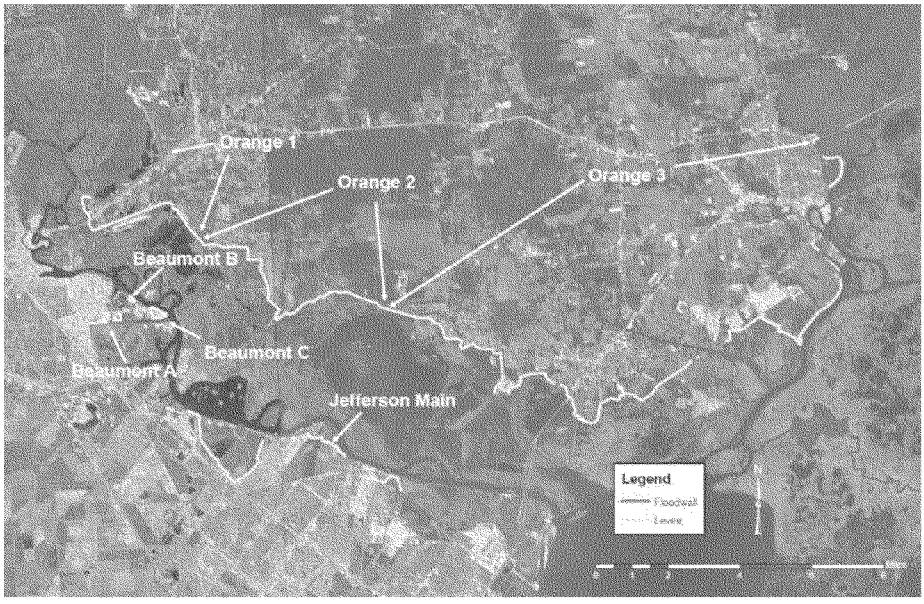


Figure 3-6: Orange-Jefferson CSRM Alternative Reaches

For the Orange 1, Orange 2, and Orange 3 alternative reaches, significant damages start at approximately the 1% ACE; the depth of flooding at the 1% ACE is approximately 8 feet. In the Jefferson Main alternative reach, significant damages start between the 2% and 1% ACE; the depth of flooding between the 2% and 1% ACE is approximately 6.5 feet and 7.5 feet. For the Beaumont A, Beaumont B, and Beaumont C reaches, the significant damages start at the 1% ACE; the depth of flooding is approximately 7.5 feet.

The total number of structures in the Orange-Jefferson CSRM is 27,125 (Orange County) and 26,605 (Jefferson Country). The total structure and content values of inventoried structures (2015 price and levels of development) for the Orange-Jefferson CSRM, in Orange County is

$6,147,511,000 ($3,170,490,000 structure value and $2,977,021,000 in content value). Total structure and content values of inventoried structures (2015 price and levels of development) for the Orange-Jefferson CSRM project area, in Jefferson County, is $8,120,438,000 ($3,998,788,000 structure value and $4,121,650,000 in content value).

Table 3-1 estimates the FWOP EADs for the damage reaches in the Orange-Jefferson CSRM. Damage categories such as commercial or industrial are provided in Appendix C, Economics.

Table 3-1: Expected Annual Damages
FWOP for the Orange-Jefferson CSRM Project Area by Alternative Reaches
(2015 price level)

Orange-Jefferson CSRM Alternative Reaches	Total
Orange 1	$312,000
Orange 2	$68,000
Orange 3	$29,987,000
Beaumont A	$6,937,000
Beaumont B	$23,000
Beaumont C	$262,000
Jefferson Main	$28,231,000

Port Arthur and Vicinity CSRM

The draft findings of the SQRA for the Freeport system were applied to the plan formulation for Port Arthur because one has not yet been done. For the Port Arthur HFPP, the detailed description of the needs is similar to what will be presented in the Freeport HFPP section. However, the Port Arthur system is different because there are no known deferred maintenance issues for the Port Arthur system at this time.

The FWOP conditions for the Port Arthur and Vicinity CSRM began with defining reaches for the system. These were based on the failure locations identified by the levee safety program in the absence of a SQRA. Figure 3-7 displays the Port Arthur HFPP failure locations. These locations were included in the plan formulation where improvements would positively impact the system's capacity for risk reduction. The following lists the Alternative Reaches at Port Arthur:

- 8-foot to 10-foot I-Wall Raise
- Closure Structure Raise
- I-Wall Raise Near Valero
- Raise Near Tank Farm

Figure 3-7: Port Arthur and Vicinity Failure Locations

The estimated start of damages for the Port Arthur and Vicinity alternative reaches is approximately 15 feet, which correlates to estimated high probability of failure of the existing HFPP based on the fragility curves. Flooding depths approximate the stage on the exterior side of the existing HFPP, which goes up to approximately 14 feet for the 0.1% ACE.

There are 43,968 structures included in the structure file for the Port Arthur and Vicinity CSRM. The total structure and content values of inventoried structures (2015 price and levels of development) for the Port Arthur and Vicinity CSRM is $19,195,051,000 (7,869,963,000 structure value and $11,625,088,000 in content value). Table 3-2 estimates the FWOP EADs for the damage reaches in the Port Arthur and Vicinity CSRM project area. Damage categories are defined in Appendix C, Economics.

Table 3-2: Expected Annual Damages
FWOP for the Port Arthur and Vicinity Project Area by Alternative Reaches
(2015 price level)

Port Arthur and Vicinity CSRM Alternative Reaches	Total
8-foot to 10-foot I-Wall Raise	$23,413,000
Closure Structure Raise	$3,784,000
I-Wall Raise Near Valero	$61,867,000
Raise Near Tank Farm	$38,009,000

Freeport and Vicinity CSRM

The draft findings of the SQRA for the Freeport system show vulnerabilities primarily associated with steady state seepage issues, and floodwall and levee overtopping. Other performance issues identified during the SQRA were the result of deferred local sponsor maintenance or alterations that local industrial stakeholders have constructed over time. Floodwall performance issues, at locations where the originally constructed floodwall is still in place and has been operated and maintained in an acceptable manner, are being evaluated to include stability and resiliency. Levee reaches that are non-uniform in height or otherwise susceptible to concentrated overtopping erosion during an event are being evaluated for raising or armoring to reduce the likelihood of breach.

The formulation of alternatives for the Freeport and Vicinity CSRM project area began with defining reaches for the system. These were based on the failure locations identified in the SQRA (Figure 3-8). These locations were then narrowed during formulation to those locations where improvements would positively impact the system's capacity for risk reduction and to reduce any redundancies. For example, improvements to the DOW Barge Canal would negate any failures at the DOW Turning Basin.

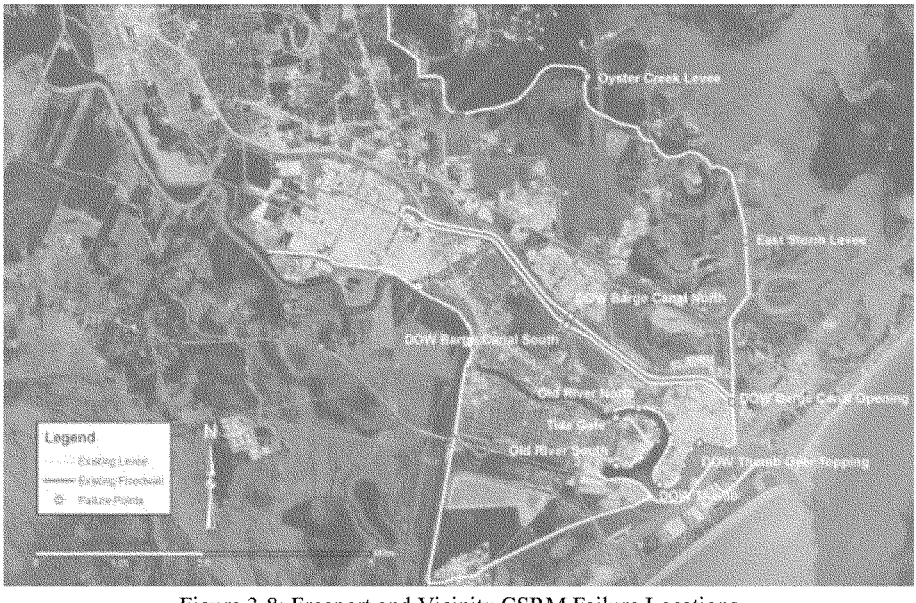


Figure 3-8: Freeport and Vicinity CSRM Failure Locations

The following is the resulting list of Alternative Reaches at the Freeport and Vicinity CSRM:

- DOW Barge Canal
- Oyster Creek Levee
- East Storm Levee
- South Storm Levee
- Freeport Dock Floodwall
- Old River Levee at DOW Thumb
- Tide Gate I-Wall

The estimated start of damages for the Freeport and Vicinity alternative reaches is approximately 15 feet, which correlates to estimated high probability of failure of the existing HFPP based on the fragility curves. Flooding depths approximate the stage on the exterior side of the existing HFPP, which goes up to approximately 19 feet for the 0.1% ACE.

There are 23,326 structures included in the structure file for the Freeport and Vicinity CSRM. The total structure and content values of inventoried structures (2015 price and levels of development) is approximately $16,700,000,000. Estimates could be higher based on additional structures in the lower reaches outside the DOW Barge Canal structure file inventory. Table 3-3 estimates the FWOP EADs for the damage reaches in the Freeport and Vicinity CSRM. Damage categories are defined in Appendix C, Economics.

Table 3-3: Expected Annual Damages
FWOP for the Freeport and Vicinity Project Area by Alternative Reaches
(2015 price level)

Freeport and Vicinity CSRM Alternative Reaches	Total
DOW Barge Canal	$166,660,000
Oyster Creek Levee	$3,800,000
East Storm Levee	$1,701,000
South Storm Levee	$254,000
Freeport Dock Floodwall	$3,960,000
Old River Levee at DOW Thumb	$2,517,000
Tide Gate I-Wall	$2,785,000

3.3 ENVIRONMENTAL CONDITIONS

The repetition of tropical storm events, hurricanes, and human modification of hydrology and coastal features has increased ecosystem vulnerability on the upper Texas coast. Successive

disturbance by storm events, reduced sediment inflows, RSLC and salt stress from interference with fresh water flows has put in jeopardy the process by which marsh sediment accretion and land accumulation occurs. "Without a healthy plant community, sedimentary deposition decreases due to the loss of plants in the water column, biogenic accretion ceases due to the lack of plant detritus, and the substrate becomes exposed, leading to rapid erosion. As a result, a tipping point may have been reached, or is about to be reached, where these wetlands will be unable to keep pace with rising sea level" (Williams et al. 2009). As a result, the extensive marshes along the upper Texas coast have reduced resiliency to storm surge impact, complicating their post-storm recovery. All of this is also occurring within the context of climate change, which is likely to result in an increase in the intensity of tropical storms, rising average annual temperatures, and an increase in the rate of RSLC (IPCC 2014).

The effects of hydrological alterations (from a variety of sources, including dams, deep draft ship channels, impoundments, reduced flows due to increasing human and agricultural use) that have decreased freshwater and sediment inflows and increased saltwater intrusion into coastal marshes are expected to continue. These alterations have resulted in the loss of coastal freshwater wetlands and the conversion of remaining fresh marsh systems to more brackish regimes, reducing native biological diversity and productivity. Increased marsh loss could alter the entire food chain in these areas, resulting in wide-reaching and long-term impacts on coastal habitats and fisheries production in terms of species like red drum, white shrimp, and blue crab.

The loss of 1.2 million acres of historic wetlands in Texas makes the remaining areas especially important for wildlife (USFWS 2013). Marsh losses like those on the Neches River, where approximately 9,500 acres of open-water areas have been created by marsh loss at Rose City, Bessie Heights, and Old River Cove, would continue. Subsidence associated with extraction of ground water, oil, and gas would continue, although possibly at a slower rate (Kennish 2001). Marshes behind the Gulf shoreline in the McFaddin and Texas Point NWRs are breaking and converting to open water as a result of subsidence and sea level rise, ultimately resulting in total loss of marsh. Hurricane Ike removed most of the natural beach berm on McFaddin NWR, creating a situation where salt water from the Gulf now washes regularly into intermediate and brackish marshes. Restricting saltwater intrusion into the Upper Salt Bayou system is critical to maintaining the Chenier Plain's continuum of fresh, intermediate, and brackish saline marshes. In addition to their significant ecological value, these marshes also serve to attenuate storm surge and provide a natural defense to shorelines.

3.4 LIFE SAFETY

The population at risk broken down by project area is included in Table 3-4. The populations at risk were developed based on the 2010 census blocks that intersect the damageable properties in

the project areas. This population reflects the residential population that could be exposed to flood risk. This does not include transportation routes for population evacuating or those at work in commercial or industrial areas. Defining the population at risk and the depth of flooding is evaluated in a risk assessment, which was not performed in this study. What is known about the project areas is the residential population that could be exposed to flood risk listed in Table 3-4. Other considerations include high-risk areas that have populations/residents with special needs, such as elderly populations over 65, hospitals, nursing homes, and schools. These types of populations were not fully defined in this study; however, the existing structures (hospitals, nursing homes, and schools) were inventoried in the project area. These structures are listed in Section 3.5 below. Additional information on the location of these structures is included in Appendix C, Economics. Flooding depths are also a consideration. Flooding depths are significant concern at approximately 15 feet where residents have limited ability to vertically evacuate. Approximate flooding depths for each project area were not developed outside of the economic analysis for the FWOP condition. The still-water level estimates for depth of flooding are included in Section 3.2.2 for the project areas.

Table 3-4: Population at Risk by Project Area and Alternative Reach

Population at Risk	
Orange-Jefferson CSRM	
Orange 1	17,014
Orange 2	13,952
Orange 3	60,044
Beaumont A	2,078
Beaumont B	2,078
Beaumont C	2,078
Jefferson Main	116,762
Port Arthur and Vicinity CSRM	116,762
Freeport and Vicinity CSRM	16,559

It is important to note the type of warning systems for the project areas in the FWOP condition. Broad warnings as storm systems develop are coordinated through various agencies such as the National Weather Service, which provides reports to the essential print and electronic media outlets. The National Weather Service generally releases tropical storm watches 48 hours in advance of any anticipated onset of tropical storm force winds. Since outside preparedness activities become difficult once winds reach tropical storm force, warnings are issued 36 hours in advance of any anticipated onset of tropical storm force winds. The Texas Department of Public Safety's Division of Emergency Management coordinates the state emergency management program, as well as implementing the Texas Emergency Tracking Network (ETN), part of a comprehensive data-management system that provides real-time information before, during, and

after a disaster. Orange and Jefferson Counties are members of the Southeast Texas Altering Network, which can alert users of emergencies, plant operations, traffic, and weather information or other outreach from emergency management. Orange and Jefferson Counties, as well as Brazoria County, have emergency management departments that engage their respective cities, including specific evacuation plans and processes.

3.5 CRITICAL INFRASTRUCTURE

The following is a description of the existing critical infrastructure in each project area. Critical infrastructure listed here includes industrial and manufacturing facilities, as well as public facilities. This is a qualitative discussion of the FWOP condition focused on the impacts associated with potential storm surge flooding. The inventory of critical infrastructure was developed from information derived from the Homeland Security Infrastructure Program (HSIP), which is an infrastructure geospatial data inventory. The critical infrastructure is reported for the project areas by type (school, chemical manufacturing, etc.). A North American Industry Classification System (NAICS) code is included in the full listing of the inventory included in Appendix C, Economics. The project areas are discussed by county; Orange-Jefferson CSRM includes Orange and Jefferson County; Port Arthur and Vicinity CSRM includes Jefferson County; Freeport includes Brazoria County. There is overlap in this discussion between the Orange-Jefferson CSRM and Port Arthur and Vicinity project areas since the Jefferson Main Alternative Reach (within the Orange-Jefferson CSRM project area) has overlapping structures located in the Port Arthur and Vicinity project area.

Orange – Jefferson CSRM (Orange and Jefferson County)

Public Facilities – Orange County

- 20 schools
- 14 law enforcement
- 2 hospitals/6 nursing homes
- 11 fire stations

Industrial and Manufacturing – Orange County

- 20 chemical manufacturing
- 5 electric generation
- 0 petroleum refining
- 1 airport

Public Facilities – Jefferson County

- 42 schools
- 19 law enforcement

- 13 hospitals/7 nursing homes
- 26 fire stations

Industrial and Manufacturing – Jefferson County

- 54 chemical manufacturing
- 1 electric generation
- 5 petroleum refining
- 1 airport

Some of the significant industrial and manufacturing facilities located in Orange-Jefferson CSRM include Exxon Mobil, DuPont, Honeywell, Firestone, Petrochemical, Chevron, Phillips, Laxness, Solvay Solexis, and Entergy. A detailed description of each critical facility is not provided here; however, to explain one in some detail, Exxon Mobil is located near downtown Beaumont, Texas, on the Neches River. The refinery processes 345,000 barrels of crude oil per day and produces 2.5 billion gallons of gasoline annually (Exxon Mobil, 2015).

Port Arthur and Vicinity CSRM (Jefferson County)

Public Facilities – Jefferson County

- 42 schools
- 19 law enforcement
- 13 hospitals/7 nursing homes
- 26 fire stations

Industrial and Manufacturing – Jefferson County

- 54 chemical manufacturing
- 1 electric generation
- 5 petroleum refining
- 1 airport

Significant industrial and manufacturing facilities located in the Port Arthur and Vicinity CSRM include Valero, Premcor, Total, Motiva Enterprises, and Huntsman Petrochemical. Jack Brooks Regional Airport is also in the project area. A detailed description of each critical facility is not provided here; however, to explain one in some detail, Motiva is the largest petroleum refinery in the United States, with a daily capacity of approximately 600,000 barrels of crude oil. (Beaumont Enterprise, 2014).

Freeport and Vicinity CSRM (Brazoria County)

Public Facilities – Brazoria County

- 6 schools
- 3 law enforcement
- 0 hospitals/0 nursing homes
- 2 fire stations

Industrial and Manufacturing – Brazoria County

- 24 chemical manufacturing
- 0 electric generation
- 0 petroleum refining

Significant industrial and manufacturing facilities located in the Freeport and Vicinity CSRM include Petroleum Reserve, DOW Chemical, Freeport LNG, Huntsman Gulf Chemicals, Phillips 66 Liquefied Petroleum Gas (LPG) Terminal, SI Group, and NALCO. A detailed description of each critical facility is not provided here; however, to explain one in some detail, DOW Chemical is the largest integrated chemical manufacturing complex in the western hemisphere. The Freeport site produces 44 percent of DOW's products sold in the U.S. and 20 percent of the company's products sold globally (DOW, 2015).

In summary, the critical infrastructure located in the project areas could be impacted during a flood in the No Action Alternative. Of note, if the refineries were closed down due to flood events, there could be significant impacts on gas supplies and multiplier effects on the economy, e.g. increase in transportation costs. Local roadways and major thoroughfares in the project areas were not evaluated in detail for the FWOP condition. Although it is included in the objectives for this study, they are considered ancillary benefits, so they are only covered in this context in the report.

3.6 RELATIVE SEA LEVEL CHANGE (RSLC)

USACE expectations of climate change and RSLC, and their impact is an important component of the FWOP condition. The planning horizon of 50 years is used in this study; however, RSLC is estimated beyond that to 100 years. Some key requirements for RSLC in a feasibility study, per ER 1100-2-8162 and ETL 1100-2-1 include:

- At a minimum 20-, 50-, and 100-year planning horizons should be considered in the analysis.
- A thorough physical understanding of the project area and purpose is required to effectively assess the project's sensitivity to RSLC.

- Sea level changes should be incorporated into models at the mean and extreme events.
- Identification of thresholds by the project delivery team and "tipping points" (points where the functionality of a project is impaired or a no longer functions as intended) within the impacted project area. This will inform both the selection of anticipatory, adaptive, and reactive options selected and the decision/timing strategies.

Tables 3-5 through 3-6 present the estimated RSLC in the project areas for the 20-, 50- and 100-year for the Low, Intermediate, and High scenarios. Additional information on how the estimates were developed are included in Appendix D. The Sabine Pass, Texas, row corresponds to the sea level rise estimates for the Orange-Jefferson CSRM and Port Arthur and Vicinity CSRM project areas; and the Freeport, Texas, row corresponds to the Freeport and Vicinity CSRM project areas.

The EAD tables presented for the FWOP condition for the final array did not include estimates for the 20-, 50- and 100-year sea level rise scenarios.

Table 3-5: Estimated RSLC over the first 20 years of the project life (2030-2050)

Tidal Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	1.08	1.38	2.38
Freeport, TX	4.35 mm/yr	.83	1.13	2.07

Table 3-6: Estimated RSLC over the first 50 years of the project life (2030-2080)

Tidal Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	1.63	2.32	4.51
Freeport, TX	4.35 mm/yr	1.26	1.94	4.13

Table 3-7: Estimated RSLC over the first 100 years of the project life (2030-2130)

Tidal Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	2.56	4.26	9.62
Freeport, TX	4.35 mm/yr	1.97	3.66	9.03

3.7 FUTURE WITHOUT-PROJECT CONDITIONS SUMMARY

Based on the evaluation of the FWOP conditions, there is the potential for significant economic damages in the Orange-Jefferson CSRM, Port Arthur and Vicinity CSRM, and Freeport and Vicinity CSRM project areas. There are also concerns for life-safety, damages to critical infrastructure, sea level changes, and impacts on significant environmental resources. These can be further characterized as problems and opportunities for the Federal Government or local interests to implement projects. The No Action Alternative forms the basis against which all potential projects are measured. Before a recommendation to implement a project can be identified, a plan formulation process in accordance with USACE policies needs to be followed. Definition of the FWOP is an important step in this process. The next sections describe the problems and opportunities, objectives and constraints, and the plan formulation process followed to identify a TSP and the subsequent Recommended Plan that meets USACE policies for implementation.

4 PROBLEMS AND OPPORTUNITIES

4.1 PROBLEMS AND OPPORTUNITIES/NEED FOR ACTION*

Problem and opportunity statements for the Sabine Pass to Galveston Bay study were initially developed after scoping comments were received from Federal, state, and local agencies, private groups, and the affected public. Four regional public scoping meetings were held across the study area during February to March 2012 jointly by USACE and the GLO. The problems and opportunities were revisited in the Planning Charette in August 2012, and were refined as the study progressed. Problems and opportunities were used to develop the planning objectives for the study and guide in selection of the TSP and the subsequent Recommended Plan as described in Sections 5 and Sections 6. The problems and opportunities listed here are the same developed in the early planning stages.

It is important to explain how a problem or opportunity led to a planning objective/constraint or whether it feeds into the comprehensive assessment of potential CSRM projects in the Galveston region (Galveston, Harris, and Chambers Counties) and potential ER projects in the entire six-county study area. For these reasons, a problem or opportunity is provided a reference code to track a problem or opportunity to an objective/constraint or to a comprehensive assessment project discussed in subsequent sections.

Due to stipulations of the 3x3x3 Rule exemption, the feasibility study effort described here has focused on CSRM recommendations for the Sabine Region (Orange and Jefferson Counties) and the Brazoria Region (the Freeport metropolitan area in southern Brazoria County). The following in-depth alternative analyses and recommendations do not include CSRM projects in the Galveston Region or ER projects throughout the six-county study area. The latter are handled comprehensively as described in Section 1.3 of this report.

4.1.1 Problem Statements

- (P1) Population at risk – Over six million people in six counties on the upper Texas coast, which include the fourth largest U.S. city (Houston), and three other metropolitan areas (Beaumont/Port Arthur/Orange, Galveston/Texas City, and Freeport/Surfside) are severely vulnerable to life safety and economic risks from coastal storm events. Approximately 2.26 million people reside within an identified storm-surge inundation zone. The population of the six-county region is expected to grow to over nine million by 2050.
- (P2) Three of the nine largest oil refineries in the world, 40 percent of the nation's petrochemical industry, 25 percent of the nation's petroleum-refining capacity, and their

associated infrastructure (pipelines, transportation networks, and utilities) will continue to be at risk without a comprehensive plan aimed at reducing susceptibility to flood and hurricane risk. Two of the nation's petroleum strategic reserves are within the surge zone.

- (P3) Three major U.S. seaports, approximately 150 miles of the GIWW (nation's 3rd busiest waterway), and associated infrastructure will continue to be susceptible to flood and hurricane storm damages. A 30-day closure of the HSC has been estimated to result in an economic loss of $60 billion to the nation.
- (P4) Storm-induced erosion is degrading nationally significant migratory waterfowl and fisheries habitats within the study area. The chenier ridges and marshes along the entire coastline of Jefferson County serve as a storm surge buffer to the GIWW, the city of Port Arthur, and several petrochemical facilities, including the largest oil refinery in the U.S. If the ridges and marshes disappear, the protective buffer would be eliminated.
- (P5) Three existing hurricane risk reduction systems at Port Arthur, Texas City, and Freeport were nearly overtopped during Hurricane Ike. These systems do not meet current design standards for resiliency and redundancy and will be increasingly at risk from storm damages due to relative sea level change and climate change. Critical infrastructure throughout the region, including hurricane evacuation routes, nationally significant medical centers, government facilities, universities, and schools were extensively damaged by recent storm events.
- (P6) This is a geologically sand-starved system; sediment removed from the system by human modifications such as jetties, navigation channels and reservoirs is not replenished. This results in continued shoreline retreat and accelerated shoreline erosion during storm events.
- (P7) The study area is located in an area with a high frequency of storm impacts and economic damages (second highest area of occurrence on Gulf coast). Environmental impacts on refineries are likely from storm damages (e.g., release of toxic substances).
- (P8) Potential damages of $100 billion could have resulted if the storm track of Hurricane Ike had been slightly to the south.
- (P9) The value of infrastructure associated with petrochemical/oil/gas refineries that could be impacted by storms is very high.
- (P10) Riverine Flooding along the lower Neches River cause life safety and economic risks when high periods of tides and high river stages occur simultaneously.

4.1.2 Opportunity Statements

- (Op1) Provide shoreline protection to reduce risks to commercial and residential property, real estate, and infrastructure within the six-county study area.
- (Op2) Enhance ecotourism and recreation opportunities.

- (Op3) Enhance public education related to coastal storm risk.
- (Op4) Reduce environmental damage associated with storm damage to refinery infrastructure.
- (Op5) Enhance or restore endangered species habitat.
- (Op6) Reduce risk for evacuation routes so they remain clear longer.
- (Op7) Manage regional sediment management for beneficial uses to navigation and other operations.
- (Op8) Increase reliability of the nation's energy supply.
- (Op9) Avoid or mitigate adverse natural resource impacts.
- (Op10) Leverage resources from multiple stakeholders for effective solutions.
- (Op11) Establish more resilient communities.

4.2 PLANNING GOALS AND OBJECTIVES

4.2.1 Planning Goals

The main goals of this project are to reduce the risk to lives and property associated with coastal storms within the Orange-Jefferson, Port Arthur and Vicinity, and Freeport and Vicinity CSRM project areas. In-depth alternative analyses for the Galveston region or ER were not performed beyond the Evaluation Array Alternatives; thus, there are no recommendations to construct ER or projects in the Galveston region as part of the Recommended Plan. As stated in the sections above, ER goals for the these project areas and the Galveston region will be addressed as part of the ongoing USACE Coastal Texas CSRM and ER Feasibility study, in conjunction with the Texas GLO.

4.2.2 Public Concerns

Public input was solicited at four public scoping meetings held in January and February 2012 in Beaumont, Seabrook, Galveston, and Freeport, Texas. During the scoping process, various members of the public voiced concern about the erosion of the GIWW shoreline, a preference that nonstructural solutions to storm surge damages be considered above all else, and a desire to keep the mouth of the San Bernard River open for recreational navigation.

4.2.3 Planning Objectives

The objectives listed in Table 4-1 were developed from the problem and opportunity statements and used to guide the plan formulation for the TSP and the subsequent Recommended Plan. It also ties the problem or opportunity to an objective as indicated by the reference codes. If a problem or opportunity is addressed in the comprehensive assessment, those fall within that respective column in the table. Some problems and opportunities cross over in the objectives. For

example, the opportunity Op10 crosses over all objectives. The intent of this opportunity is to capture data, reports, outputs from SSPEED, Texas A&M Galveston, other risk reduction studies, etc. that have already been performed in the study area. The row highlighted in green in Table 4-1 is the previous ER objective developed for this study, but is not included in development of the TSP and subsequent Recommended Plan.

Table 4-1 is organized to align the study planning objectives to the "four accounts" listed in the Economic and Environmental Principles for Water and Related Land Resources Implementation Studies. These "principles" were established pursuant to P.L. 89-80, and amended. The four accounts are established to facilitate evaluation and display of effects of alternative plans. The four accounts are: 1) National Economic Development (NED); 2) Environmental Quality (EQ); 3) Regional Economic Development (RED); and 4) Other Social Effects (OSE).

- NED: account displays changes in the economic value of the national output of goods and services.
- EQ: account displays non-monetary effects on significant natural and cultural resources.
- RED: account registers changes in the distribution of regional economic activity that result from each alternative plan. Evaluations of regional effects are to be carried out using nationally consistent projections of income, employment, output, and population.
- OSE: account registers plan effects from perspectives that are relevant to the planning process, but are not reflected in the other three accounts.

Alternative plans were formulated to reduce the risk of damages from coastal storms, minimize impacts to floodplains, and avoid environmentally significant resources. Where impacts could not be avoided, environmental impacts were quantified and a mitigation plan was formulated. The location of potential ER projects relative to new levee system alternatives were considered during plan formulation. ER opportunities identified by this study are described and mapped in Appendix A. They are located outside of the new levee alternatives, in the floodplain of the Neches River and on the coastal plain south of the Orange-Jefferson CSRM project area. The location of the new levee alignment and the design of the culvert system minimized impacts on wetlands and floodplains, both inside and outside of the system, to the greatest extent practicable. The potential for marshes to migrate landward due to RSLC is low because of the abrupt 8- to 10-foot elevation change between the floodplain and the upland in most of project area. Therefore, there would be no impacts on potential future ER projects. Where impacts of the Recommended Plan could not be avoided, impacts were quantified and a mitigation plan was formulated. A mitigation estimate was developed and included as a project cost.

Table 4-1: Sabine Pass to Galveston Bay, Texas Planning Objectives and Measurements

Planning Objectives	NED**		OSE**	RED**	EQ**	Comprehensive Assessment
	Coastal Storm Surge Damage Benefits	Costs	Population at Risk	Critical Infrastructure Impacts	Ecosystem Functionality	
1. Reduce economic damage to business, residents and infrastructure for the Sabine and Brazoria region for the 50-year period of analysis. Problem/Opportunity Code: P7, P8, Op1, Op2, Op9, Op10, Op11	Benefits for coastal storm damages averted (ADCIRC floodplain and water elevation; CAD values)	First Cost of Construction; O&M Life Cycle Cost***; Mitigation & Monitoring Cost				Problem/Opportunity Code: P4, P6, Op5, Op7
2. Reduce risk to human life from storm surge impacts for the Sabine and Brazoria region for the 50-year period of analysis. Problem/Opportunity Code: P1, P8, Op3, Op10, Op11			Number of people for which risk is reduced (2010 census)			
3. Maintain and/or restore coastal habitat that contributes to storm surge attenuation where feasible for the 50-year period of analysis.					Average Annual Habitat Units (AAHUs)	
4. Enhance energy security and reduce economic impacts of petrochemical supply-related interruption for the Sabine and Brazoria region for the 50-year period of analysis. Problem/Opportunity Code: P2, P8, Op5, Op10, Op8	CAD value of facilities			Effect of transportation disruptions after storms		
5. Reduce risks to critical infrastructure (e.g., medical centers, ship channels, schools, transportation, etc.) for the Sabine and Brazoria region for the 50-year period of analysis. Problem/Opportunity Code: P3, P8, Op4, Op9, Op10, Op11				Number of critical facilities and evacuation routes for which risk is reduced		
6. Identify opportunities to enhance functionality of existing hurricane risk reduction system including evaluation of impacts due to sea level rise for the 50-year period of analysis. Problem/Opportunity Code: P5, P8, Op10	Benefits for coastal storm damages averted (ADCIRC floodplain and water elevation; CAD values)					

**These columns correspond to the Principle and Guidelines four accounts: National Economic Development (NED), Other Social Effects (OSE), Regional Economic Development (RED) and Environmental Quality (EQ)

*** Operation, Maintenance, Repair, Replacement and Rehabilitation (OMRR&R) costs were not included and are not expected to impact plan formulation since they would impact the alternatives proportionally

4.2.4 Planning Constraints

The following constraint was developed from the problem and opportunity statements and used to guide the plan formulation for this study. Reducing life-safety risk is a planning objective of the study; however, careful consideration is required to ensure structural plans do not increase risk. As such, any features that increase risk to human life from storm surge impacts in the Sabine and Brazoria regions for the 50-year period of analysis was not be considered in the TSP or subsequent Recommended Plan.

4.3 RELATED PROJECT DOCUMENTS

Related project documents include the following:

- 1975 Final Environmental Impact Statement: Maintenance Dredging Gulf Intracoastal Waterway Texas Section, Main Channel and Tributary Channels. Volumes 1, 2, and 3. Galveston, Texas
- 2003 Final Environmental Assessment, Houston-Galveston Navigation Channels, Texas – Upper Barge Lanes. Galveston District, Galveston, Texas
- 2003 Final Feasibility Report and Environmental Assessment, Gulf Intracoastal Waterway, High Island to Brazos River, Texas, Section 216 Study. Galveston District, Galveston, Texas
- 2005 Draft Feasibility Report, Freeport and Vicinity, Texas Hurricane Flood Protection Project. Galveston District, Galveston, Texas
- 2008 Final General Reevaluation Report and Environmental Assessment, Texas City Channel Deepening Project. Galveston District, Galveston, Texas
- 2010 Final Environmental Assessment, Houston-Galveston Navigation Channels, Texas – Expansion of Placement Areas 14 and 15. Galveston District, Galveston, Texas
- 2011 Final Environmental Impact Statement, Sabine-Neches Waterway Channel Improvement Project, Southeast Texas and Southwest Louisiana. Galveston District, Galveston, Texas
- 2012 Final Environmental Impact Statement, Freeport Harbor Channel Improvement Project, Brazoria County, Texas. Galveston District, Galveston, Texas
- 2013 Draft Environmental Assessment, Galveston Harbor Channel Extension Post-Authorization Change Report, Galveston County, Texas (March 2013). Galveston District, Galveston, Texas

5 FORMULATION AND EVALUATION OF ALTERNATIVE PLANS*

Note: This chapter describes the alternative development, formulation, and evaluation process that led to the identification of the TSP. The information contained herein was presented in the Sept 11, 2015 DIFR-EIS that was released for public review. Changes to the TSP that have occurred since the public review are briefly described at the end of this chapter. The changes to the TSP that resulted in the final Recommended Plan are presented in Chapter 6.

5.1 PLAN FORMULATION RATIONALE

Plan formulation is the process of building alternative plans that meet planning objectives and develop alternatives within the planning constraints. Alternative plans are a set of one or more management measures functioning together to address one or more planning objectives. A management measure is a feature or activity that can be implemented at a specific geographic site to address one or more planning objectives.

The planning process for this feasibility study is driven by the overall objective of developing a comprehensive plan that will help manage risks associated with coastal storms within the study counties while avoiding and minimizing impacts on the area's environmental resources.

Preliminary plans were formulated by combining management measures. Each plan was formulated in consideration of the following four criteria described in the Principles and Guidelines (P&G):

- Completeness: Extent to which the plan provides and accounts for all necessary investments or actions to ensure realization of the planning objectives.
- Effectiveness: Extent to which the plan contributes to achieving the planning objectives.
- Efficiency: Extent to which the plan is the most cost-effective means of addressing the specified problems and realizing the specified opportunities, consistent with protecting the nation's environment.
- Acceptability: Workability and viability of the alternative plan with respect to acceptance by Federal and non-Federal entities and the public, and compatibility with existing laws, regulations, and public policies.

Initial study efforts involved a determination of the magnitude and extent of the problems within the study area in order to develop and evaluate an array of alternative solutions that meet the

existing and long-range future needs of the non-Federal sponsor and the public. At the initiation of the feasibility phase of the project, lines of communication were opened with Federal, state, and local agencies, private groups, and the affected public. Four regional public scoping meetings were held across the study area during February to March 2012.

5.2 MANAGEMENT MEASURES

The initial array of measures was developed with public, local government, and agency input gathered during the four scoping meetings. During the scoping process, the measures were grouped geographically into the three major regions (Sabine, Galveston, and Brazoria).
Potential structural and nonstructural measures considered were:

- Structural (raising roadways, levees, flood walls, flood gates, breakwaters, marsh/dune/shoreline restoration, hardening of infrastructure, etc.)
- Nonstructural (buyouts, raising structures, flood warning systems, floodplain management, regional sediment management, etc.)

Potential projects for the Sabine area include Gulf shoreline protection and restoration measures such as beach nourishment, dune restoration, chenier ridge restoration, sediment management, shoreline armoring, and submerged near-shore breakwaters. Potential projects for the Galveston area include various Gulf shoreline protection and restoration measures such as beach nourishment, dune restoration, beach ridge restoration, sediment management, shoreline armoring, and submerged near-shore segmented breakwaters. A feasibility study completed in 1979 (USACE 1979) served as an important reference for the development of structural alternatives in the Galveston and Sabine regions. Viability of Gulf shoreline projects is dependent on the GLO's ability to acquire easements. Potential projects for the Brazoria area include various Gulf shoreline protection and restoration measures such as beach nourishment, dune restoration, sediment management, shoreline armoring and submerged near-shore breakwaters. Specific targets include Quintana/Bryan Beach, Surfside Beach, and Follets Island. At the SMART Planning Charette (Charette), the full Vertical Team (USACE District, Division, Headquarters, and Office of Water Project Review) and the local sponsor worked through an abbreviated version of the six-step planning process, considered a full array of measures and alternatives, and then formulated comprehensive (regional) plans to include in the "Initial Alternative Plans Array." Information gathered during the public scoping process, combined with work conducted at the Charette, resulted in identification of approximately 39 individual implementable measures and five comprehensive regional alternative plans addressing the entire six-county area. Each plan included structural and nonstructural measures that would address CSRM and ER objectives.

During the Charette, the team identified three criteria that would be utilized to evaluate the initial array of alternatives. The three criteria are 1) Implementation Costs; 2) Damages Reduced; and 3) Environmental Benefits. It was envisioned at the Charette that these criteria would be used to evaluate the five alternatives that were developed from the measures during the Charette. After the Feasibility Cost Share Agreement (FCSA) for the study was signed and efforts began on data collection, the study team determined that many of the components of the different alternatives were redundant and that information on the measures was incomplete. The Project Delivery Team (PDT) decided to deconstruct the alternatives, collect available targeted information, and refine/reformulate the measures for completeness and to eliminate redundancies.

This resulted in a list of about 75 reformulated initial measures that served as the building blocks of alternative plans. These nonstructural and structural measures were considered as part of the study analysis and were developed to address study objectives previously presented in Section 4. These measures were combined with other measures, nonstructural or structural, to form alternatives to be evaluated in the study process. These alternatives are screened in the Plan Formulation Phase, as discussed in the next section. The majority of the measures developed were structural; however, it should be noted that nonstructural measures were carried forward to the Final Array of Alternatives. The structural measures included new coastal and inland structural barriers, reconstruction of existing and construction of new regional hurricane risk reduction systems, local surge risk reduction systems, raising roads as surge or overwash protection barriers, Gulf shoreline protection (beach and dune restoration, nearshore breakwaters, chenier ridge restoration), GIWW erosion protection, marsh restoration, and salinity/water control structures. Measure Information Sheets with descriptions and maps of each measure are presented in Appendix A. Table 2-1 of Appendix B includes the list of the 75 initial measures.

After the reformulation of the initial 75 measures, each measure was evaluated to determine whether it would address the planning objectives. If they did not, they were removed from further consideration. This screening process removed 15 measures from the study. Table 5-1 summarizes this process and the criteria used. Section 3.1.2 of Appendix B describes the reasons for elimination.

Table 5-1: Summary of Management Measures and Initial Screening of Measures

	Number of Measures	**Screening Criteria**
Management Measures	75 Measures in Sabine, Galveston, and Brazoria Regions	None, this was the initial array of management measures

	Number of Measures	Screening Criteria
Initial Screening of Measures	Resulted in elimination of 15 measures from the 75 measures	Economic Damages Reduces based on water surface elevations; Acres of habitat protected/restored by the plan; and order of magnitude parametric costs (Class 5 cost estimate)

5.3 SUMMARY OF ALTERNATIVES ANALYSES

The initial measures were screened to determine if they adequately addressed the problems and objectives of this study. The remaining measures were then formed into arrays of alternatives plans, which were screened to determine the most effective alternatives. The screening produced three iterations of alternatives including:

- Initial Array of Alternatives;
- Evaluation Array of Alternatives; and
- Final Array of Alternatives.

5.3.1 Initial Array of Alternatives

In this phase, comprehensive alternative plans were formulated for each of the three regions in the six-county study area. This was done to make the task of formulating alternatives for such a large and diverse area more manageable. The alternatives were meant to be stand-alone plans that can be compared directly to one another. Alternatives have been included that are anchored to existing or proposed structural projects (or "hard" structures), as well as "soft" structural alternatives that could reduce impacts with ER or protection measures and improve the resiliency of the system. Some alternatives were intended to provide all-inclusive plans and others were drafted to focus more closely on traditional structural or ER measures. The Initial Array of Alternatives included eleven alternatives for the Sabine Region, nine alternatives for the Galveston Region and five alternatives for the Brazoria Region, for a total of 25 alternatives considered in the Initial Array of Alternatives. A detailed description of the alternatives is included in Section 5.2 of Appendix B (note that each alternative was provided an Alternative Number). A summary of the alternatives is provided below.

For the Sabine Region, the eleven alternatives included evaluation of existing HFPPs in the region, construction of additional levees to protect Orange County, the use of gated surge barrier structures in combination with the new levees, as well as environmental restoration measures such as beach and dune restoration, marsh and barrier island restoration, shoreline protection along the Gulf and

the GIWW, nearshore breakwaters, and hydrologic restoration. Nonstructural alternatives were also considered.

Nine alternatives were developed for the Galveston region, including alternatives which addressed CSRM and ER in combination and individually. These alternatives included evaluation of the existing HFPP in the region, a coastal barrier, ring levees, gated surge barrier structures, as well as environmental restoration measures such as beach and dune restoration, marsh and barrier island restoration, shoreline protection along the Gulf and the GIWW, and nearshore breakwaters. Nonstructural alternatives were also considered.

For the Brazoria Region, the five alternatives included plans for evaluating the existing HFPP, as well as environmental restoration measures such as beach and dune restoration, shoreline protection along the GIWW, and a groin. Nonstructural alternatives were also considered.

The Initial Array of Alternatives was screened using three quantitative criteria (economic benefits, environmental benefits and implementation costs) and one qualitative criterion (environmental impacts) (Table 5-2) to develop the Evaluation Array of Alternatives.

Table 5-2: Criteria for Screening Initial Array of Alternatives

Criteria	Metric
Damages reduced	Economic damages reduced based on water surface elevation
Environmental benefits	Acres habitat protected/restored by the plan
Implementation costs	Order of magnitude parametric (Class 5 cost estimates)
Environmental Impacts	Qualitative Analysis using: construction impacts to wetlands and sensitive habitat; system-wide hydrologic impacts' and endangered species impacts

This screening process removed eight alternatives from the Sabine Region, five from the Galveston Region and two from the Brazoria Region. Section 5.5 of Appendix B summarizes the reasons for eliminating alternatives.

5.3.2 Evaluation Array of Alternatives

The screening process described in the previous section led to the identification of the Evaluation Array of Alternative Plans, which is composed of ten alternatives (three from Sabine Region, four from Galveston Region, and three from Brazoria Region) to be evaluated in more detail. The Evaluation Array of Alternatives are listed and described in Table 5-3.

The Evaluation Screening of Alternatives was used as a decision point to determine whether the data collected and utilized for this analysis is sufficient to make the determination of which

alternatives to carry forward for detailed analysis or needed to be modified. For example, between alternatives S5 and S8 the CSRM measures included a gate across the Neches River vs a levee system paralleling both sides of the river. It was estimated the measures in the plans would provide roughly the same amount of benefits no matter which option was selected. Therefore, since the benefits are roughly the same, the primary determining factor was cost, allowing the measure with the lowest cost to be the measure to be carried forward into more detailed evaluation.

Table 5-3: Evaluation Array of Alternatives

Alternatives	Name	Description
S5	Sabine Inland Barrier CSRM Focus(Neches Gate/Sabine Levees/HFP)	Neches River Navigation Gate, Sabine Levees, Port Arthur HFP
S8	Sabine ER (with surge barrier on upper Sabine River)	Beach and dune restoration, restore beach ridge, nearshore breakwaters, GIWW shoreline protection, marsh restoration on Neches River and at Keith Lake and Texas Point, Salt Bayou hydrologic restoration, Sabine River levees and gate
S11	Sabine Nonstructural Alternative	Buyouts and Lone Star-type conservation plan
G2	Galveston Coastal Barrier CSRM Focus	Coastal barrier and gates, and buyouts/relocations within a 500 ft buffer
G5	South Galveston Bay Inland Barriers CSRM	Surge barrier and gates near Hartman Bridge, Tx City HFP, Galveston Ring Levee, Chocolate Bayou ring levee, Raise Hwy 146 and buyouts/relocations within a
G7	Galveston Bay ER	Beach and dune restoration, GIWW shoreline protection, marsh restoration, East Bay shoreline protection, closing Rollover Pass
G9	Galveston Bay Nonstructural Alternative	Buyouts and Lone Star-like conservation plan. The Lone Star plan is an attempt fund the acquisition of large natural coastal areas in the study area's coastal zone that would serve as a natural buffer to tropical storm surge
B2	Brazoria Coastal Barrier CSRM	Freeport HFP
B3	Brazoria ER	Beach and dune restoration, groin, and GIWW shoreline protection

Alternatives	Name	Description
B5	Brazoria Nonstructural Alternative	Buyouts and Lone Star-like conservation plan. The Lone Star plan is an attempt fund the acquisition of large natural coastal areas in the study area's coastal zone that would serve as a natural buffer to tropical storm surge
Per a 25 February 2014 3x3x3 Rule Exemption memo, alternatives in grey were carried forward for future studies evaluating ER and CSRM projects in the region.		*Per a 25 February 2014 3x3x3 Rule Exemption memo, alternatives in blue were carried forward to focus the evaluation on two sub-regions, Sabine and Brazoria*

Consideration was given to a variety of factors including engineering, economics, costs, and environmental impacts for the two options between the gate and no-gate measures; however, the cost of the Gate measure is approximately $865 million more expensive than the no-gate measure. This cost difference is significant and further refinement and detailed analyses would not be expected to reduce this difference. Therefore, the alternative (S5) was modified to include the no gate option for further consideration in the study.

5.3.3 Scoping of Study under 3x3x3 Guidelines

In addition to evaluating the alternatives in more detail under Table 5-3, the USACE recently underwent a planning modernization which resulted in guidelines under which this study was to be developed at the time of screening of the alternatives. A scope was developed for completion of the study that would evaluate a final array of structural and non-structural alternatives in the six-county study area and that would be completed in 3 years for $3 million. However, it was determined that the level of detail would not be policy compliant. Therefore the USACE Galveston District (SWG) developed an option for completing the study in a manner that was low to moderate risk and requested an exemption from the 3x3x3 guidelines to complete this study. The recommendation was to pursue a $4.4 million comprehensive assessment of the six-county study area and focused evaluation on two sub-regions, Sabine and Brazoria, within the study area as the first interim study for CSRM project implementation. This first interim feasibility study would be followed by future studies recommending CSRM projects in the Galveston region, as well as ER opportunities throughout the entire six-county region. Future feasibilities, including Coastal Texas, will leverage studies, data, and models currently under development by others in the Galveston region. The alternatives shown in grey on Table 5-3 will be taken into consideration by these future studies. The exemption request was approved by USACE Headquarters and the recommended focus of the study in the Sabine and Brazoria regions continued into the final array of alternative plans, shown in blue.

5.3.4 Final Array of Alternatives

In accordance with the exemption request approval, the Sabine and Brazoria CSRM alternatives were carried forward into detailed feasibility analysis. The Final Array of Alternatives is presented

in Table 5-4. These alternatives were evaluated in detail in the final evaluation to determine the TSP and the subsequent Recommended Plan.

In the final evaluation, it became necessary to redefine the names for the Final Array of Alternatives. For example, the S5 Alternative was split into two individual alternatives: 1) Orange-Jefferson CSRM; and 2) Port Arthur and Vicinity CSRM. The project areas are listed by their name in Table 5-4.

Table 5-4: Final Array of Alternatives

Alternative Number	Description
No Action	No Action or Future Without Project
S5 (1)	Orange-Jefferson CSRM
S5 (2)	Port Arthur and Vicinity CSRM
B2	Freeport and Vicinity CSRM
S11 & B5	Brazoria and Sabine Nonstructural

5.4 COMPARISON OF FINAL ARRAY OF ALTERNATIVE PLANS AND DECISION CRITERIA

The Final Array of Alternatives are listed in Table 5-4. This list is considered the project area for the remainder of the discussion of the evaluation and comparison of the final array. The "Optimization Alternatives" embedded in the project area listed in Table 5-4 are the actual final array evaluated and compared to determine the TSP. The Optimization Alternatives are defined in Table 5-5. As described in section 3.2.2, still water levels were used to determine the overall economic efficiency of the final array alternatives. The "11-, 12-, 13- and 14-foot New Levee" represents different still water levels evaluated. The Alternative Reaches are included in the table for reference. The No Action Alternative is not listed in the table since it is the FWOP condition for each of the project areas. Brazoria and Sabine Nonstructural are also not listed because Alternative Reaches were not required for the nonstructural evaluation.

Table 5-5: Relationship with Project Area, Alternative Reaches and Optimization Alternatives

Project Area	Alternative Reaches	Optimization Alternatives
Orange-Jefferson CSRM	Orange 1	11-, 12-, 13- and 14-foot New Levee
	Orange 2	11-, 12-, 13- and 14-foot New Levee
	Orange 3	11-, 12-, 13- and 14-foot New Levee
	Jefferson Main	11-, 12-, 13- and 14-foot New Levee
	Beaumont A	11-, 12-, 13- and 14-foot New Levee
	Beaumont B	11-, 12-, 13- and 14-foot New Levee

Project Area	Alternative Reaches	Optimization Alternatives
	Beaumont C	11-, 12-, 13- and 14-foot New Levee
Port Arthur and Vicinity CSRM	8-10 ft I-Wall	No Fail, 1-foot Raise, 2-foot Raise
	Closure Structure	No Fail, 1-foot Raise, 2-foot Raise
	I-Wall Near Valero	No Fail, 1-foot Raise, 2-foot Raise
	I-Wall Near Tank Farm	No Fail, 1-foot Raise, 2-foot Raise
Freeport and Vicinity CSRM	DOW Barge Canal	Levee Rehabilitation; Gate Structure
	Oyster Creek Levee	No Fail, 1-foot Raise, 2-foot Raise
	East Storm Levee	No Fail, 1-foot Raise, 2-foot Raise
	South Storm Levee	1-foot Raise, 2-foot Raise
	Freeport Dock Floodwall	Partial Fail, No Fail, 1-foot Raise
	Old River Levee at DOW Thumb	No Fail, 1-foot Raise, 2-foot Raise
	Tide Gate I-Wall	No Fail, 1-foot Raise, 2-foot Raise

5.4.1 Final Screening Criteria

In order to select a plan from the final array, screening criteria were developed that align with the objectives of the study (See Table 4-1, Section 4.2.3) and listed below.

- Objective 1: Reduce economic damages to business, residents, and infrastructure for the Sabine and Brazoria region for the 50-year period of analysis.
- Objective 2: Reduce risk to human life from storm surge impacts for the Sabine and Brazoria region for the 50-year period of analysis.
- Objective 3: Maintain and/or restore coastal habitat that contributes to storm surge attenuation where feasible for the 50-year period of analysis.
- Objective 4: Enhance energy security and reduce economic impacts of petrochemical supply-related interruption for the Sabine and Brazoria region for the 50-year period of analysis.
- Objective 5: Reduce risk to critical infrastructure (e.g., medical centers, ship channels, schools, transportation) for the Sabine and Brazoria region for the 50-year period of analysis.
- Objective 6: Identify opportunities to enhance functionality of existing hurricane risk reduction systems including evaluation of impacts due to sea level rise for the 50-year period of analysis.

The planning objectives were aligned with the four accounts: NED, EQ, RED, and OSE. The Optimization Alternatives were evaluated in detail, then compared against each other to identify which plan contributes most to the objectives. This screening criteria is different than the screening process used in the Initial and Evaluation Array of Alternatives. The Optimization Alternatives

were evaluated first for the NED objectives (Objectives 1, 4 and 6) using the HEC-FDA model. The EADs presented in this report use storm surge levels without considering sea level rise scenarios for the 20-, 50- and 100-year sea level rise scenarios. Alternative Reaches were defined in the FWOP; this condition is the baseline to show reductions in EAD and to identify which plan reasonably maximizes net economic benefits, i.e., the NED plan. The compilations of each NED plan from the project areas are considered for the TSP. The screening criteria for RED and OSE objectives are qualitative (Objectives 4 and 2, respectively). For RED, critical infrastructure impacts are discussed qualitatively with focus on the effect of transportation disruptions after storms and the number of critical facilities and evacuation routes for which risk is reduced. For OSE, alternative performance is measured based on the number of people for which risk is reduced. This is discussed qualitatively for the final array. Another means to measure reduction in life-safety risk is to utilize a quantitative model. The HEC-FIA model has not been used to evaluate the final array. The final array evaluation results are described first in terms of economic performance, i.e. the net benefits are displayed for each Optimization Alternative. The net benefits were developed by comparing the Optimization Alternatives to the FWOP EADs. The qualitative discussion of life-safety, critical infrastructure, and consideration of RSLC is provided in Section 5.4.4.

5.4.2 Final Array Evaluation Results

The following sections present the results of the evaluation of the final array. This section focuses on a description of the Optimization Alternatives and the economic evaluation results. Additional description of the Optimization Alternatives is provided in Appendix D, Section 1.9, and the detailed economic evaluation results is provided in Appendix C, Economics.

5.4.2.1 No Action/Future Without-Project Condition

The FWOP is defined in Section 3 of this report; this condition is the baseline EADs to show how well an alternative performs against the NED planning objective and to identify which plan reasonably maximizes net economic benefits, i.e., the NED plan.

5.4.2.2 Orange-Jefferson CSRM Project Area

The following section describes the proposed Orange-Jefferson CSRM Optimization Alternatives. The plans in this project area include a combination of new levees and floodwalls at varying heights to address the storm surge flood risk. The Optimization Alternatives run along the north side of the Neches River and the west bank of the Sabine River. Figure 5-1 shows the location of the Optimization Alternatives listed below.

- Orange 1 consists of approximately 27,000 linear feet (LF) of levee and 16,500 LF of floodwall (total of 8.2 miles); levee heights evaluated include 11-foot, 12-foot, 13-foot, and 14-foot;
- Orange 2 consists of approximately 34,600 LF of levee (6.6 miles); levee heights evaluated include 11-foot, 12-foot, 13-foot, and 14-foot;
- Orange 3 consists of a combination of 113,600 LF of levee and 29,800 LF of floodwall (total of 27 miles); levee heights evaluated include 11-foot, 12-foot, 13-foot, and 14-foot;
- Jefferson Main runs along the south side of the Neches River and consists of approximately 41,700 LF of levee and 16,200 LF of floodwall (11 miles); levee heights evaluated include 11-foot, 12-foot, 13-foot, and 14-foot;
- Beaumont A is combination of 3,100 LF of levee and 200 LF of floodwall (0.6 mile); levee heights evaluated include 11-foot, 12-foot, 13-foot, and 14-foot;
- Beaumont B is 2,500 LF of levee (0.5 mile); levee heights evaluated include 11-foot, 12-foot, 13-foot, and 14-foot; and
- Beaumont C is 6,800 LF of levee (1.3 mile); levee heights evaluated include 11-foot, 12-foot, 13-foot, and 14-foot.

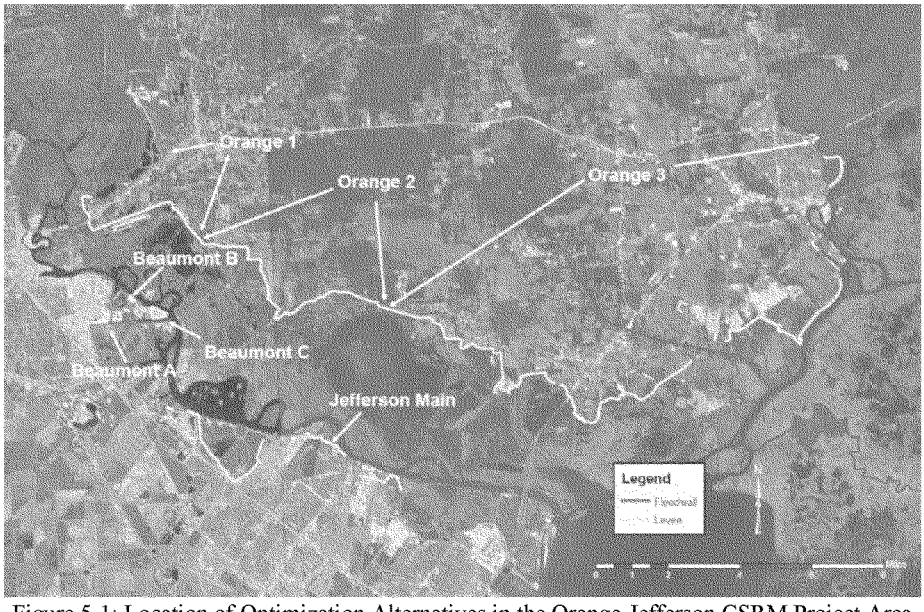


Figure 5-1: Location of Optimization Alternatives in the Orange-Jefferson CSRM Project Area

Economic Evaluation

The net benefits of Optimization Alternatives for the Orange-Jefferson CSRM project area are presented in Table 5-6. Negative net benefits are shown in red text. Fish and wildlife/wetland mitigation costs were included in the economic evaluation. The approved WVA model was used to quantify habitat impacts for a conservatively wide footprint of the alignment's construction right-of-way. Estimated mitigation costs (first costs and monitoring/adaptive management costs)

Table 5-6: Net benefits of Optimization Alternatives for the Orange-Jefferson CSRM project area

Alternative Reach	Optimization Alternatives	Net Benefits
Orange 1	11-foot New Levee	($1,769,000)
	12-foot New Levee	($2,380,000)
	13-foot New Levee	($2,996,000)
	14-foot New Levee	($3,617,000)
Orange 2	11-foot New Levee	($1,757,000)
	12-foot New Levee	($2,112,000)
	13-foot New Levee	($2,467,000)
	14-foot New Levee	($2,822,000)
Orange 3	11-foot New Levee	$9,851,000
	12-foot New Levee	$10,232,000
	13-foot New Levee	$9,804,000
	14-foot New Levee	$8,810,000
Jefferson Main	11-foot New Levee	$22,461,000
	12-foot New Levee	$22,580,000
	13-foot New Levee	$22,496,000
	14-foot New Levee	$22,123,000
Beaumont A	11-foot New Levee	$2,743,000
	12-foot New Levee	$2,992,000
	13-foot New Levee	$3,037,000
	14-foot New Levee	$2,942,000
Beaumont B	11-foot New Levee	($58,000)
	12-foot New Levee	($82,000)
	13-foot New Levee	($106,000)
	14-foot New Levee	($131,000)
Beaumont C	11-foot New Levee	($442,000)
	12-foot New Levee	($449,000)
	13-foot New Levee	($574,000)

were developed based upon conceptual mitigation plans. Test cases of the WVA model were run to size potential mitigation areas that would compensate for the total AAHU impacts of each alternative. Costs per acre, taken from recent similar mitigation efforts, were multiplied by the

acres needed to provide the target AAHUs. The same mitigation cost was applied to all height alternatives in each segment, as the impacts and mitigation would be similar for all heights and the cost variation among them would be small. When compared to other cost elements, estimated fish and wildlife mitigations costs were not large enough to affect plan selection.

5.4.2.3 Port Arthur and Vicinity CSRM

The following section describes the proposed Port Arthur and Vicinity CSRM Optimization Alternatives. The plans include modifications to the existing HFPP at Port Arthur. Figure 5-2 shows the location of the Optimization Alternatives listed below.

- 8- to 10-foot I-Wall
  - No fail: 3,500 LF of 15-foot- wide 6-inch scour pad
  - 1-foot raise: 7,500 LF of 15-foot-wide 6-inch scour pad. This option would include adding capacity to the system in this reach by addressing low areas of the levee system, raising 2,000 LF of levee 1 foot and providing overtopping erosion protection.
  - 2-foot raise: 7,500 LF of 15-foot-wide 6-inch scour pad; and 60,000 LF of levee raising 2 feet along with raising the Highway 87 and Highway 73 levee crossings. Floodwalls at two pump stations would be added along with 1,000 LF of floodwall reconstruction at the Taylors Bayou closure. This option would also require the replacement of one gravity drainage structure and one vehicle closure structure.

- *Closure Structure*
  - No fail: Construction of two, 300 LF of 100-foot-wide 6-inch scour pads, one on each side of the structure to provide erosion protection to reduce the likelihood of a brittle failure if the systems' capacity is exceeded.
  - 1-foot raise: This includes replacement of a vehicle closure structure that is 12 feet high by 30 feet wide. It also includes 300 LF of 100-foot-wide 6-inch scour pad, one on each side of the structure to provide erosion protection to reduce the likelihood of a brittle failure if the systems' capacity is exceeded. This option also included raising 12,000 LF of levee 1 foot.
  - 2-foot raise: Replace two vehicle closure structures/gate structures that are 12 feet high by 30 feet wide, including two 300 LF of 100-foot-wide 6-inch scour pad along both sides of each closure structure. This plan includes raising 12,000 LF of levee 2 feet and adding floodwalls at two pump stations, 500 LF total (7 feet tall) along with reinforcing pump station walls at four existing pump stations.

- I-Wall Near Valero

- No fail: Construction of 5,000 LF of 15-foot-wide 6-inch scour pad to provide additional structural integrity to the I-Wall and erosion protection to reduce the likelihood of failure.

Figure 5-2. Optimization Alternatives – Port Arthur and Vicinity CSRM Project Area

- 1-foot raise: Construction of 5,000 LF of 15-foot-wide 6-inch scour pad with a 1-foot levee raise over 3,000 LF to provide additional system capacity, increase structural integrity of the I-wall, and provide erosion protection to reduce the likelihood of system overtopping.
- 2-foot raise: This option will require significant reconstruction of the HFPP in the evaluated area including 5,000 LF of flood wall (15 feet tall), 10 closure structures 15 feet high and 20 feet wide, 3,000 LF of levee raised 2 feet along with the work specified in the I-wall near Tank Farm (2-foot raise) and 8- to 10-foot I-Wall (2-foot raise) required work.

- *I-Wall Near Tank Farm*
  - No fail: Construction of 1,800 LF of 15-foot-wide 6-inch scour pad to provide erosion protection to reduce the likelihood of a brittle failure if the systems' capacity is exceeded. Structurally reinforce the I-Wall to protect against wall failure.
  - 1-foot raise: Construction of 1,800 LF of 15-foot-wide 6-inch scour pad and batter piling and wailer system with 1-foot rise will provide additional system capacity, increase structural integrity of the I-wall and provide erosion protection to reduce the likelihood of a brittle failure if the systems' capacity is exceeded. Additionally, 7,000 LF of levee will need to be raised 1 foot.
  - 2-foot raise: Construction of 2,000 LF of floodwall (15 feet tall) along with 19,400 LF of levee raised 2 feet. There would be construction of a floodwall at one pump station (200 LF at 7 feet tall), replacing an additional 12,000 LF of floodwall (15 feet tall). There would be rebuilding of four existing pump stations at 1,100 cubic feet per second (cfs).

Economic Evaluation

The net benefits of Optimization Alternatives for the Port Arthur and Vicinity CSRM project area are presented in Table 5-7. No environmental impacts were identified for this element and therefore no mitigation costs were included in the cost estimate.

Table 5-7: Net Benefits of Optimization Alternatives for the Port Arthur and Vicinity CSRM Project Area

Alternative Reach	Optimization Alternatives	Net Benefits
8- to 10-foot I-Wall	No Fail	$13,305,000
	1-Foot Raise	$17,292,000
	2-Foot Raise	$17,215,000
Closure Structure	No Fail	$2,622,000
	1-Foot Raise	$2,908,000
	2-Foot Raise	$2,628,000
I-Wall Near Valero	No Fail	$45,153,000
	1-Foot Raise	$50,662,000
	2-Foot Raise	$41,076,000
I-Wall Near Tank Farm	No Fail	$12,758,000
	1-Foot Raise	$20,932,000
	2-Foot Raise	$18,843,000

5.4.2.4 Freeport and Vicinity CSRM

The following section describes the proposed Freeport and Vicinity CSRM Optimization Alternatives. The plans include modifications to the existing HFPP at Freeport. Figure 5-3 shows the location of the Optimization Alternatives listed below.

- *Dow Barge Canal Protection*

The Dow Barge Canal levees are approximately eight miles long and represent a significant risk to the HFPP performance at and above the design event. This risk is primarily from seepage and instability caused by seepage through the "sandy" levee and foundation material. Significant risk also exists with numerous pipeline penetrations, I-wall instability, and non-uniform levee heights. The study team utilized a closure structure and pump station constructed at the junction of the North Barge Canal and East Storm Levee. This structure would allow barge traffic to pass during routine operations and will have a pumping capacity of 2,000,000 gallons per min (gpm). The structure length would be approximately 500 feet long with two sector gates totaling approximately 80 feet wide for vessel traffic. Additional tidal circulation would be provided by two sluice gates approximately 15 feet wide each. The final configuration of this structure would match the proposed level of risk reduction for the system.

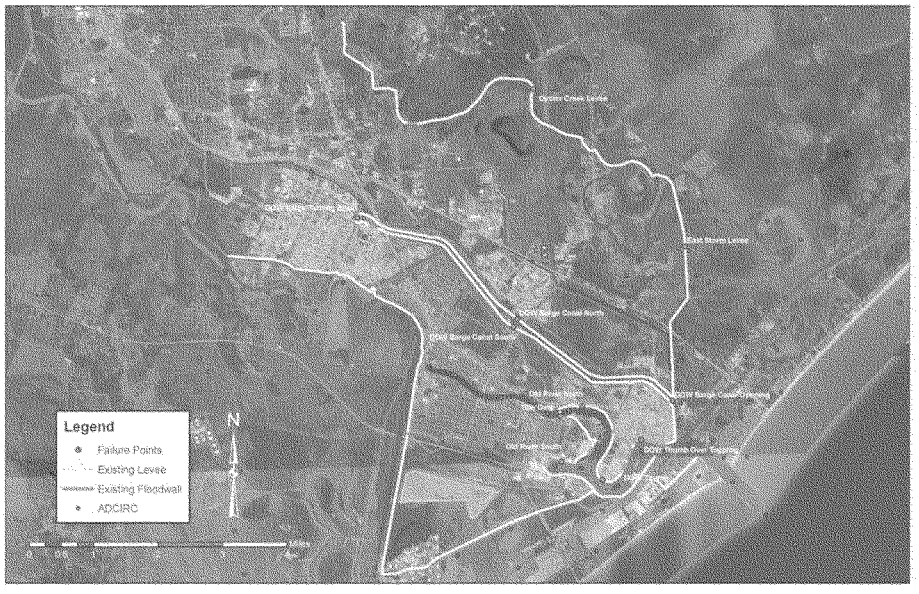


Figure 5-3: Location of Optimization Alternatives in the Freeport CSRM Area

- *Oyster Creek Levee*

Oyster Creek Levee was constructed at varying elevations to account for the changes in flood elevation as noted in the hydraulic modeling. Updated hydraulic modeling showed a height deficiency over 3,500 LF.

- No fail: The Oyster Creek levee would be raised 2 feet over 3,500 LF in order to correct the noted height deficiency. The construction procedure would include stripping topsoil, removal of a 12-foot-wide asphalt road, placement of fill, replacement of a 12-foot-wide road and turfing.
- 1-Foot Raise: Construction would include 3,500 LF of 3-foot levee raise and 10,000 LF of 1-foot levee raise for a total distance of 13,500 LF. The construction procedure would include stripping topsoil, removal of a 12-foot-wide asphalt road, placement of fill, replacement of a 12-foot-wide road and turfing.
- 2-Foot Raise: Construction would include 3,500 LF of a 4-foot levee raise and 33,000 LF of a 2-foot levee raise, replacing 1,000 feet of floodwall reconstruction at 8 feet high, raising 2,300 LF of Highway 523 at the levee crossing, construction of one pump station with 1,100 cfs capacity, and replacement of six gravity structures would be required.

- *East Storm Levee*

East Storm Levee is a large earth embankment that faces the Gulf of Mexico and has direct wave and surge impacts from the Gulf. The proposed construction procedure will include stripping topsoil, removal of a two-lane asphalt road, placement of fill, and replacement of a two-lane road and turfing.

- No Fail: Construction of 13,115 LF of High Performance Turf Reinforcing Mat (HPTRM)
- 1-foot raise: Construction would include 13,115 LF of levee raised 1 foot with HPTRM
- 2-foot raise: Construction would include 19,115 LF of levee raised 2 feet with HPTRM, 800 LF of new floodwall at one pump station, reinforcing pump station walls and raising 2,500 LF of Highway 332 at the levee crossing.

- *South Storm Levee*

The south storm levee is a frontal levee that has potential for direct wave impact from the Gulf of Mexico during storm loading. When this levee was originally constructed, the area south of the levee was very low in elevation. Over the last 40 years, USACE constructed dredge material placement areas for the deep draft navigation channel in this low area. Continued use of the material placement areas has increased the elevation of the low area to a point that it is now higher than the South Storm Levee.

  - 1-foot raise: Construction would include earth placement on top of the existing earth embankment for a 1-foot raise.
  - 2-foot raise: Construction would include earth placement on top of the existing earth embankment for a 2-foot raise.

- *Freeport Dock Floodwall*

The Freeport Dock floodwall is a 3-foot floodwall that was added to the dock face at the Port Freeport docks after Hurricane Ike under PL 84-99. This floodwall has drop-in panels that are removable to allow for "roll on, roll off" cargo loading. During evaluation of the HFPP for CFR 65.10, the local sponsor noted that the wall/panels were structurally deficient. This deficiency was confirmed during the Freeport SQRA.

  - Partial Fail: Construction would include replacing the drop-in panels and anchor system.
  - No Fail: Reinforcement of 3,000 lf of floodwall to meet all USACE requirements for a wall/drop-in panel system located at a port facility.
  - 1-Foot Raise: Construction of the 1-foot raise would require complete reconstruction of 3,000 LF of dock and flood wall assembly.

- *Old River Levee at Dow Thumb*

This reach of levee is an earth embankment that would be susceptible to erosion during an overtopping event. Updated modeling shows an area of this reach that has significant risk to large wave attack and overtopping from wave propagation along the adjacent deep draft navigation channel.

  - No Fail: Construction of 14,500 LF of HPTRM and 4,000 LF of 15-foot-wide 6-inch scour pad to provide erosion protection to reduce the likelihood of failure.

- 1-Foot Raise: Construction of 4,000 LF of 15-foot-wide 6-inch scour pad along with 3,000 LF of levee raised 1 foot and 14,500 LF of HPTRM to "level up" the low spots and provide erosion protection to reduce the likelihood of a brittle failure if the system's capacity is exceeded.
- 2-Foot Raise: Due to extremely low Factors of Safety (FOS) for global stability, raising the levee over existing heights by adding additional earth fill is not an option; therefore, under this scenario, the existing embankment would be removed and 12,000 LF of 10-foot-tall floodwall would be constructed. In areas that do not have stability issues 6,500 LF of levee would be raised 2 feet, one drainage structure would be replaced, and the saltwater intake at DOW A801 would be replaced.

- *Tide Gate I-Wall*

The I-wall located at the Tide Gate was constructed as part of the original HFPP construction when the earth embankment section could not reach design elevation. The very soft foundation materials that were present in the old river channel would not support the additional weight of the embankment section. The proposed construction would be to reconstruct the I-wall as a pile-founded T-wall. The overall length of the T-wall is approximately 362 feet.

- No Fail: Construction of 362 LF of floodwall 10 feet tall.
- 1-Foot Raise: Construction of 700 LF of floodwall (11 feet tall) along with 2,000 LF of levee raised 1 foot.
- 2-Foot Raise: Construction of 700 LF of floodwall (12 feet tall) and 3,500 LF of levee raised 2 feet along with adding a floodwall at one pump station (200 LF at 7 feet tall). The tide gate structure adjacent to the I-wall will require significant modification or complete reconstruction to accommodate a 2-foot raise.

Economic Evaluation

The net benefits of Optimization Alternatives for the Freeport and Vicinity CSRM project area are presented in Table 5-8. No environmental impacts were identified for this element and therefore no mitigation costs were included in the cost estimate.

Table 5-8: Net Benefits of Optimization Alternatives for the Freeport and Vicinity CSRM Project Area

Alternative Reach	Optimization Alternatives	Net Benefits
DOW Barge Canal	Levee Rehabilitation; Gate Structure	$113,914,000
Oyster Creek Levee	No Fail	$2,010,000
	1-Foot Raise	$2,314,000
	2-Foot Raise	$490,000
East Storm Levee	No Fail	$796,000
	1-Foot Raise	$835,000
	2-Foot Raise	$120,000
South Storm Levee	1-Foot Raise	($74,000)
	2-Foot Raise	($164,000)
Freeport Dock Floodwall	Partial Fail	$123,000
	No Fail	$2,093,000
	1-Foot Raise	($3,944,000)
Old River Levee at DOW Thumb	No Fail	$969,000
	1-Foot Raise	$1,241,000
	2-Foot Raise	($2,196,000)
Tide Gate I-Wall	No Fail	$1,526,000
	1-Foot Raise	$1,721,000
	2-Foot Raise	$549,000

5.4.2.5 Brazoria and Sabine Nonstructural

Surveys of aerial imagery for the three counties were performed to look for the potential for nonstructural buyouts. Buyouts would be ancillary to the implementation of new levees/floodwalls in Orange and Jefferson Counties and to the enhancement of features in the Port Arthur and Freeport CSRM project areas. Buyout opportunities in Brazoria are virtually non-existent and very limited in both Orange and Jefferson Counties. Several structures in Jefferson have the potential for being bought out; however, these structures are commercial and buying out these structures is very unlikely to be economically viable. Figure 11 of Appendix C shows the potential for buyouts in Orange County. Initially approximately 20 residential structures appeared to be economically viable, but some of the parcels appeared to have no structures located on them. Later inspections of county appraisal records, in many cases, showed improvements on a lot of these parcels. Visual inspections of aerial photos and further inspection of the appraisal records showed that many of these were agricultural improvements and would, therefore, not be subject to any permanent evacuation analysis. A quantitative analysis was conducted to determine the viability of any proposed nonstructural buyout. The analysis showed the nonstructural buyouts had negative net

benefits and any potential buyouts were screened from the analysis. The economic evaluation results are included in Table 13 of the Economic Appendix.

5.4.3 Comparison of Alternative Plans

This section provides a summary of the results of the Final Array of Alternatives evaluation and a comparison of plans. The screening criteria were applied to select a TSP. Table 5-10 presents the final array plans and a summary of the contributions to the planning objectives. Plans were evaluated first to identify an NED plan.

Objectives 1, 4, and 6 are described first since they were the objectives related to NED. The following is a summary and comparison of the plans for these objectives. For Objective 1, the net benefits were calculated for each Optimization Alternative. The plan that reasonably maximizes net benefits is the NED plan. Objective 4 is embedded within the NED and RED accounts. Specifically for the NED, the values of the critical infrastructure were included in the economic analysis, and measured when the economic evaluation of the Optimization Alternatives was performed and an NED plan was identified.

In the Orange-Jefferson CSRM project area, Optimization Alternatives within the Orange 1, Orange 2, Beaumont B, and Beaumont C Alternative Reaches did not have positive net benefits; therefore, the new levees considered at the various heights for those reaches were screened from further consideration. In the Port Arthur and Vicinity CSRM project area, all Alternative Reaches had positive net benefits. In the Freeport and Vicinity CSRM project area, all Alternative Reaches had positive net benefits except the South Storm Levee. The raises considered for that reach was screened from further consideration. The nonstructural buyouts for the Sabine and Brazoria Regions were not economically viable and were screened from further consideration. The plans that reasonably maximized NED from each project area are highlighted in green in Table 5-10 and listed below:

The NED plan for the Orange-Jefferson CSRM is:

- Orange 3 New Levee (11-foot)
- Jefferson Main New Levee (11-foot)
- Beaumont A New Levee (12-foot)

The NED plan for the Port Arthur Vicinity CSRM is:

- 8- to 10-foot I-Wall Raise (1-foot)
- Closure Structure Raise (1-foot)

- I-Wall Raise Near Valero (1-foot)
- I-Wall Raise Near Tank Farm (1-foot)

The NED plan for the Freeport and Vicinity CSRM is:

- DOW Barge Canal Gate Structure
- Oyster Creek Levee Raise (1-foot)
- East Storm Levee Raise (1-foot)
- Freeport Dock Floodwall Raise (1-foot)
- Old River Levee Raise at Dow Thumb (1-foot)
- Tide Gate I-Wall Raise (1-foot)

Regarding Objective 6, the EADs presented in this report use storm surge levels without considering sea level rise scenarios for the 20-, 50- and 100-year sea level change scenarios; however, a performance of the NED plans against RSLC is provided. Table 5-9 shows the performance of the NED plans against the 50-year RSLC estimated for the project areas. This table was developed by averaging levee heights specified by engineering criteria for the 50-year RSLC and comparing them to the elevation of the index points used in the HEC-FDA model for the NED Plans. The column highlighted yellow is the height of the NED plans in the economic analysis. The comparison shows the NED Plans perform well with the RSLC scenario for the 50-year period, except for areas in the "Sabine Region." The rows highlighted light blue show the Orange-Jefferson CSRM (NED plan) is deficient in height at the 50-year project life. Table 5-10 summarizes the range in RSLC deficits for the Orange-Jefferson CSRM project area. As the height of the plan decreases, the range in the deficit increases among the Optimization Alternatives. The locations listed in Table 5-9 correspond to locations included in the H&H analysis.

The expectation for each project area would be that all plans would positively impact life-safety risk and reduce the likelihood of secondary impacts on critical infrastructure to meet Objectives 2 and 4. This is shown in Table 5-10 as an expected positive impact. Additional qualitative discussion of Objectives 2 and 4 is provided in the next section. Objective 3 was removed from consideration in this planning study from an ER implementation standpoint. As stated in section 5.3.3 this study only focused evaluation on two sub-regions, Sabine and Brazoria for CSRM project implementation. Future studies recommending CSRM projects in the Galveston region, as well as ER opportunities throughout the entire six-county region would be pursued under different study authorizations. Future feasibilities, including Coastal Texas, will leverage studies, data, and models currently under development by others in the Galveston region.

Table 5-9: Average Recommended Relative Sea Level Change (RSLC), Feet NAVD

Location	Without RSLC	Low RSLC	Int.[1] RSLC	High RSLC	Height in Economic analysis[2]	Surplus/ Deficit (Without)	Surplus/ Deficit (Low)	Surplus /Deficit (Int.)	Surplus/ Deficit (High)
Dow Barge Canal	15.85	16.58	17.15	18.93	26.00	10.15	9.43	8.85	7.08
Sabine Floodwall	12.50	13.43	13.98	15.77	11.00	-1.50	-2.43	-2.98	-4.77
Sabine Levee	12.33	13.24	13.83	15.59	11.00	-1.33	-2.24	-2.83	-4.59
Freeport Levee	16.42	17.13	17.66	19.45	20.75	4.33	3.63	3.09	1.30
Oyster Creek	16.41	16.41	16.41	16.41	19.00	2.59	2.59	2.59	2.59
Port Arthur Floodwall	13.25	16.10	16.72	18.25	19.00	5.75	2.90	2.28	0.75
Port Arthur Levee	12.94	13.86	14.43	16.20	18.00	5.06	4.14	3.58	1.80

[1]Note Int. – Intermediate

[2] Note heights listed are different under the recommended plan, due to final refinements under feasibility design

Table 5-10: Comparison of Final Array of Alternative by Planning Objectives

	NED			OSE		RED
	Objective 1		Objective 6	Objective 2		Objective 4 and 5
	Net Benefits	Screening Status	Sea Level Rise	Population at Risk		Critical Infrastructure Impacts
Orange-Jefferson CSRM						
Orange 1			Surplus/Deficit Range (Approx. Feet NAVD)	PAR FWOP/Expected Impact		Number of Facilities by County
11-foot Raise	($1,769,000)	Screened Out		17,014	Expected Positive Impact	Reduces likelihood of secondary impacts on: • 20 schools • 14 law enforcement • 2 hospitals/6 nursing homes • 11 fire stations • 20 chemical manufacturing • 5 electric generation • 0 petroleum refining
12-foot Raise	($2,380,000)	Screened Out				
13-foot Raise	($2,996,000)	Screened Out				
14-foot Raise	($3,617,000)	Screened Out				
Orange 2						
11-foot Raise	($1,757,000)	Screened Out		13,952	Expected Positive Impact	
12-foot Raise	($2,112,000)	Screened Out				
13-foot Raise	($2,467,000)	Screened Out				
14-foot Raise	($2,822,000)	Screened Out				
Orange 3						
11-foot Raise	$9,851,000	$9,851,000	-1.3 – 4.8 feet deficit	60,044	Expected Positive Impact	
12-foot Raise	$10,232,000	$10,232,000	-0.5 – 3.8 feet deficit			
13-foot Raise	$9,804,000	Screened Out	0.5 surplus - 2.8 feet deficit			
14-foot Raise	$8,810,000	Screened Out				
Beaumont A						
11-foot Raise	$2,743,000	Screened Out	-1.3 – 4.8 feet deficit	2,078	Expected Positive Impact	Reduces likelihood of secondary impacts on: • 42 schools • 19 law enforcement • 13 hospitals/7 nursing homes • 26 fire stations • 54 chemical manufacturing • 1 electric generation • 0 petroleum refining • 1 airport
12-foot Raise	$2,992,000	$2,992,000	-0.5 – 3.8 feet deficit			
13-foot Raise	$3,037,000	$3,037,000	0.5 surplus - 2.8 feet deficit			
-foot Raise	$2,942,000	Screened Out				
Beaumont B						
11-foot Raise	($58,000)	Screened Out		2,078	Expected Positive Impact	
12-foot Raise	($82,000)	Screened Out				
13-foot Raise	($106,000)	Screened Out				
14-foot Raise	($131,000)	Screened Out				
Beaumont C						
11-foot Raise	($442,000)	Screened Out		2,078	Expected Positive Impact	
12-foot Raise	($449,000)	Screened Out				
13-foot Raise	($574,000)	Screened Out				
Jefferson Main						
11-foot Raise	$22,461,000	$22,461,000	-1.3 – 4.8 feet deficit	116,762	Expected Positive Impact	
12-foot Raise	$22,580,000	$22,580,000	-0.5 – 3.8 feet deficit			
13-foot Raise	$22,496,000	Screened Out	0.5 surplus - 2.8 feet deficit			
14-foot Raise	$22,123,000	Screened Out				
Port Arthur and Vicinity CSRM[2]						
8-10ft I-Wall						
No Fail	$13,305,000	Screened Out		116,762	Expected Positive Impact	Reduces likelihood of secondary impacts on: • 42 schools • 19 law enforcement • 13 hospitals/7 nursing homes • 26 fire stations • 54 chemical manufacturing • 1 electric generation • 0 petroleum refining • 1 airport
1-foot Raise	$17,292,000	$17,292,000				
2-foot Raise	$17,215,000	Screened Out				
Closure Structure						
No Fail	$2,622,000	Screened Out				
1-foot Raise	$2,908,000	$2,908,000				
2-foot Raise	$2,628,000	Screened Out				
I-Wall Near Valero						
No Fail	$45,153,000	Screened Out				
1-foot Raise	$50,662,000	$50,662,000				
2-foot Raise	$41,076,000	Screened Out				
I-Wall Near Tank Farm						
No Fail	$12,758,000	Screened Out				
1-foot Raise	$20,932,000	$20,932,000				
2-foot Raise	$18,843,000	Screened Out				
Freeport and Vicinity CSRM[2]						
Dow Barge Canal				16,559	Expected Positive Impact	Reduces likelihood of secondary impacts on: • 6 schools • 3 law enforcement • 0 hospitals/0 nursing homes • 2 fire stations • 24 chemical manufacturing • 0 electric generation • 0 petroleum refining
No Fail	$113,914,000	$113,914,000				
Oyster Creek Levee						
No Fail	$2,010,000	Screened Out				
1-foot Raise	$2,314,000	$2,314,000				
2-foot Raise	$490,000	Screened Out				
East Storm Levee						
No Fail	$769,000	Screened Out				
1-foot Raise	$835,000	$835,000				
2-foot Raise	$120,000	Screened Out				
Freeport Dock						
Partial Fail	$123,000	Screened Out				
No Fail	$2,093,000	$2,093,000				
1-foot Raise	($3,944,000)	Screened Out				
Old River at Dow Thumb						
No Fail	$969,000	Screened Out				
1-foot Raise	$1,241,000	$1,241,000				
2-foot Raise	($2,196,000)	Screened Out				
South Storm Levee						
1-foot Raise	($74,000)	Screened Out				
2-foot Raise	($164,000)	Screened Out				
Tide Gates						
No Fail	$1,526,000	Screened Out				
1-foot Raise	$1,721,000	$1,721,000				
2-foot Raise	$549,000	Screened Out				
Sabine Nonstructural Buyout		Screened Out				
Brazoria Nonstructural Buyout		Screened Out				

[2] The comparison shows the economic analysis performs well with the RSLC scenario for the 50-year period for Port Arthur and Vicinity and the Freeport and Vicinity CSRM; therefore, the surplus is not reported in this table

5.4.4 Identifying a Tentatively Selective Plan (TSP)

The decision criteria for selecting a TSP in the study was based on building a plan for each project area that reasonably maximized net benefits (Objective 1 for the study) from the Final Array of Alternatives. The TSP is the NED plan for each project area, as it reasonably maximizes net national economic development consistent with the Federal objective of protecting the Nation's environment. The TSP presented in the DIFR-EIS included the following features:

Orange-Jefferson CSRM

- Orange 3 New Levee (11-foot)
- Beaumont A New Levee (12-foot)
- Jefferson Main New Levee (11-foot)

Port Arthur and Vicinity CSRM

- 8- to 10-foot I-Wall Raise (1-foot)
- Closure Structure Raise (1-foot)
- I-Wall Raise Near Valero (1-foot)
  I-Wall Raise Near Tank Farm (1-foot)

Freeport and Vicinity CSRM

- Dow Barge Canal Gate Structure
- Oyster Creek Levee Raise (1-foot)
- East Storm Levee Raise (1-foot)
- Freeport Dock Floodwall Raise (1-foot)
- Old River Levee Raise at Dow Thumb (1-foot)
- Tide Gate I-Wall Raise (1-foot)

5.4.5 Selection of the TSP for the DIFR-EIS

USACE guidance (ER 1105-2-100, Section 2-3(f)) requires selection of a single alternative plan or a decision to take no action. Since no ER alternatives were evaluated, the alternative CSRM plan that most reasonably maximizes net economic benefits consistent with protecting the Nation's environment, the NED plan, must be selected. The TSP was the environmentally preferable alternative. Because it is generally the lowest height of all action alternatives that were evaluated, it would result in the narrowest footprint and the fewest environmental impacts, while reasonably maximizing coastal storm risk reduction to the affected communities. The No Action Alternative would provide no coastal storm risk reduction to the vulnerable populations and infrastructure of the study area.

The DIFR-EIS underwent public, policy, Agency Technical Review (ATR), and Independent External Peer Review (IEPR), and the study team has addressed all comments from these reviews. The decision to select a plan other than the TSP was not based on quantitative economic analysis alone, but rather takes into consideration other factors that could justify higher project cost and more robust construction than could be otherwise justified. The following discussions identified other compelling factors that might support a plan larger than the TSP for the Orange-Jefferson CSRM. This information was taken into consideration by the Senior Leader Panel Agency Decision Milestone (ADM) held after the release of the DIFR-EIS. The ADM was the decision point where a Senior Leader Panel confirmed the TSP and made a decision on the Recommended Plan to carry forward for detailed feasibility-level design based on policy, public, ATR, and IEPR reviews of the draft report.

Table 5-11 is a summary of comparable Optimization of Alternatives in terms of net benefits, percent change in net benefits, annual costs, and total project cost differences within the Orange-Jefferson CSRM project area. An increase in 1 foot among the Optimization Alternatives would cost about $72 million more but would only provide about $545,000 more in net annual benefits. Based on economics alone, even though the 11-foot levee is incrementally justified, it does not make sense to recommend a plan that costs that much more for such minimal benefits.

Table 5-11: Cost Analyses Comparison for Optimization Alternatives in the Orange-Jefferson Project Area

Objective 1						
	Net Benefits	**Net Benefits % Change**	**Annual Cost**	**Annual Cost % Change**	**Total Project Cost**	**Incremental Change in Total Project Cost**
Orange-Jefferson CSRM						
Orange 3						
11-foot Raise	$9,851,000	N/A	$14,895,000	N/A	$246,811,000	N/A
12-foot Raise	$10,232,000	3.9%	$16,711,000	12.2%	$288,284,000	$41,473,000
Beaumont A						
12-foot Raise	$2,992,000	N/A	$3,075,000	N/A	$70,202,000	N/A
13-foot Raise	$3,037,000	1.5%	$3,405,000	10.7%	$77,743,000	$7,541,000
Jefferson Main						
11-foot Raise	$22,461,000	N/A	$3,250,000	N/A	$64,726,000	N/A
12-foot Raise	$22,580,000	0.5%	$4,212,000	29.6%	$87,674,000	$22,948,000

However, based on the qualitative evaluation performed, each alternative reach is expected to have a positive impact on life-safety, because reductions in economic damages are generally considered

highly correlated to reductions in risk in terms of life-safety. For the Orange-Jefferson CSRM project area, the population at risk is estimated as follows:

- Orange 3 Alternative Reach – 60,044 residents
- Beaumont A Alternative Reach – 2,078 residents
- Jefferson Main Alternative Reach – 116,762 residents

The risk assessment for the Orange-Jefferson CSRM is largely qualitative. Defining the population at risk, above, and the depth of flooding is evaluated in a risk assessment. Other considerations include populations in high risk areas with special needs, such as elderly populations over 65, and care and shelter facilities including hospitals, nursing homes and schools. Figures 5-4 and 5-5 depict the locations of hospitals, nursing homes, and schools in the areas of Orange and Jefferson Counties that would be protected by the TSP. Flooding depths for the Orange 3, Beaumont A, and Jefferson Main Alternative Reaches are approximately 6-8 feet (estimated depths of flooding at the 1% ACE from the economic analysis). Disabled residents are a high risk population that would be vulnerable in 6 to 8 feet of flooding if there were not sufficient lead time for evacuations or if evacuation procedures are not implemented appropriately. Approximately 19 percent of the 178,884 people at risk in the Orange-Jefferson CSRM project area, or 33,000 people, would be considered disabled (2015 U.S. Census). Of the approximately 500,000 people in New Orleans during Hurricane Katrina, 100,000 were too elderly, disabled, or lacked transportation and resources to evacuate, with disastrous results. (2015 datacenterresearch.org), and it is assumed that the Orange-Jefferson CSRM project area could experience similar outcomes. In addition, given the critical infrastructure and refining capacity also located in the project area, a compelling argument can be made to provide a higher level of storm surge risk reduction by building a foot higher than the current TSP.

In addition to increased life-safety benefits, there are other non-traditional secondary or ancillary economic benefits not included in the NED Plan that should be considered, including preventing disruptions in business such as loss of revenue, wages, and sales tax, and their multiplier effects. The cost of emergency response and cleanup would be avoided. Most importantly, increased risk reduction would also avoid disruption of significant industrial and manufacturing facilities located in the project area; notably, the Motiva and Exxon Mobil refineries that have the capacity to refine 945,000 barrels of crude oil per day and can produce 6.7 billion gallons of gasoline annually. In 2014, the U.S. Energy Information Administration reports that the U.S. consumed 136.78 billion gallons of gasoline. These two refineries alone can produce about 5 percent of that demand. If they were running at full production with gas prices at $2.50/gallon and were to go out of production for even a month, this could be up to a $1.4 billion hit to the national economy and would be even more significant to the regional and local economies. Spending $72 million to provide an additional foot of performance and lower the probability of being impacted would seem

to be a small investment to protect such significant infrastructure and would be worth the investment.

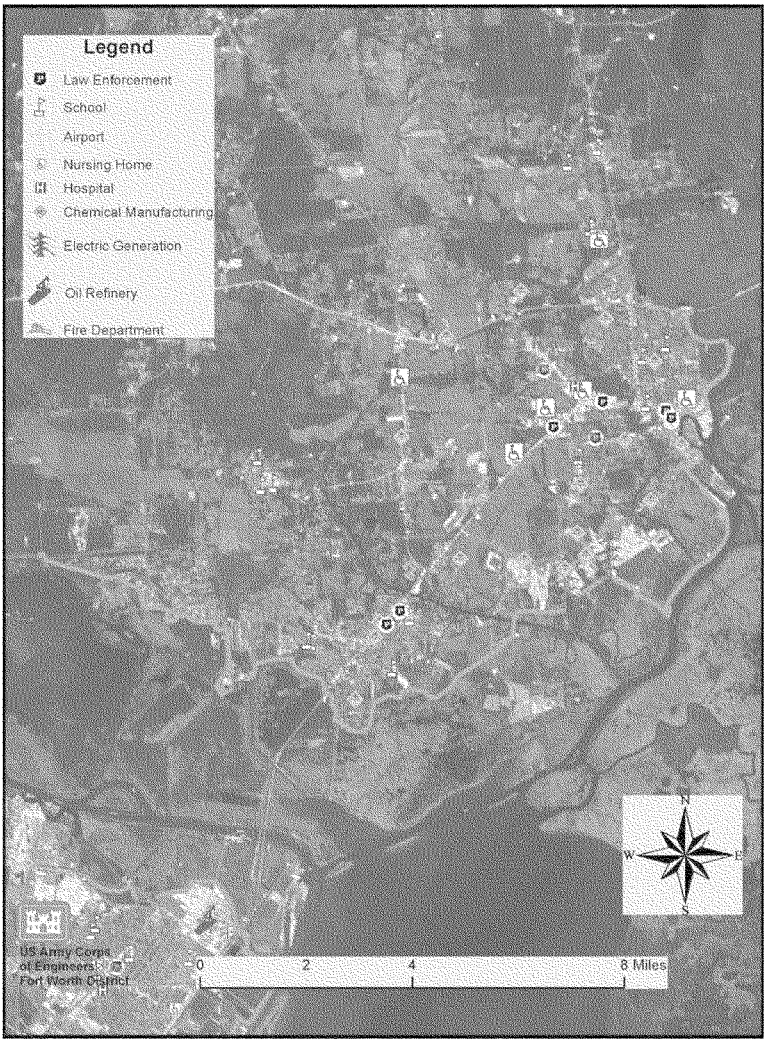


Figure 5-4: Orange County Critical Infrastructure

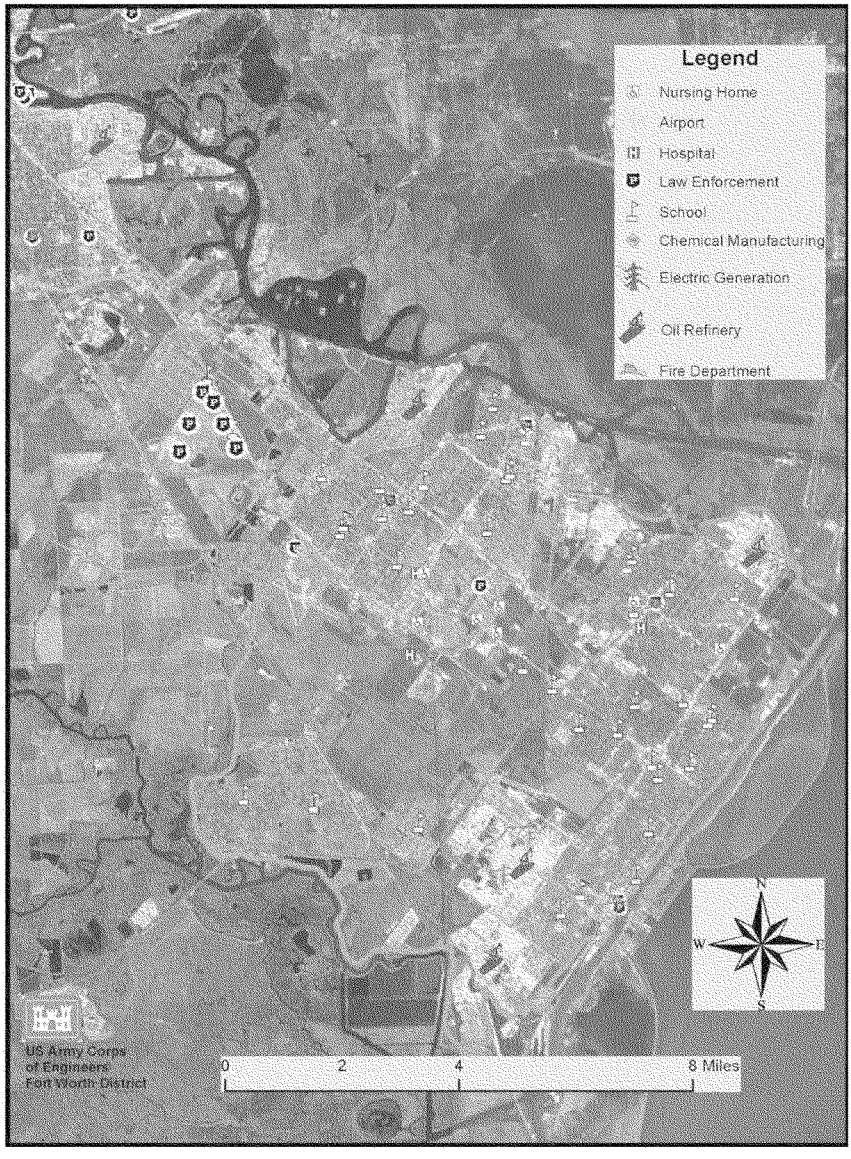


Figure 5-5: Jefferson County Critical Infrastructure

In addition, the current TSP could result in larger future project modifications to account for RSLC in the Orange-Jefferson CSRM project area. Efficiencies would be gained by spending an additional $72 million now to account for projected RSLC. Table 5-12 displays the ranges for RSLC for each of the alternative reaches. The deficit is already a concern for feasibility-level design and would need to be taken into further consideration in the study to ensure the Recommended Plan would meet USACE design criteria for RSLC. With this in mind, the 12-foot levees would perform better than the NED Plan when considering RSLC scenarios and would be worth the additional Federal investment. If the NED plan remains the final recommendation from the Senior Leader Panel at the ADM, then it may still be appropriate for USACE to consider cost sharing in the design and construction of any recommended floodwall or I-wall to accommodate future construction for RSLC adaptation. This expense would be minimal compared to the significant expense of project replacement in the future. Additional discussion of design criteria for RSLC is provided in Section 6.2.2.

Table 5-12: Ranges for RSLC for the Orange-Jefferson CSRM Project Area

Orange 3	**Range of RSLR Projected**
11-foot Raise	-1.3 – 4.8 feet deficit
12-foot Raise	-0.5 – 3.8 feet deficit
13-foot Raise	0.5 surplus - 2.8 feet deficit
Beaumont A	
11-foot Raise	-1.3 – 4.8 feet deficit
12-foot Raise	-0.5 – 3.8 feet deficit
13-foot Raise	0.5 surplus - 2.8 feet deficit
Jefferson Main	
11-foot Raise	-1.3 – 4.8 feet deficit
12-foot Raise	-0.5 – 3.8 feet deficit
13-foot Raise	0.5 surplus - 2.8 feet deficit

5.4.6 Comparison of Environmental Impacts for Final Array of Alternatives

5.4.6.1 WVA Modeling of Alternatives

WVA modeling was utilized to quantify impacts of the Final Array of CSRM Alternatives on marsh and forested wetlands. This modeling was conducted only for the Orange-Jefferson CSRM project area, as no wetland impacts were identified in the Port Arthur and Freeport and Vicinities CSRM project areas. The WVA Marsh Model was approved for use by HQUSACE memo dated May 6, 2014; WVA Swamp and Bottomland Hardwood models are certified. The approval memo, a description of the WVA model and a detailed description of the WVA application to this study, are presented in Appendix O. The WVA is a suite of habitat-based models originally developed by the USFWS that utilizes a community approach to quantify changes to fish and wildlife habitat quality and quantity, measured in AAHUs.

Direct impacts as quantified by the model reflect the assumed loss of all marsh and forested wetlands within the construction right-of-way of the Orange 1 ,2, and 3 Alternative Reaches, Jefferson Main, and Beaumont Alternative Reaches A, B, and C in the first year of construction. Staging areas would be situated to avoid impacts on wetlands or other significant environmental resources; numerous suitable areas are available. In previously disturbed areas, impacts were assessed for a conservatively-wide alignment right-of-way, which would accommodate construction of any of the four height alternatives and adjustments to account for RSLC. Construction rights-of-way for floodwalls and related direct impacts would be roughly the same for all height alternatives. Construction rights-of-ways for the 11, 12, and 13 feet levee height alternatives for all of the reaches would be proportionately lower than the 14 feet Alternative, as levee footprints would be slightly narrower. Differences would be small when compared to the overall width of the right-of-way assessed for impacts. The width of the construction right-of-way varies based on existing ground elevation and the type of structure proposed. In general, impacts were captured for earthen levee right-of-way segments from 200 to 325 feet in width; impacts for floodwall segments were captured for right-of-way segments ranging from 150 to 200 feet in width.

Given the small differences in right-of-way widths among the height alternatives, as well as uncertainties inherent in the preliminary engineering alignment and the future rate of RSLC, direct impacts were modeled using only the oversized width and applied to all RSLC scenarios. RSLC was considered in determining indirect impact areas for the 50-year period of analysis.

The general area of the levee alignment was carefully evaluated to identify areas into which wetlands would have migrated under the three RSLC scenarios in the FWOP condition. The NOAA Sea-Level Rise Viewer (NOAA 2015) was used to identify new tidally-influenced areas, and the NOAA marsh impacts/migration viewer was used to map changes in marsh type and extent for a 50-year sea-level rise approximating the low, intermediate, and high rates in this area.

The NOAA method for mapping marsh migration due to RSLC assumes that specific wetland types exist within an established tidal elevation range, based on an accepted understanding of what types of vegetation can exist given varying frequency and time of inundation, as well as salinity impacts from such inundation (NOAA 2012). The viewer maps changes associated with sea-level rise in 1-foot increments. The potential changes associated with projected 50-year intermediate and high RSLC in the Sabine region were evaluated using the 2- and 4-foot Sea Level Rise and Marsh Impacts views.

No FWP impacts were identified for most of the areas identified as vulnerable to RSLC in the FWOP condition. Increasing sea levels would be expected to increase the extent of tidal flow into

the smaller bayous and streams, which cut from the upland to the floodplain. The higher water levels would flood low-lying bayou and stream bottoms, creating new wetlands in several areas shown in Appendix O. In general, however, relatively high valley walls along the upland terraces of the Sabine and Neches Rivers would prevent large-scale overland flooding over the period of analysis. Indirect impacts associated with installation of the levee system would be minimized by maintaining flows in tidal bayous and streams equivalent to the FWOP condition. Culverts would be sized and modified as needed to provide for increased tidal flows expected with RSLC. With tidal access maintained at FWOP flows, RSLC-related landscape and wetland changes to areas both inside and outside of the levee system would occur with the project in place, as they would have occurred in the FWOP condition.

Indirect impacts identified for the Orange 1 and 3 Reach Alternatives are related to two primary effects – those associated with fisheries access impacts on the extensive marshes in the lower Adams Bayou and Cow Bayou floodplains (a functional impact), and indirect impacts related to changes in hydrologic connectivity caused by the new levee system and the Cow Bayou structure, which would result in the loss of wetland acreage. Indirect impacts that would result in the loss of wetland acreage in Orange 1 and 3 were modeled separately for the three RSLC scenarios. Indirect fisheries impacts on marsh function associated with the surge gate impacts on fisheries access were modeled for the low RSLC scenario, and these impacts were applied to the intermediate and high scenarios for the Orange 3 reach only. Higher tidal inundation would improve fisheries access even with the structures in place; the low RSLC condition thus provides a conservatively high impact assessment.

5.4.6.2 Orange-Jefferson CSRM Project Area

The three reaches in Orange County (Orange 1, 2, and 3) and the four reaches in Jefferson County (Jefferson Main, Beaumont A, B, and C) were each evaluated with four separate height alternatives – 11, 12, 13, and 14 feet Alternatives. Direct and indirect impacts on marsh and forested wetlands, as quantified using the WVA model, for all of the Jefferson Main and Beaumont Alternatives are presented in Table 5-13, and impacts on Orange 1, 2, and 3 Alternatives are presented in Table 5-14. No impacts were identified for Beaumont B, and no indirect impacts were identified for the Jefferson Main or Beaumont A and C; impacts for each reach are limited to direct impacts which apply to all levee height alternatives and all RSLC scenarios. The impacts are minimal, reflecting the developed and industrialized nature of these project areas.

Table 5-13: Total Wetland Impacts of Jefferson Main and Beaumont Alternatives (All RSLC Scenarios)

Wetland Type	Jefferson Main		Beaumont A		Beaumont C	
	All Height Alternatives and All RSLC Scenarios					
	Acres	AAHU	Acres	AAHU	Acres	AAHU
Swamp	0.9	-0.4				
Bottomland Hardwood	13.9	-6.4	0.3	-0.2		
Forested Wetland Subtotal	14.8	-6.8	0.3	-0.2		
Fresh Marsh	13.4	-6.1	2.6	-1.6		
Intermediate Marsh	0.4	-0.2	0.6	-0.3	1.0	-0.6
Brackish Marsh	9.9	-4.9				
Marsh Subtotal	23.7	-11.2	3.2	-1.9	1.0	-0.6
Total Impacts	**38.5**	**-18.0**	**3.5**	**-2.1**	**1.0**	**-0.6**

Impacts for Orange 3 are much higher than for Orange 1 and 2 (Table 5-14). Orange 3 is about twice as long as Orange 1 and 2 combined, and this size difference is reflected in the higher direct impacts. In addition, direct and indirect wetland impacts related to construction of the Adams and Cow tidal surge gates are associated with Orange 3; surge gates are not required for Orange 1 and 2.

Orange 1 impacts (direct and indirect) would be the same for all RSLC scenarios (63.8 acres; -29.9 AAHUs). Indirect impacts in this reach are associated with wetland loss caused by the permanent alteration of tidal access, and thus the effects would be the same across all RSLR scenarios. Orange 2 impacts would also be the same for all RSLC scenarios (24.7 acres; -13.9 AAHUs); no indirect impacts were identified in this reach. Orange 3 impacts increase slightly with each higher RSLC scenario because wetland losses due to hydrologic modifications related to the location of the levee alignment increase with RSLC. For example, it was assumed that some swamp would convert to brackish marsh under intermediate and high RSLR because of changes to the salinity regime and higher water elevations. Likewise, some marsh areas would switch from intermediate to brackish or brackish to saline due to the changing salinity regime. At other locations, former uplands were assumed to convert to marsh as tides pushed into new areas due to intermediate and high RSLR.

Table 5-14: Direct and Indirect Wetland Impacts of Orange 1, 2, and 3 Alternatives (All RSLC Scenarios)

DIRECT IMPACTS																		
	Orange 1 (All Height Alternatives)						Orange 2 (All Height Alternatives)						Orange 3 (All Height Alternatives)					
	Low RSLR		Intmd RSLR		High RSLR		Low RSLR		Intmd RSLR		High RSLR		Low RSLR		Intmd RSLR		High RSLR	
Wetland Type	Acres	AAHU	Acres	AAHU	Acres	AAHU	Acres	AAHU	Acres	AAHU	Acres	AAHU	Acres	AAHU	Acres	AAHU	Acres	AAHU
Forested Wetlands																		
Swamp	18.9	-7.7	18.9	-7.7	18.9	-7.7	0.7	-0.4	0.7	-0.4	0.7	-0.4	18.0	-10.6	18.0	-10.6	18.0	-10.6
Bottomland Hardwood	13.4	-5.7	13.4	-5.7	13.4	-5.7	18.0	-10.1	18.0	-10.1	18.0	-10.1	94.1	-57.3	94.1	-57.3	94.1	-57.3
Subtotal	32.3	-13.4	32.3	-13.4	32.3	-13.4	18.7	-10.5	18.7	-10.5	18.7	-10.5	112.1	-67.9	112.1	-67.9	112.1	-67.9
Coastal Marsh																		
Fresh Marsh	25.0	-14.7	25.0	-14.7	25.0	-14.7	6.0	-3.4	6.0	-3.4	6.0	-3.4	34.4	-18.8	34.4	-18.8	34.4	-18.8
Intermediate Marsh													10.9	-6.2	10.9	-6.2	10.9	-6.2
Brackish Marsh													101.1	-48.8	101.1	-48.8	101.1	-48.8
Subtotal	25.0	-14.7	25.0	-14.7	25.0	-14.7	6.0	-3.4	6.0	-3.4	6.0	-3.4	146.4	-73.8	146.4	-73.8	146.4	-73.8
Total Direct Impacts*	**57.3**	**-28.1**	**57.3**	**-28.1**	**57.3**	**-28.1**	**24.7**	**-13.9**	**24.7**	**-13.9**	**24.7**	**-13.9**	**258.5**	**-141.7**	**258.5**	**-141.7**	**258.5**	**-141.7**

INDIRECT IMPACTS																		
Forested Wetlands																		
Swamp	4.4	-0.8	4.4	-0.8	4.4	-0.8							1.9	-0.8	0	-0.1	0.0	-0.1
Bottomland Hardwood	0.7	-0.3	0.7	-0.3	0.7	-0.3							12.7	-5.1	12.7	-5.1	12.7	-5.1
Subtotal	5.1	-1.1	5.1	-1.1	5.1	-1.1							14.6	-5.9	12.7	-5.2	12.7	-5.2
Coastal Marsh																		
Fresh Marsh	1.4	-0.7	1.4	-0.7	1.4	-0.7							785.2	-18.8	785.2	-18.8	785.2	-18.8
Intermediate Marsh													342.1	-14.2	322.5	-12.6	322.5	-13.8
Brackish Marsh													1075	-50.4	1130.4	-63.4	1092.6	-60.7
Saline Marsh																	49.7	-9.7
Subtotal	1.4	-0.7	1.4	-0.7	1.4	-0.7							2202.2	-83.4	2238.1	-94.8	2250.0	-103.0
Total Indirect Impacts*	**6.5**	**-1.8**	**6.5**	**-1.8**	**6.5**	**-1.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2216.8**	**-89.3**	**2250.8**	**-100.0**	**2262.7**	**-108.2**

TOTAL IMPACTS BY REACH																		
Total Forested Wetlands	37.4	-14.5	37.4	-14.5	37.4	-14.5	18.7	-10.5	18.7	-10.5	18.7	-10.5	126.7	-73.8	124.8	-73.1	124.8	-73.1
Total Coastal Marsh	26.4	-15.4	26.4	-15.4	26.4	-15.4	6.0	-3.4	6.0	-3.4	6.0	-3.4	2348.6	-157.2	2384.5	-168.6	2396.4	-176.8
Total Impacts by Reach*	**63.8**	**-29.9**	**63.8**	**-29.9**	**63.8**	**-29.9**	**24.7**	**-13.9**	**24.7**	**-13.9**	**24.7**	**-13.9**	**2475.3**	**-231.0**	**2509.3**	**-241.7**	**2521.2**	**-249.9**

* Totals may not add exactly due to rounding.

The great majority of Orange 3 acreage impacts are due to indirect functional impacts related to reductions in fisheries access in the Adams and Cow Bayou floodplains. Under low RSLC, a total of 2,475.3 acres would be impacted, resulting in the loss of -236.0 AAHUs; under intermediate RSLC, 2,509.3 acres would be impacted, resulting in the loss of -241.7 AAHUs; and under high RSLC, 2,521.2 acres would be impacted, resulting in the loss of -249.9 AAHUs. Of these totals, functional impacts would affect roughly 2,137 acres and result in the loss of about -50.5 AAHUs for all RSLC scenarios.

The Orange-Jefferson CSRM Alternatives would result in the loss of EFH. Impacts on estuarine emergent marsh by Orange 1, 2, and 3, Jefferson Main, and Beaumont A and C are shown in Tables 5-2 and 5-3 above. Orange 1, 2, and 3 direct impacts would result in the loss of about 25.0, 6.0, and 146.4 acres of estuarine emergent marsh, respectively. Jefferson Main and Beaumont A and C would impact 23.7, 3.2, and 1.0 acre, respectively. Beaumont B would result in no EFH impacts. Orange 3 would also result in the loss of approximately 11 acres of estuarine soft bottom EFH.

This is the area estimated for the footings of the Adams and Cow Bayou surge gate structures. The structures themselves would provide artificial hard bottom habitat in the same area, increasing the diversity of EFH bottom types in the area. The net long-term loss of EFH bottom habitat from the Cow and Adams gate structures would therefore be negligible. Functional impacts on about 2,137 acres of estuarine emergent marsh along Adams and Cow Bayous in Orange 3 would result in the loss of about 50.5 AAHUs.

The potential HTRW impacts for all alternatives in the Orange-Jefferson CSRM project area have been determined to be low, as no unresolved current or recent hazardous materials releases were identified within 0.25 mile of the alternative alignments by the HTRW Assessment presented in Appendix N. Numerous facilities that produce or store hazardous materials were identified adjacent to Orange 3, Jefferson Main, and Beaumont A, B and C; none were identified adjacent to the Orange 1 and 2 reaches. Therefore, risks that currently unidentified HTRW sites may be impacted are higher for all height alternatives of the Orange 3, Jefferson Main, and Beaumont reaches than they are for Orange 1 and 2.

No other significant environmental impacts have been identified for the any of the Orange-Jefferson CSRM project area alternatives. Air emissions modeling (presented in Appendix I) was developed for a conservatively high estimate of construction equipment needs and durations. The modeling determined that total emissions for construction of all reaches would be below *de minimis* thresholds; and thus, construction would have no significant impacts on ambient air quality in the area. Emissions would be proportionately higher for each height alternative, assuming that the time needed to construct levee segments would be proportionately longer as the height increases. Impacts on prime farmlands were roughly similar across all reaches and would be differ proportionately by the height of each alternative. No ESA impacts have been identified for any of the project area reaches. Water and sediment quality impacts would be similar for all reaches/height alternatives with the exception of Orange 3. Fill material needed to construct earthen levees would be obtained commercially for all reaches and tested as needed to ensure suitability for use. Temporary sediment load and turbidity impacts would be minimized using best management practices (BMPs) as the levees are constructed. Orange 3 would have additional temporary turbidity and bottom sediment impacts during construction of the Adams and Cow Bayou surge gates. The potential for temporary noise impacts on sensitive receptors is greatest in Orange 3 since it passes through several communities; Orange 1 would create temporary noise impacts for the Rose City area; few sensitive receptors are located adjacent to the Orange 2 right-of-way. The potential for historic properties impacts on historic structures or cemeteries is greatest for Orange 3, since it passes through residential and business centers in the city of Orange and Bridge City; potential for impacts on prehistoric archeological sites may be higher in Orange 1 and 2, since much of those alignments remain undeveloped. Potential for historic properties impacts

in all of the Jefferson County reaches is low because of the extensive industrial and residential development in the vicinity of those alignments.

5.4.6.3 Port Arthur and Vicinity CSRM Project Area

No direct or indirect impacts on wetlands would be expected with construction of any of the alternatives, as construction activities would be generally be undertaken within the existing Port Arthur HFPP right-of-way. Additional temporary and permanent rights-of-way would be needed for construction of modifications in the Taylor Bayou Turning Basin area; all of this additional area is previously disturbed by industrial development. Staging areas would be situated to avoid impacts on wetlands or other significant environmental resources; numerous suitable areas are available. The TSP 1-foot raise alternative for the four alternatives would require the raising of about 4.5 miles of levee, construction of about 2.8 miles of scour pads, the replacement of one vehicle closure structure and the reinforcement of the I-Walls near Valero and near the Tank Farm. Raising levees and floodwalls by 2 feet over all of the four alternative project areas, rather than 1 foot as described for the TSP, would require the raising of approximately 18 miles of levee, construction of about 1.5 miles of scour pads, replacement of about 3.8 miles of I-Walls, construction of about 0.25 mile of new floodwalls at pump stations, replacement of drainage structures, reconstruction of about 13 vehicle closure structures, elevation of about 1.5 miles of highways, and the rebuilding of four pump stations at higher elevations. While this is significantly more construction than that required for the 1-foot raise, most construction activity would be confined to the existing right-of-way; areas where additional right-of-way would be needed are previously disturbed. Additional staging areas would be situated to avoid environmental impacts.

No other significant environmental impacts have been identified for the any of the Port Arthur and Vicinity CSRM project area alternatives. Air emissions modeling (presented in Appendix I) was developed for a conservatively high estimate of construction equipment needs and durations, including the 2-foot raise described above. The modeling determined that total emissions for construction of all reaches would be below *de minimis* thresholds; and thus, construction would have no significant impacts on ambient air quality in the area. Emissions would be proportionately higher for each height alternative, assuming that the time needed to construct levee segments would be proportionately longer as the height increases. No ESA or prime farmland impacts were identified. Water and sediment quality impacts would be similar for all reaches/height alternatives. Fill material needed to construct earthen levees would be obtained commercially for all reaches and tested as needed to ensure suitability for use. Temporary sediment load and turbidity impacts would be minimized using BMPs as the levees are constructed. The potential for historic properties impacts on historic structures or cemeteries is greatest for the I-Wall Raise near Tank Farm (all height alternatives) because it passes adjacent to 43 residential structures in Port Arthur. There is a potential for temporary noise impacts on residents in the homes near the same reach.

Potential historic properties and temporary noise impacts would be greater for the 2-foot raise because much longer reaches of the levee/floodwall system, passing adjacent to about 180 residential structures, would be reconstructed.

The greatest potential impact is associated with the HTRW sites located in the vicinity of the I-Wall Raise Near Tank Farm, I-Wall Raise Near Valero, and 8-10 ft I-Wall Raise Alternatives. While no unresolved current or recent hazardous materials releases were identified within 0.25 mile of these reaches alignments (see Appendix N), industrial facilities that produce or store hazardous materials were identified adjacent to these reaches. Therefore, risks that currently unidentified HTRW sites may be impacted are higher for all height alternatives of the three reaches listed above.

5.4.6.4 Freeport and Vicinity CSRM Project Area

The TSP 1-foot raise for all of the alternative project areas would require the raising of about 6 miles of levee, reinforcement of about 2.75 miles of existing levee and 0.6 mile of floodwall, replacement of 700 LF of I-Wall, construction of about 0.75 mile of scour pads, and construction of the new surge gate on the DOW barge canal. A 2-foot raise for all of the alternative project areas would require the raising of about 11.2 miles of levee, reinforcement of about 0.6 mile of floodwall, replacement of 1.5 miles of floodwall, construction of 0.2 mile of new floodwalls, construction of the new surge gate on the DOW barge canal, reconstruction of the Tide Gate, construction of a new pump station, and the replacement of numerous gravity drains. No direct or indirect impacts on wetlands would be expected with construction of any of the alternatives, as construction activities would be generally be undertaken within the existing Freeport HFPP right-of-way. However, some additional temporary and permanent rights-of-way would be needed for construction of all alternative heights in the Oyster Creek Levee Raise, Tide Gate I-Wall Raise, Old River North at DOW Thumb Levee Raise, and Freeport Dock Floodwall Raise reaches. All but one of these reaches are previously disturbed by industrial development. The approximately 3-mile-long Oyster Creek Levee Raise may require a minor amount of additional right-of-way, estimated at this time to be about 10 feet wide. The area that would be disturbed is upland scrub-shrub and forest; no wetlands would be impacted. The DOW Barge Canal Gate Structure would be constructed within the existing project right-of-way and in areas already impacted by previous construction. No significant water quality or benthic impacts are anticipated with installation of a gate in this artificial canal. Staging areas would be situated to avoid impacts on wetlands or other significant environmental resources; numerous suitable areas are available.

No other significant environmental impacts have been identified for the any of the Freeport and Vicinity CSRM alternatives. Air emissions modeling (presented in Appendix I) was developed for a conservatively high estimate of construction equipment needs and durations, including the 2-

foot raise described above. The modeling determined that total emissions for construction of all reaches would be below *de minimis* thresholds; and thus, construction would have no significant impacts on ambient air quality in the area. A consistency determination would not be required. Emissions would be proportionately higher for each height alternative, assuming that the time needed to construct levee segments would be proportionately longer as the height increases. No ESA or prime farmland impacts were identified. Water and sediment quality impacts would be similar for all reaches/height alternatives. Fill material needed to construct earthen levees would be obtained commercially for all reaches and tested as needed to ensure suitability for use. Temporary sediment load and turbidity impacts would be minimized using BMPs as the levees are constructed. There is little potential for historic properties impacts for most of the reaches; however, three archeological sites near the Oyster Creek Levee Raise would need to be avoided by project construction. Construction of any of the height alternatives of the Tide Gate I-Wall Raise and the Oyster Creek Levee Raise would result in temporary noise impacts on approximately five residences each; the East Storm Levee Raise would result in temporary noise impacts on approximately 13 residences. The remainder of the reaches pass adjacent to industrialized areas where historic property and noise impacts are not likely.

The greatest potential impact is associated with the HTRW sites located in the vicinity of the Old River North at DOW Thumb, the Freeport Dock Floodwall Raise, and the Tide Gate I-Wall Raise Alternatives. While no unresolved current or recent hazardous materials releases were identified within 0.25 mile of these reaches alignments (see Appendix N), industrial facilities that produce or store hazardous materials were identified adjacent to these reaches. Therefore, risks that currently unidentified HTRW sites may be impacted are higher for all height alternatives of the three reaches listed above.

5.4.6.5 Environmentally Preferable Alternatives

The TSP for the Orange-Jefferson, Port Arthur and Vicinity, and Freeport and Vicinity CSRM Plans is the environmentally preferable alternative. Because it is generally the lowest height of all action alternatives that were evaluated, it would result in the narrowest footprint and the fewest environmental impacts, while reasonably maximizing coastal storm risk reduction to the affected communities. The No Action Alternative would provide no coastal storm risk reduction to the vulnerable populations and infrastructure of the study area.

5.4.6.6 Comparison of Socioeconomic Impacts of Final Array Alternatives

The Orange-Jefferson CSRM would impact roughly 31 acres of land currently classified as residential and 36 acres of commercial and industrial land in Orange County. In Jefferson County, about 3 acres of residentially zoned land would be impacted, but approximately 100 acres of

commercial and industrial land would be impacted, as well as 63 acres of vacant land. Up to approximately 100 structures in Orange and Jefferson Counties, including private residences, could be impacted by the construction of the Orange-Jefferson CSRM Plan. Efforts will be made during final feasibility planning to reduce impacts on existing structures. The proposed Orange-Jefferson CSRM would provide risk reduction to a number of residential and commercial properties in the two counties. Improvements to the Freeport CSRM would further protect a large portion of Port Freeport where, as noted, a number of petrochemical facilities exist, as well as the importation of commodities such as crude, paper goods, and liquid natural gas. Freeport is also the location of a Strategic Petroleum Reserve site. Enhancements at the Port Arthur and Vicinity CSRM would provide additional risk reduction to key refineries in the area, including faculties operated by Valero, Premcor, Total, and Motiva Enterprises. The proposed TSP would also have beneficial impacts on a diverse population in the three counties. Jefferson, the more racially diverse of the three counties, has a population that is over 50 percent non-white according to the most recent Census Bureau data. Brazoria also has a substantial minority population, while Orange County is less diverse.

5.5 CHANGES TO TSP AND SELECTION OF THE RECOMMENDED PLAN SUMMARY

As described in the DIFR-EIS the alternatives in each project area were evaluated in detail, then compared against each other to identify which plan contributes most to the objectives. This process continued throughout the detailed feasibility analysis. As described in section 5.4.5., after the release of the DIFR-EIS, and after policy, public, ATR, and IEPR reviews a Senior Leader Panel Agency Decision Milestone (ADM) was held to confirm the TSP and initiate detailed feasibility-level design. At the time of the DIFR-EIS, the TSP selection followed ER-1105-2-100 which states that "Where two cost-effective plans produce no significantly different levels of net benefits, the less costly plan is to be the NED plan, even though the level of outputs may be less" (Appendix G, pp. G-7 to G-8). Based on this guidance, the 11-foot raise at Orange 3 was included in the TSP final recommendations under the DIFR-EIS. At the Agency Decision Milestone (ADM) the USACE reviewed additional considerations, such as qualitative risk assessment described in section 5.4.5 when making its final recommendations. Table 5-15 presents an overview of the TSP and changes from the DIFR-EIS with considerations included. During technical reviews and based on new information from the feasibility level design phase of the study, additional work and other assessments were completed for several of the features presented in the DIFR-EIS as the TSP. Additional details on features such as, required pump stations, required road crossings and required OMRR&R increased the overall construction and OMRR&R cost for all plans. Changes to the TSP subsequent to public review of the draft report were not significant enough to require a second

NEPA review. The sections below explain the changes that have occurred since the release of the DIFR-EIS.

Table 5-15: Overview of changes since release of DIFR-EIS

Project Area	Elements presented in Sept 11, 2015 DIFR-EIS	Elements in Final Recommendation
Orange-Jefferson CSRM	Orange 3 New Levee (11-foot)	**Included in Final Recommended Plan**
	Beaumont A New Levee (12-foot)	Removed due to limited net benefits, and recently constructed risk reduction improvements.
	Jefferson Main New Levee (11-foot)	Removed due to limited net benefits
Port Arthur and Vicinity CSRM	8-10 ft I-Wall Raise (1-foot)	**Included in Final Recommended Plan**
	Closure Structure Raise (1-foot)	**Included in Final Recommended Plan**
	I-Wall Raise Near Valero (1-foot)	**Included in Final Recommended Plan**
	I-Wall Raise Near Tank Farm (1-foot)	**Included in Final Recommended Plan**
	-------	**Final Recommended Plan included an additional 1,830 LF of new levee added to Existing Port Arthur and Vicinity HFPP to address flanking of surges**
Freeport and Vicinity CSRM	Dow Barge Canal Gate Structure	**Included in Final Recommended Plan**
	Oyster Creek Levee Raise (1-foot)	**Included in Final Recommended Plan**
	East Storm Levee Raise (1-foot)	**Included in Final Recommended Plan**
	Freeport Dock Floodwall Raise (1-foot)	**Included in Final Recommended Plan**
	Old River Levee Raise at Dow Thumb (1-foot)	**Included in Final Recommended Plan**
	Tide Gate I-Wall Raise (1-foot)	**Included in Final Recommended Plan**
Brazoria and Sabine Nonstructural	-------	Buyouts were considered ancillary to the implementation of new levees/floodwalls in Orange and Jefferson Counties and to the enhancement of features in the Port Arthur and Freeport CSRM project areas. Buyout opportunities in Brazoria were virtually non-existent and very limited in both Orange and Jefferson Counties. A quantitative analysis was conducted to determine the viability of any proposed nonstructural buyout. The analysis showed the nonstructural buyouts had negative net benefits and any potential buyouts were screened from the analysis.

5.5.1 Removal of Beaumont A New Levee (12-foot) and Jefferson Main New Levee (11-foot) from Recommended Plan

After the ADM, the Beaumont A New Levee (12-foot) and Jefferson Main New Levee (11-foot) were removed from consideration under the Recommended Plan. Beaumont A New Levee (12-foot was removed due to recent local industrial actions to reduce the area's risk from storm surges. In the last few years the local industries have developed a levee and floodwall system at the same location as the TSP. The structural integrity of the existing system is not fully known; however, an assessment of the systems height appears to place it above the heights considered in the Recommended Plan. Additional detailed economic evaluation of Beaumont A was not performed following the ADM; however, it was estimated that the current residual economic damages and life-safety risk are now limited. Risk from storm surge flooding is mainly concentrated to the industrial areas which is now being mitigated for with the newly constructed system. Based on the considerations above the Beaumont A New Levee (12-foot) was removed from the final Recommended Plan.

The Jefferson Main New Levee was removed from the final Recommended Plan based on a lack of local sponsorship and due to the limited perceived benefits. During the concurrent review period, local entities suggested that the economic performance of Jefferson Main should be reevaluated because there was not a perceived need for this component of the TSP. There was limited life-safety risk due to the industrial makeup of the area. Based on results of these evaluation, the sponsor decided to not to pursue this component of the final Recommended Plan.

5.5.2 Reevaluation of Orange 3 as a component of the Recommended NED Plan

Due to the increases in construction cost and OMRR&R there were concerns on whether Orange 3 required a reevaluation against other alternatives to confirm it was still the NED component of the plan. The selected plan does obtain positive net benefits, but during final technical reviews there were questions on whether other measures or alignments such as the Gate and No-Gate Alternatives discussed in section 5.3.2 would have achieved higher net benefits if carried forward through feasibility design. The sections below explains why the Orange 3 plan is still the plan that reasonably maximizes net benefits.

5.5.2.1 Revaluation of Orange 3 vs Gate

At the time of the DIFR-EIS the cost of the Gate Alternative was approximately $865 million more expensive than the No-Gate Alternative. Although there were significant cost increases from the TSP to the Recommended Plan the estimated first cost differences presented under the DIFR-EIS would not have changed plan selection by making the "gate" alternative a cheaper alternative. Cost

increases would have also been applied to the gate alternative. The "gate" alternative includes additional factors, shown in table 5-16, limited its viability.

Table 5-16: Planning Review of "gate" alternative

Areas of Focus	Planning Evaluation
Cost	West of Bridge City the final Recommendation included 33,700 LF of levees and 9,500 LF of floodwalls (43,200 LF Total) and although the "gate" is approximately half that length, the cost per linear foot for a floodwall crossing a river system is significantly higher vs a levee system built near upland areas due to soil stability in the area.
	The two largest pump stations, Adams and Cow Bayous, would still be included in the Orange 3 system with or without the gate option. The overall structure cost account will just increase with another structure across the Neches River.
	A gate across the Neches River would significantly increase the annual OMRR&R.
Benefits	There would be limited benefits to be gained on the east and west side of the Neches River above the point of the gate closure. The current residual economic damages and life-safety risk are now limited. Risk from storm surge flooding is mainly concentrated to the industrial areas which is now being mitigated for with the newly constructed system.
Environmental Impacts	The floodwall and gate crossing the Neches River would impact additional wetlands. Also, there would be concerns with indirect impacts. None of these cost were included in the original evaluation.

5.5.2.2 Reevaluation of Orange 3 vs Ring Levees or Nonstructural Measures

Additional details on features such as, required pump stations, required road crossings and required OMRR&R increased the overall construction and OMRR&R cost for the Recommended Plan. One of the largest cost changes for Orange 3 was the addition of the two largest pump stations in the system at Adams and Cow Bayou. Due to the large increases in cost with these features additional investigation into the viability of removing these features was conducted. Based on the FWOP conditions it was determined that the only two viable alternatives investigating were smaller ring levee systems avoiding the gates and pump stations on Adams and Cow Bayou or complete acquisitions of structures at risk.

Nonstructural Measures, such as acquisitions of structures to achieve the same level of benefits as the Recommended Plan were deemed to be infeasible and would be detrimental to community cohesion in the area. Over 9,000 residential and nonresidential structures are in the 100 yr floodplain and would have to be relocated out of the floodplain if a relocation plan was selected. Relocating outside of the floodplain would also have NED tradeoffs. Although NED damages would be avoided, residents and local municipalities would occur increased NED cost, since many of the vital commercial activities would still take place within the floodplain. Many of the residents in the area depend on the local waterways for commerce. There would be added travel times to reach these commerce centers adding to increased NED cost. Also there are limited opportunities for mixed nonstructural and structural plans, such as raising structures and providing ring levees, due to the fact that there are limited damages to the residential structures associated with the Orange 3 project area. Only 15% of the total without equivalent annual damages are to residential structures. 65% of the damages in Orange 3 are to the industrial damage category, which are not conducive nonstructural measures. In addition there were also OSE concerns with leaving local communities exposed while trying to only address industrial damages. Developing risk reduction systems (i.e. levees and floodwalls) for only the industrial areas could potentially induce stages in the local communities. Even if nonstructural improvements were included (i.e. Flood proofing and Raising), the area would still face detrimental flooding depths, limiting their ability to recover post storm events.

A review of measures using ring levees enclosing the same benefit areas as Orange 3 was also conducted to determine if there would be cost saving by removing the high cost features along Adams and Cow Bayou. The evaluation determined that due to the extent of the flooding and very flat nature of the flood plain, ring levees would not have been a viable alternative. Although the plan would have removed two of the large pump stations, smaller ring levees would have required additional cost, further reducing the economic viability of this option. As shown on Table 5-17 smaller ring levee would have add 29 extra miles of levees and floodways to obtain the same level of risk reduction as with the Adams and Cow Bayou closures. There would also be added cost with approximately 30 extra drainage, railroad and roadway crossings. Environmental impacts, as also shown in table 5-17, would have limited this alternatives viability.

Table 5-17 Evaluation of Orange Ring Levees

Review Parameter	Options Reviewed			vs	Recommendation: Orange 3	Comments
	System of Ring Levees					
Cost	Ring 1 (Bridge City)	14.58 miles	Total of 55.6 Miles		Total of 27 miles	Requires ~29 extra miles of levees and floodwalls with system of ring levees option. Plan removes Adams and Cow Bayou Gate structures and pump stations, but the addition of ~29 miles of levee/floodwall, would increase the overall cost of plan when compared to the recommended plan. There could be adjacent impacts (induced flooding) to areas previously behind levee
	Ring 2 (Industrial Area)	16.32 miles				
	Ring 3 (City of Orange)	24.7 miles				
	12 Additional New Significant Roadway/Railroad Crossing				32 Closure Gates (Road/Railroad Crossings)	Most of the 32 closure gates exist near the City of Orange which wouldn't be removed with smaller ring levees. Ring Levee would cross major highways; and evacuation routes that were avoided under the single levee plan.
Environmental	Ring 1 (Bridge City)	~ 3 miles of habitat along Cow Bayou	~ 6.5 miles of habitat		Currently impacts are to less than 2 miles when crossing Cow and Adams Bayou.	A switch to ring levees would have significant impacts to the Adams and Cow Bayou habitat. The system would require significant environmental control features for the ring levees. This would also add to the overall cost.
	Ring 2 (Industrial Area)	~1 mile of habitat along Cow Bayou ~1.5 miles of habitat along Adams Bayou				
	Ring 3 (City of Orange)	~.1 miles of habitat along Adams Bayou				
Life Safety Risk	Increased Life Safety Risk to residents inside of the small ring levees. There would be minimum time to react to exceedance events due to the limited storage capacity. Also all evacuations routes would likely be flooded.	Increased Life Safety Risk to residents outside of the ring levee system. There could be induced stages outside of the ring levees and changes in historical flood patterns could catch resident off guard.			Under exceedance events the surge overtopping the system would be allowed to expand over the flat coastal flood plain. Under the current plan there are limited structures outside of the proposed levee system, reducing the risk of induced stages and life safety risk.	Smaller ring levees would go against a key Constraint: Structural plans do not increase life-safety risk.

All of these features would have doubled the size of the system that would have to be operated under storm event (Figure 5-6), making it an unreasonable alternative when compared to the Recommended Plan.

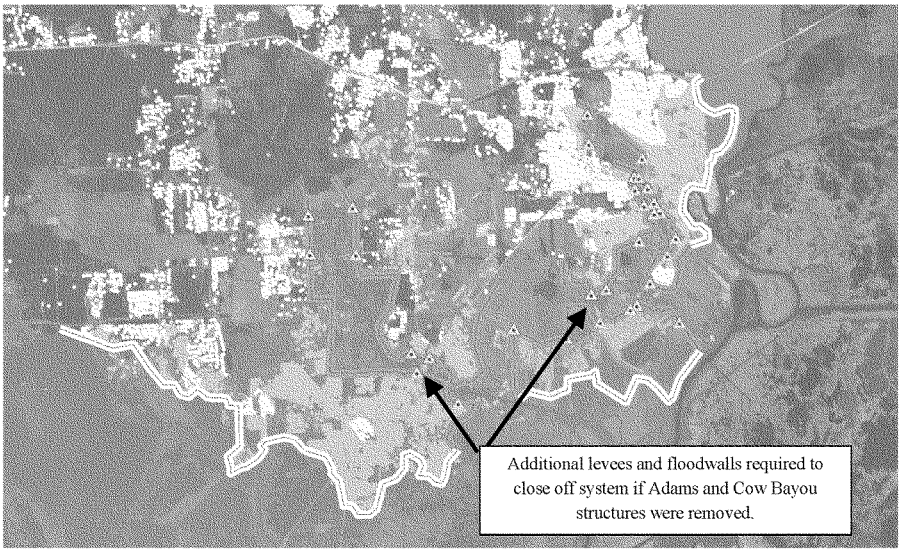


Figure 5-6: Ring Levee Review

5.5.3 Confirmation of Orange 3 as a component of the Recommended NED Plan

Based on the information presented in Section 5.5.2, Orange 3 still would have the lowest total cost (including mitigation), the highest BC ratio, and the highest net benefits. In conclusion, Orange 3 is still the plan that maximizes NED benefits while protecting the nation's environment, pursuant to national environmental statutes, applicable executive orders, and other Federal planning requirements.

6 RECOMMENDED PLAN

6.1 PLAN COMPONENTS

As discussed in Section 5, after the TSP was verified, the team developed feasibility-level designs for the Recommended Plan. Investigations included detailed cost estimates, benefits, impacts, and implementation requirements. Below is a summary project description of the Recommended Plan. The TSP phase had broken out certain sections of the Port Arthur and Freeport HFPP as requiring rehabilitation per failure modes from the SQRA. After the TSP, the team determined that this method of analyzing the levee system was not accounting for the levee functioning as a system. Therefore a system wide approach method was used in determining the Recommended Plan, by including all areas of the levee system in the analysis. This changed the naming configuration of the alternatives from specific areas of the levee system (i.e. Old River at Dow Thumb, Freeport Dock, I-Wall Raise Near Valero, I-Wall Raise Near Tank Farm, etc.) to a system wide approach according to levee height (NF, NF + 1, NF + 2) The components of the Recommended Plan are illustrated in Figures 6-1 through 6-3. Section 6.1.1 describes the Recommended Plan in detail; additional detail of the Recommended Plan description is provided in the Engineering Appendix. An economic summary of the Recommended Plan is provided in Tables 17, 18, and 19 of Appendix C, Economics.

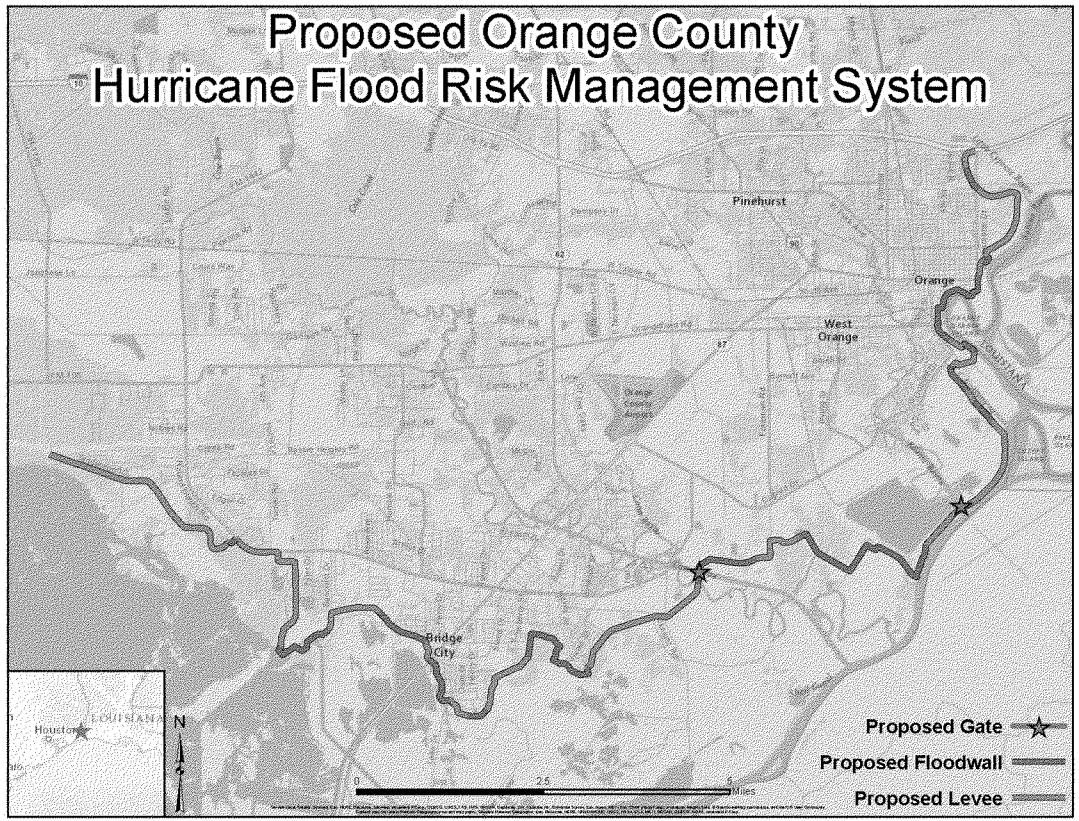


Figure 6-1: Orange-Jefferson CSRM Plan

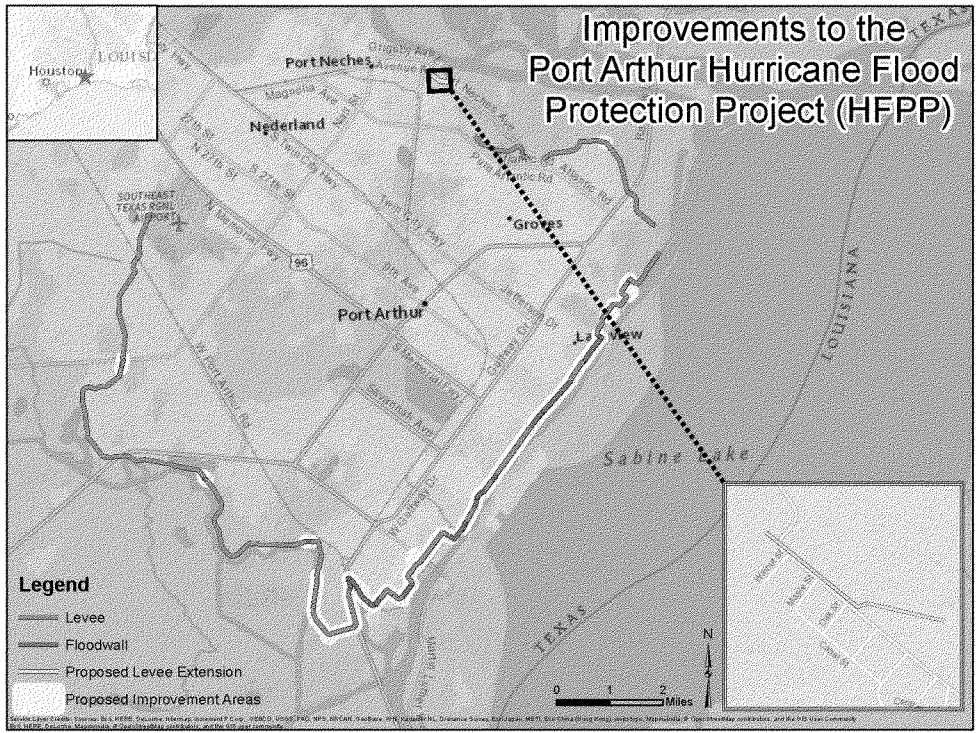


Figure 6-2: Port Arthur and Vicinity CSRM Plan

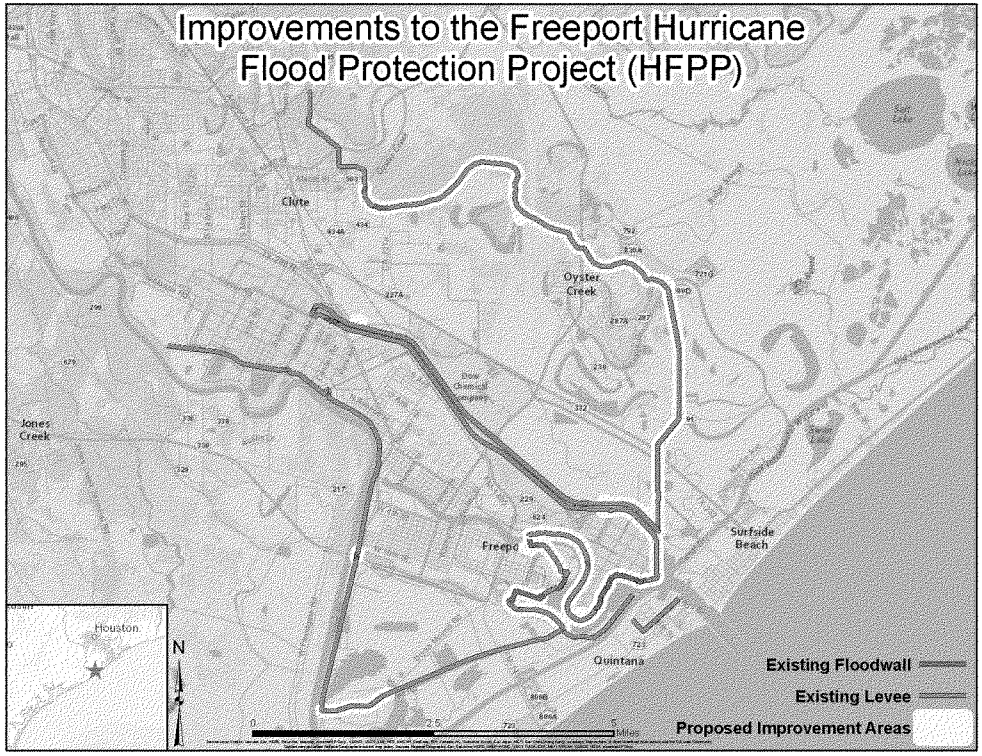


Figure 6-3: Freeport and Vicinity CSRM Plan

6.2 DESCRIPTION OF THE RECOMMENDED PLAN

6.2.1 Orange CSRM Project Area

Orange 3 New Levee (11-Foot)

The Orange 3 New Levee is a levee/floodwall flood risk reduction system that would serve to reduce the flood-damage potential from storm surge for much of the southern half of Orange County along the Sabine River and Bessie Heights Marsh. The Orange 3 system, consisting of earthen levee and floodwalls, begins at Interstate-10 at its northeast end, about 1.75 miles west of where the highway crosses the Sabine River. From there, the alignment roughly parallels the Sabine River to the south and then to the southwest to an industrial canal 1.65 miles northeast of the mouth of Cow Bayou. Along this reach, the alignment crosses Adams Bayou, which is used for navigation. There, the alignment turns sharply to the northwest, going up to a point near the south corner of the DuPont Sabine River Works plant. From this point, the alignment runs southwesterly to Bridge City, crossing Cow Bayou along the way, which is also used for navigation. The alignment then wraps around Bridge City to the south, turning northwesterly along the north side of the Bessie Heights Marsh to an end point less than a mile southwest of Farm to Market Road (FM) 1135, where it intersects FM 105 (Orangefield Road). Along this reach, the system will protect an electrical power-generating plant. In total, the length of the system will be approximately 26.7 miles. The system also assumes 10.75 miles of concrete floodwall would be need because the levee system alignment traverses several sensitive environmental habitat areas where impacts should be limited, places where the land area is insufficient for levee construction, or there are other real estate constraints. The borrow material for the levee and backfill of the floodwall is assumed to come from commercial sources.

The crossing of both Adams Bayou and Cow Bayou will require navigable gate structures incorporated into the levee alignment. The structures include a sector gate for navigation and adjacent vertical lift floodgates for allowing normal channel flow. The proposed alignment crosses several secondary roads, State Highway 87, Adams and Cow Bayous, an industrial canal, and a power plant intake canal. The features associated with the Orange 3 Reach are listed in Table 6-1. Please note that after the TSP was verified, the team developed feasibility-level designs for the Recommended Plan, the final features may vary slightly when compared from the DIFR-EIS.

Table 6-1: Orange 3 Reach – Features of Work

Feature of Work	Length (ft)
Floodwall	56,755
Levee	82,169
	Each
Pump Stations	7
Drainage Structures	56
Closure Gates (Road/Railroad Crossings)	32

Throughout the alignment water control structures and pump stations have been added to aid drainage when the system is both open and closed for storm events. The pump stations range in size from 131 to 8,190 CFS for their respective discharge capacities. Where feasible, initial smaller pump station locations were combined into larger and more efficient pump stations. Hydrologic connectivity would be maintained to the extent practicable through water control structures except during closure for hurricanes or tropical storms. When the system is closed, the pumps will operate. The risk reduction system is only authorized to address storm surge caused by hurricane and tropical storm events. It is not authorized to mitigate for or reduce impacts caused by higher day-to-day water levels brought about by increases in sea level rise. All drainage features through the levee system were sized to match the existing gravity drainage system, and would mimic the existing drainage patterns when the system is not closed. Any operational changes implemented to address changing sea level rise conditions or for any other non-project-related purpose would be considered a separate project purpose requiring separate authorization, new NEPA documentation, and/or permit approvals. In addition the NFS has an obligation relating to the operation of the project, specifically pump station capacities during storm events, to prevent encroachments that would impact the utility of the project when the pump station is operating. The NFS will be required to comply with flood plain management requirements and ensure that project features such as pump stations would not be impacted by developments in the areas behind the risk reduction system. The pump system designed to match the existing gravity drainage capacity when the system is closed. The NFS would have a responsibility to ensure that this operation of the project features is maintained.

The Orange 3 New Levee reduces the flood-damage potential from storm surge within the cities of Orange, West Orange, Pinehurst, Bridge City, and Orangefield. It also protects petrochemical plants and Entergy Texas Inc.'s Sabine (Power) Plant in Bridge City. The performed optimization efforts for the Orange 3 reach found the 11-foot still water elevation alternative to be the most

economically feasible and justifiable plan. This elevation was utilized to determine the appropriate levee and floodwall heights for the features of work listed in Table 6-1. The heights were raised by a design offset and calculated from a storm index point in order for the system to have a uniform annual chance exceedance throughout its length. The heights were then rounded up to 0.5 foot increments for quantity calculations and to more easily describe the system. The heights shown on Table 6-2 are the final feasibility Recommended Elevations for the Orange 3 CSRM. Please note that after the TSP was verified, the team developed feasibility-level designs for the Recommended Plan, the final heights may vary slightly when compared from the DIFR-EIS. The risk reduction system has been designed to provide a risk reduction against a 1% probability storm based on the 2080 intermediate RSLR forecast condition within current data and modeling capabilities. The current design elevations varies across the system and utilizes the 2080 intermediate RSLR forecast condition to obtain a 1% level of risk reduction throughout the length of the system. The system should be monitored on a frequent basis to determine if there have been any changes from the initial level of risk reduction stated.

Table 6-2: Orange 3 Levee and Floodwall Elevations Recommended Elevations (NAVD88)

Geo Point ID	Levee	Floodwall
A	14.00	14.00
B	12.00	14.50
C	15.50	16.00
D	14.00	13.00
E	14.00	N/A
F	15.50	15.00
G	N/A	13.50
H	17.50	15.50
N	16.50	14.00

6.2.2 Port Arthur and Vicinity CSRM Project Area

The Port Arthur and Vicinity CSRM Project involves construction of floodwalls, raising of levees and replacement of vehicular closure structures. Several sections of floodwall and levee require raising due to a necessary increase in system capacity to further reduce the likelihood of failure of the system. The borrow material for the levee and backfill of the floodwall is assumed to come from commercial sources. For resiliency of the levee system, erosion protection is recommended to be installed around all concrete structures which are part this plan. The No-Fail + 1 alternative was chosen as the most economically justifiable and feasible plan. The Recommended Plan is described in further detail under each of the reaches for the project in Table 1-1 of the Engineering Appendix. The values presented in Table 6-3 are the features of work for each reach. Please note that after the TSP was verified, the team developed feasibility-level designs for the Recommended

Plan, the final features may vary slightly when compared from the DIFR-EIS.

Table 6-3: Port Arthur and Vicinity CSRM Project Area - Features of Work

Reach	Floodwall (ft)	Levee (ft)	Closure Gates (Road/Railroad Crossings)
1	690	0	3
2	10,940	9,000	0
3	7,030	8,250	10
4	9,790	8,950	12
5	1,640	3,000	1
Addition	0	1,830	0

Elevations utilized to determine the appropriate levee and floodwall heights for the features of work listed in Table 6-3, are show in Table 6-4. The heights were calculated from a storm index point in order for the system to have a uniform annual chance exceedance throughout its length. The heights were rounded up to 0.5 foot increments. The heights then had an additional 1-foot added, which is the Recommended Plan (No-Fail + 1). The existing levee elevation throughout the system was taken from recent surveys completed by the local sponsor. For purposes of this study, an average elevation was used for the lengths of levee or floodwall within each reach. The final recommended levee heights were then used against the existing surveyed elevations of the system to calculate the required raise of the existing levee and were rounded up to 0.5 foot increments. The same process was completed for the floodwall heights of the Recommended Plan. For the floodwall, if the calculated height was lower than the existing height for the same location, the existing height was used for the Recommended Plan. Additional details, such as plan views and detailed descriptions by levee reach can be found in the Engineering Appendix. Please note that after the TSP was verified, the team developed feasibility-level designs for the Recommended Plan, the final features or heights may vary slightly when compared from the DIFR-EIS. The risk reduction system has been designed to provide a risk reduction against a 1% probability storm based on the 2080 intermediate RSLR forecast condition within current data and modeling capabilities. The current design elevations varies across the system and utilizes the 2080 intermediate RSLR forecast condition to obtain a 1% level of risk reduction throughout the length of the system. The system should be monitored on a frequent basis to determine if there have been any changes from the initial level of risk reduction stated.

Table 6-4: Port Arthur Levee and Floodwall Recommended Elevations (NAVD88)

Geo Point ID	Levee	Floodwall
O	14.39	14.50
P	14.40	17.00
Q	14.93	
R	14.99	16.50

Geo Point ID	Levee	Floodwall
S	16.41	19.50
T		19.50
U	16.31	17.00
V	16.60	17.50
W	16.30	17.50
X	16.60	
Y	17.10	19.00
Z		18.00
Z1		19.50
Z2		19.50
Z3	17.20	
Z4	16.30	16.50
Z5	15.91	18.00
Z6	15.66	
Z7	15.21	15.50
Z8	14.70	16.00

6.2.3 Freeport and Vicinity CSRM Project Area

The Freeport and Vicinity CSRM Project involves construction of floodwalls, raising of levees, replacement of vehicular closure structures, and constructing a navigable gate structure in an active barge canal. Several sections of floodwall and levee require raising due to a necessary increase in system capacity to further reduce the likelihood of failure of the system. The borrow material for the levee and backfill of the floodwall is assumed to come from commercial sources. For resiliency of the levee system, erosion protection is recommended to be installed around all concrete structures which are part this plan. The No-Fail + 1 alternative was chosen as the most economically justifiable and feasible plan. The Recommended Plan is described in further detail under each of the reaches for the project in Table 1-1 of the Engineering Appendix. The values presented in Table 6-5 are the features of work for each reach. Please note that after the TSP was verified, the team developed feasibility-level designs for the Recommended Plan, the final features may vary slightly when compared from the DIFR-EIS.

Table 6-5: Freeport and Vicinity CSRM - Features of Work

Reach	Floodwall (ft)	Levee (ft)	Closure Gates (Road/Railroad Crossings)	Drainage Structures (EA)
Oyster Creek & Oyster Creek Extension	1,220	28,400	0	3
East Storm	320	17,370	0	0
DOW Barge Canal	3,190	9,150	2	1
Old River North	15,660	3,030	0	0

Reach	Floodwall (ft)	Levee (ft)	Closure Gates (Road/Railroad Crossings)	Drainage Structures (EA)
Tide Gate	530	0	0	0
Old River South	7,855	7,025	8	0
South Storm	0	4,400	0	0
East Bank Brazos River	430	0	0	0

Elevations utilized to determine the appropriate levee and floodwall heights for the features of work listed in Table 6-5, are show in Table 6-6. The heights were calculated from a storm index point in order for the system to have a uniform annual chance exceedance throughout its length. The heights were rounded up to 0.5 foot increments. The heights then had an additional 1-foot added, which is the Recommended Plan (No-Fail + 1). The existing levee elevation throughout the system was taken from recent surveys completed by the local sponsor. For purposes of this study, an average elevation was used for the lengths of levee or floodwall within each reach. The final recommended levee heights were then used against the existing surveyed elevations of the system to calculate the required raise of the existing levee and were rounded up to 0.5 foot increments for the quantity calculations. The same process was completed for the floodwall heights of the Recommended Plan. For the floodwall, if the calculated height was lower than the existing height for the same location, the existing height was used for the Recommended Plan. Additional details, such as plan views and detailed descriptions by levee reach can be found in the Engineering Appendix. Please note that after the TSP was verified, the team developed feasibility-level designs for the Recommended Plan, the final features or heights may vary slightly when compared from the DIFR-EIS. The risk reduction system has been designed to provide a risk reduction against a 1% probability storm based on the 2080 intermediate RSLR forecast condition within current data and modeling capabilities. The current design elevations varies across the system and utilizes the 2080 intermediate RSLR forecast condition to obtain a 1% level of risk reduction throughout the length of the system. The system should be monitored on a frequent basis to determine if there have been any changes from the initial level of risk reduction stated.

Table 6-6: Freeport and Vicinity CSRM Levee and Floodwall Recommended Elevations (NAVD88)

Geo Point ID	Levee	Floodwall
OC_1	20.31	
OC_2	20.40	
OC_3	20.00	
OC_4	20.15	
OC_5	20.00	
OC_6	16.30	16.50
OC_7	13.40	16.00
N_1	22.00	22.00
N_2	22.50	

Geo Point ID	Levee	Floodwall
N_3	23.50	
N_4	23.20	
N_5	23.00	
N_6	23.50	
N_7	23.16	
DBC_1	19.92	
DBC_2	19.27	
DBC_3	19.21	
DBC_4	19.18	
DBC_5	19.50	19.50
W_1	16.81	19.00
S_1	17.85	
S_2	17.40	
S_3	18.83	
S_4	17.86	
S_5	17.32	
PF_1	25.85	26.00
PF_2	19.76	20.00
PF_3W	20.62	
PF_3T	19.28	19.50
PF_4T	18.96	19.00
PF_4P	17.17	
US_1	18.89	
US_2	20.04	20.50
IH_1	19.00	19.00
LS_1	18.82	19.00

6.3 SEPARABLE ELEMENTS

A region wide systems approach for construction of Orange 3, Port Arthur and Freeport CSRM Plan is being recommended to ensure that all of the benefits stated would be achieved. However, Orange 3, Port Arthur, and Freeport CSRM Plans are able to function individually and are separable. The Economic Appendix presents the cost and benefits of each separable element. Construction and completion of a region wide risk reduction system would help to lessen the financial and social impacts that tropical storms and hurricanes can cause by reducing the risk of property damage that displaces residents, shuts down commercial and industrial services, and disrupts livelihoods. If structures avoid or have reduced damages because of a regional risk reduction system, families and businesses can rebound much more quickly after a tropical event. This is exemplified by increasing the opportunity to return residents to their homes and children to schools that have less or no damage from surge events. In addition, lost work days are reduced

for workers who support the local or regional economy by reducing hurricane storm surge damage to houses, businesses and other non-residential structures; by minimizing the debris from hurricane storm damaged structures that can affect other properties; and by generally improving the opportunity and time necessary for residents, businesses and government to return to normal function after an event. Concurrent construction of all three elements would help to ensure that the regional economy would continue to operate after a storm event and the stress and hardship associated with hurricane storms would be lessened. The study area supports national needs, logistics, and persona. For example, the nation relies on the uninterrupted supply of energy and material goods from the study area. Pronounced impacts from repetitive hurricane storm surge events, threatens the productivity and sustainability of these important national interests by reducing the continuity, functionality, and export of supplies, and commerce.

6.4 FISH AND WILDLIFE MITIGATION

6.4.1 Summary of Environmental Impacts

Environmental impacts on specific resources are described in Section 7. No significant environmental impacts have been identified for the Port Arthur and Freeport and Vicinities CSRM Plans. All environmental impacts identified for the Recommended Plan are associated with the Orange 3 CSRM Plan, and these are limited to wetland impacts (Table 6-7). Direct impacts, affecting approximately 160.2 acres, would result from construction of the new levee-floodwall system, and indirect impacts on about 2,249.5 acres would be associated with functional impacts to fisheries access and sediment, nutrient and organic matter exchange on the extensive marshes in the lower Cow and Adams Bayous floodplains and limited impacts from construction of the levee and surge gates in a few locations.

Table 6-7: Direct and Indirect Impacts (Intermediate RSLC)- Recommended Plan

Wetland Type	Direct Impacts		Indirect Impacts				Total Impacts (acres)	Total AAHUs Lost
	Direct Wetland Impacts (acres)	AAHUs	Indirect Wetland Impacts (acres)	AAHUs	Functional Impacts (affected acres)	AAHUs		
Forested Wetlands								
Swamp	10.6	-7.2	1.9	-0.1	0.0	0.0	12.5	-7.3
Bottomland Hardwood	44.3	-30.3	12.7	-5.1	0.0	0.0	57.0	-35.4
Subtotal	54.9	-37.4	14.6	-5.2	0.0	0.0	69.5	-42.7
Coastal Marsh								
Fresh Marsh	24.3	-11.4	0.0	0.0	785.2	-18.8	809.5	-30.2
Intermediate Marsh	6.8	-4.0	19.2	-8.5	322.5	-4.1	348.5	-16.6
Brackish Marsh	74.2	-33.7	78.5	-35.2	1029.5	-27.6	1182.2	-96.5
Subtotal	105.3	-49.0	97.7	-43.7	2137.2	-50.5	2340.2	-143.3
Total Impacts*	**160.2**	**-86.5**	**112.3**	**-48.9**	**2137.2**	**-50.5**	**2409.7**	**-186.0**
* Totals may not add exactly due to rounding.								

In total, approximately 69.5 acres of forested wetland and 2,409.7 acres of coastal marsh would be impacted. Mitigation would be needed to compensate for a loss of 42.7 AAHUs from forested wetlands and 143.3 AAHUs from emergent marsh. However, potential exists for impacts on buried hazardous and toxic materials during construction of improvements. Additional investigation would be required during PED to identify areas of concern and strategies for minimizing impacts.

A comprehensive list of assumptions underlying our analysis of the Recommended Plan's proposed direct and indirect effects on wetlands, fish and wildlife habitat, and EFH are provided below. If changes made to the project during the PED, Construction or Operations phases undermine these assumptions, consultation with resource agencies will be required and additional mitigation could be identified.

- Impact assessment is dependent upon the exact location of the levee system features; changes in the footprint of the levee system, or identification of new access routes/work areas/system features during the PED and Construction Phases could increase project impacts.
- Fill material for levee system construction is assumed to come from approved commercial borrow sources.

- Indirect EFH fisheries access impacts assumed that the proposed surge gates in Cow and Adams Bayous would constrict flow in the waterways by no more than 50 percent.
- Construction of culverts and the Cow and Adams Bayou surge gates would follow NMFS 2008 Fisheries Friendly Design and Operation Considerations for Hurricane Flood Protection Water Control Structures (provided by the Baton Rouge field office) to the greatest extent practicable.
- Construction of mitigation areas is assumed to start concurrently with new levee system construction.
- The Operation Plan for the new Orange system would require that culverts/gates remain open during normal operations, closing for no longer than two weeks at a time during surge and maintenance events.
- Coordination with resource agencies would continue through the PED, Construction and Operations Phases to ensure appropriate consideration of project changes, implementation of mitigation, and completion of the monitoring/adaptive management plan.

6.4.2 Mitigation Plan

In accordance with the mitigation framework established by Section 906 of the Water Resources Development Act (WRDA) of 1986 (33 USC 2283), as amended by Section 2036 of WRDA 2007 and Section 1040 of the Water Resources Reform and Development Act (WRRDA) of 2014, the Council on Environmental Quality (CEQ)'s National Environmental Policy Act (NEPA) regulations (40 CFR Sections 1502.14(f), 1502.16(h), and 1508.20), and Section C-3 of Engineer Regulation (ER) 1105-2-100, USACE will ensure that project-caused adverse impacts to ecological resources are avoided or minimized to the extent practicable, and that remaining, unavoidable impacts are compensated to the extent justified.

Mitigation would be needed to compensate for a loss of 42.7 AAHUs from forested wetlands and 143.3 AAHUs from coastal wetlands. Impacts were avoided and minimized to the greatest extent practicable in several iterations of planning the footprint of the proposed new levee system alignment. The levee system right-of-way was located as close to the upland-wetland margin as possible to minimize wetland impacts, while also minimizing social effects and maximizing economic benefits. Engineering design incorporated USFWS and NMFS conservation recommendations to avoid and minimize impacts. Remaining unavoidable impacts have been fully compensated with in-kind mitigation.

Mitigation banks with service areas including the project impact areas were investigated to determine if sufficient and appropriate mitigation credits were available. None have been identified that could be utilized for S2G mitigation. Only one approved bank (the Blue Elbow

Swamp) has a service area that includes S2G impact areas and affected wetland types. However, it is a single-client bank with credits reserved for the Texas Department of Transportation (TXDOT). Since mitigation banks are not available to compensate for all or even a portion of project impacts, areas in the floodplains of the Neches and Sabine Rivers within and adjacent to the study area were reviewed to identify potential in-kind mitigation sites.

A wide array of potential mitigation measures, described more fully in Appendix O, were evaluated to select the final array of mitigation alternatives. Selection of potential mitigation sites and modeling of benefits were conducted in coordination with Federal and state resource agencies. Mitigation measures that were initially considered included various types of hydrologic restoration (canal backfilling; removal of berms, oil field pads or roads that block tidal flows; improving drainage), marsh restoration, forested wetland restoration, and preservation in perpetuity. These measures are presented in an attachment to Appendix O, along with the screening decisions. Reasons for exclusion from the evaluation array varied but generally were based on small benefits relative to amount of compensation needed, lack of need for the restoration, incompatibility with existing land use, contamination concerns, or combination/incorporation with other mitigation measures.

Areas evaluated as potential mitigation areas excluded areas already identified for beneficial use or mitigation in conjunction with other projects. Specifically, authorized improvements to the SNWW navigation project include the restoration of large areas within both Bessie Heights and Old River Cove marshes with the beneficial use of dredged material. In addition, areas in the process of being restored by TPWD have also been excluded. Any mitigation sites selected for this project augment, and do not replace, these other proposals.

Three measures (marsh restoration, preservation, and forested wetland restoration) were used to build the seventeen mitigation alternatives that were advanced for screening in the evaluation array. WVA modeling was conducted to quantify benefits (AAHUs) of mitigation measures. Feasibility-level costs of selected mitigation measures were developed, and the IWR Planning Suite software was used to identify a best buy mitigation plan for each affected wetland type. This certified software conducts a cost effectiveness-incremental cost analysis and identifies Best Buy mitigation plans that fully compensate for all impacts. The analysis was structured to ensure that the Best Buy Plans would provide sufficient in-kind mitigation for each wetland type. To achieve this, separate planning sets were developed for swamp, BH, and each of the marsh types (fresh, intermediate and brackish).

Preliminary costs were developed to support mitigation plan selection. Costs include real estate, construction and monitoring/adaptive management costs. These costs were annualized using the

IWR-Plan Annualizer. Construction costs include construction of containment dikes, pumping dredged material into open water areas, dewatering, marsh plantings and containment dike removal.

The result of the incremental analysis is illustrated on Table 6-8. The IWR Planning Suite identified multiple best buy plans for each of the wetland types (8 each for Swamp and BH; 3 each for fresh, intermediate and brackish marsh). Column 3 "Best Buy Plan #" identifies the plan number from the Planning Suit's "Incremental Cost of Best Buy Plans" table. Plan 1 is always the No-Action Plan, with no cost and no output. For all wetland types, the Best Buy Plan with the lowest incremental cost (Plan 2) was selected for inclusion in the Mitigation Plan. The fourth column "Best Buy Plans" lists all of the wetland alternative codes in that planning set for the indicated Best Buy Plan, with a "0" following those that were not included in the Best Buy Plan, and a "1" after those codes which are included. The codes with the number "1" indicator are shown in bold. Each Plan 2 provided compensation greater than the target for that specific wetland type. When considered together, the Best Buy plans for all of the affected wetland types provide 262.9 AAHUs of compensation for a total mitigation target of -186.0 AAHUs.

Table 6-8. Mitigation Best Buy Plans

Wetland Type	Mitigation Target	Best Buy Plan #	Best Buy Plan(s)	Best Buy Alternatives	AAHUs	Average Annual Cost ($1,000)
Swamp	-7.3	2	**S111**S120S140S150H170H220H240	S11	13.2	$ 4.4
Bottomland Hardwood	-35.4	2	BH110BH120BH140BH150BH260**BH1611**	BH161, Scale 1	49.3	$ 2.5
Fresh Marsh	-30.2	2	F420**F521**	F52	33.4	$ 82.9
Intermediate Marsh	-16.6	2	**I311**I320I1430	I31	60.4	$ 243.1
Brackish Marsh	-96.5	3	B270**B281B291**	B28 and B29	100.4	$ 310.1
Totals	-186.0				262.9	$ 643.0
*S11 provides bottomland hardwood (BH) benefits of 6.2 AAHUs at no additional cost because BH are intermingled with swamp.						

While this combination of Best Buy plans is the most cost effective plan, it provides about 40 percent more compensation than is required. This excess is due to two factors. First, the mitigation plan is made up of six separate mitigation areas, which are needed to provide in-kind mitigation for five different habitat types. The mitigation for each habitat type needs to exceed the mitigation target for that type in order to fully compensate for each kind of loss. Most of the areas provide a small amount of excess benefits, but Area 31 provides an excess of 43.8 AAHUs or a little over half of the total excess benefits. This measure is the most cost effective plan because it utilizes natural features (uplands, islands and existing marsh) and existing levees to contain the hydraulically-pumped material that will be used for marsh restoration. Costs for constructing

containment levees and impacts to existing wetlands associated with containment construction are thus minimized with this configuration.

6.4.2.1 Description of the Mitigation Plan

A detailed description of the mitigation plan is presented in Appendix O. The description provided below is a brief summary of the information presented there. Appendix Q presents sensitivity analyses of the WVA marsh models using a sensitivity spreadsheet prepared by the ERDC Environmental Lab (USACE, 2013). These sensitivity analyses provide additional information to assist in the investigation of several unresolved issues related to the suitability graphs for Variables 1 and, 2, and the aggregation method used to combine the marsh habitat units and open water habitat units for each sub-model.

The mitigation plan for forested wetlands consists of preservation in perpetuity of approximately 447 acres of swamp and bottomland hardwoods (BH) in Mitigation Area 11 in the bottomlands of the Sabine River and about 112.5 acres of BH forest in Mitigation Area 161 on the upland/wetlands margin of the Neches River in the Bessie Heights area (Figures 6-4 and 6-5). These lands would be acquired during the construction phase by the NFS for project implementation. The NFS would manage the property and grant USACE right of entry for monitoring to verify preservation through the 50 year period of analysis.

"Preservation only" was evaluated as potential mitigation for forested wetlands because the extensive interagency evaluation of restoration measures found very limited opportunities for forested wetland restoration in the study area. The selected forested wetland Best Buy plans are the best performing measures under the CE/ICA analysis and provide a high ratio of preservation. Hydrologic restoration of three swamp areas in the Blue Elbow/Tony Houseman WMA were evaluated, and one Chinese tallow control measure was evaluated for bottomland hardwood. The CE/ICA analysis determined that these forested wetland restoration plans were the lowest ranking of all plans, with significantly higher incremental costs per output than the restoration only plans. In addition, the hydrologic swamp restoration measures may not be implementable because TxDOT approval is required to restore these areas, which are co-managed with USFWS as a single user mitigation bank.

Figure 6-4. Swamp and Bottomland Hardwood Mitigation Area 11

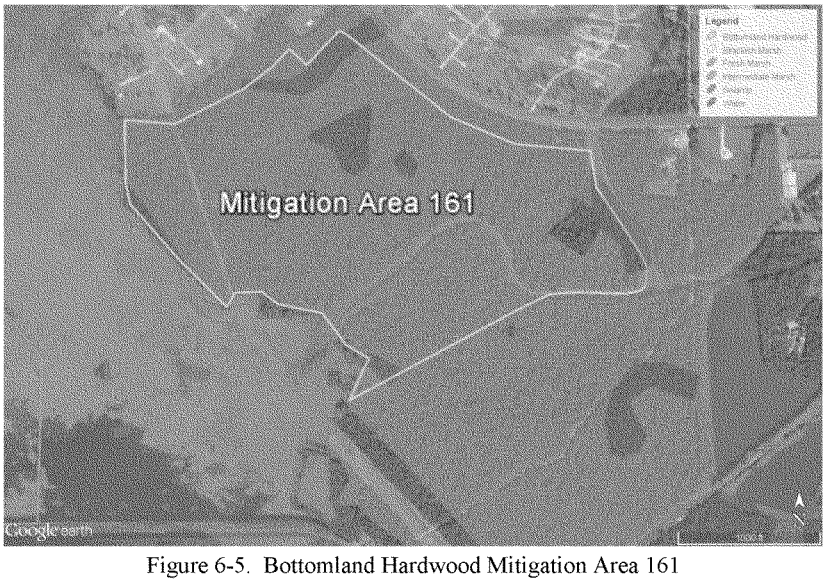


Figure 6-5. Bottomland Hardwood Mitigation Area 161

The mitigation plan would restore approximately 63 acres of fresh marsh and associated shallow ponds and sinuous channels in Mitigation Area 52, 151 acres of intermediate marsh and associated waters in Mitigation Area 31, and 239 acres of brackish marsh and associated waters in Mitigation Areas 28 and 29 (Figures 6-6, 6-7 and 6-8). Mitigation Areas 28, 29 and 31 are owned by TPWD. Mitigation Area 52 is privately owned; acquisition and preservation of this area would be accomplished as described for Mitigation Areas 11 and 161.

Shoaled sediments from maintenance dredging of the adjacent deep-draft navigation channels of the Sabine-Neches Waterway (SNWW) would be used to restore marsh in areas of open water within the outlined areas shown on Figures 1-3 through 1-5. Marsh would be constructed to target elevations determined during the PED phase in coordination with the resource agencies, utilizing comparisons to nearby reference marshes to establish the optimum post-settlement elevation range. At this time, it is projected that a range of elevations between 1.2 and 1.5 feet (NAVD88) would be achieved for emergent marsh and 0 to – 2.0 feet MLLW for restored ponds and channels within the marsh.

The construction estimate assumes that shoaled material from SNWW's Sabine-Neches Canal B, which extends across the north end of Sabine Lake from the mouth of the Neches River to the mouth of the Sabine River, would be used to construct mitigation areas 28 and 29. This is the closest segment of the SNWW to the Old River mitigation sites. This channel is not regularly dredged, so cost estimates included the full cost of maintenance dredging to hydraulically dredge the material and pump it into targeted open water areas. Maintenance material from the SNWW's Neches River Channel might be used instead of, or in addition to, the Sabine-Neches Canal B material for these areas. Material from regularly scheduled maintenance dredging of nearby reaches of the Neches River Channel is proposed for construction of mitigation areas 31 and 52. Only the incremental cost of additional hydraulic pipeline, pumping and pipe movement needed to create the marsh is included in the cost estimates for these alternatives.

Shoaled sediments in the Sabine region are fine-textured (mean percent clay is 76 percent) and generally of good quality, as evidenced by testing of water and sediments in conjunction with maintenance dredging of existing navigation channels and proposed modifications for the SNWW (USACE, 2011; SOL, 2012). SNWW sediments are routinely used for beneficial use projects, both on private and TPWD properties in the region. A routine water and sediment testing contract is planned in the near future to support USACE maintenance dredging of the Neches River Channel; sediment testing for dioxin has been added due to recent information confirming the historic presence of paper mills in the region.

Figure 6-6. Fresh Marsh Mitigation Area 52

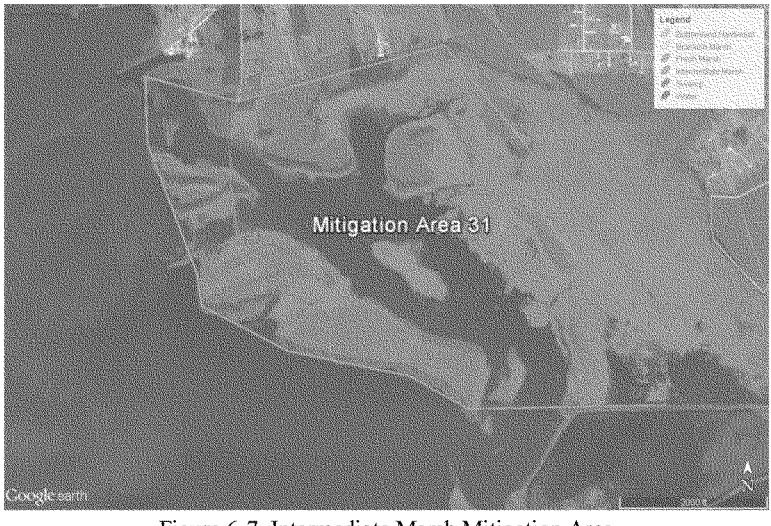


Figure 6-7. Intermediate Marsh Mitigation Area

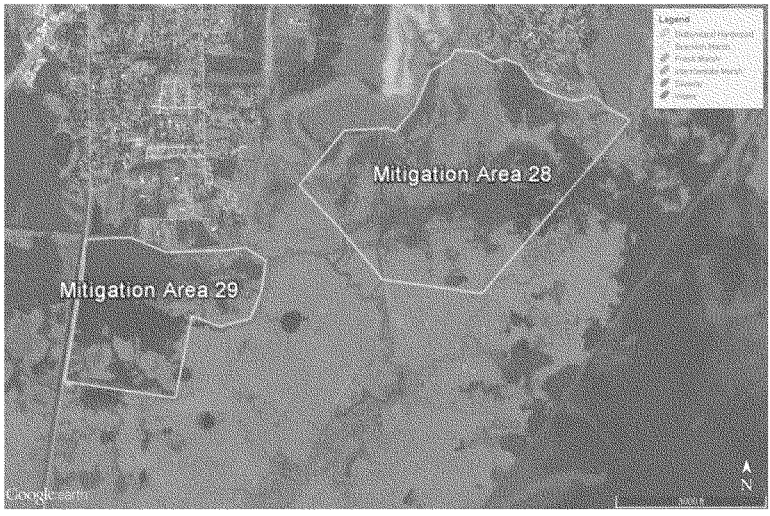


Figure 6-8. Brackish Marsh Mitigation Areas

Based upon the high percentages of fines in the SNWW sediments (55 – 94% from stations SNR-13-1 through SNR-13-13), binding of chemical constituents to sediment is expected to be significant and irreversible, resulting in low to no desorption from the sediments into surface water and elutriate during placement into mitigation features. The surface water and elutriate data support this, showing a high degree of consistency over the samples analyzed with virtually 100 percent of the results being below the reporting limit. With these findings, USACE believes that the material is suitable for like-to-like placement within the SNWW system.

Recent sediment and water testing in the Neches River in conjunction with a Galveston District regulatory action identified one positive result for dioxin in the elutriate of one sample (EPA, personal communication, 2016). This result is suspect, since dioxins are polar, highly chlorinated organic compounds with low water solubility and a high binding affinity. Given these characteristics, dioxin's affinity for binding with fine sediments over water, and the dominance of fine textured sediments in this waterway, this single positive elutriate result for dioxins could well be the result of a laboratory handling artifact where elutriate sampling were not filtered. Such a laboratory procedure could result in a false positive. However, given this anomalous dioxin elutriate result, during PED the USACE would evaluate the results of O&M maintenance material sediment testing, and if warranted based upon the results of this testing and evaluation, conduct additional sediment testing prior to construction to confirm the suitability of SNWW sediments

for use in marsh mitigation features. The risk of identifying insufficient quantities of suitable sediment for the mitigation features is considered to be low based on the large quantity of shoaled sediments available in adjacent navigation channels, routine O&M water and sediment testing results, and the acceptability of this material for several recent Neches River beneficial use projects.

6.4.2.2 Monitoring/Adaptive Management Plan

A detailed description of the monitoring/adaptive management plan is presented in Appendix P. The description provided below is a brief summary of the information presented there. All of the mitigation areas would require periodic inspection as part of normal operations and maintenance (O&M), in accordance with ER 1105-2-100, Section C-3(e)(10) and Section 2(d) of implementation guidance for WRDA 2007 Section 2036(a) (USACE, 2006). Monitoring to determine the success of mitigation measures is primarily the responsibility of the NFS for project implementation. The monitoring cost has been included in the O&M cost. Specific methods for the surveys and data collection described below would be developed in coordination with resource agencies during the PED phase.

An effective monitoring program is required to determine if the mitigation outcomes are consistent with performance standards. Mitigation success criteria were developed as the basis of determining ecological success and to determine if adaptive management actions are required. Upon completion of the mitigation area acquisition and construction, monitoring for ecological success would be initiated and would continue until ecological success is achieved, as defined by the mitigation success criteria. The objectives, performance standards and success criteria are presented in detail in Appendix P.

If one or more of the monitoring reports detailed in Appendix P indicates that mitigation success is threatened, as determined by USACE and the NFS in coordination with the resource agencies, significant corrective actions would be necessary as described in the Adaptive Management Plan (Section 3.0 of Appendix P). The need for such actions could trigger the need for additional monitoring, including the need to extend monitoring beyond the times indicated. The NFS would be responsible for conducting this additional monitoring, preparing monitoring reports, and conducting required corrective actions. Necessary corrective actions would be determined by USACE in coordination with the NFS and the resource agencies.

6.4.2.3 Resource Agency Views on the Best Buy Mitigation Plan

The Best Buy Mitigation Plan and Monitoring and Adaptive Management Plan were provided to the resource agencies for review and comment prior to release of the FIFR-EIS. Resource agency views described below were provided during a meeting, and in subsequent emails and

correspondence. The proposed Mitigation Plan fulfills recommendations by USFWS (August, 2016), and letters from EPA (Oct 30, 2015), NMFS (October 26, 2015), TCEQ (October 21, 2015) and TPWD (October 26, 2015).

- The final USFWS CAR (August 9, 2016) noted that the proposed mitigation plan was discussed with resource agencies during a meeting on June 15, 2016. The CAR states that the USFWS accepts the proposed mitigation plan and the monitoring/adaptive management plan, and recommends continued coordination with all of the resource agencies during PED and the Construction phases.
- In their letter concluding EFH consultation (August 10, 2016), NMFS accepted USACE responses to their Conservation Recommendations, including the proposed mitigation plan and its compensation for direct and indirect EFH impacts.
- EPA in their Section 404 CWA comments (provided as an attachment to their Oct 30, 2015 comments on the DIFR-EIS) indicated that "preservation only" mitigation plans are their "lowest priority, and thus least desirable option." In subsequent meetings, EPA also expressed concern about the suitability of shoaled sediments to be used in marsh mitigation features. USACE has determined that shoaled sediments in the SNWW are acceptable for marsh mitigation and are already being used beneficially for other marsh restoration projects in the area. More information regarding selection of the 'preservation only" measures and concerns regarding sediment suitability are provided in Section 6.4.1.2.
- TPWD (October 2016 letter) has agreed that the feasibility-level impact analysis is sufficient at this time, pending additional study and consultation during the PED phase as planned by USACE. Further H&H analysis would be conducted at that time to confirm assumptions related to potential alterations of sheet flow from uplands to coastal marshes. Final approval or concurrence by TPWD cannot occur until requirements of Chapter 26 of the Parks and Wildlife Code are met, and that cannot occur until after the FEIS is complete and the project is authorized. At this time, no significant obstacles to this approval have been identified. TPWD is willing to accept locating mitigation areas on lands in the Lower Neches WMA and has requested that USACE consider hydrologic or invasive species restoration measures in the Blue Elbow/Tony Houseman WMA as mitigation for the project's impacts to cypress-tupelo swamp. TWPD would like USACE to consider the value of restoration in the WVA because it functions as one of the greatest examples of the demonstration of, and education about, wildlife habitat in Texas. More information about the value of the Blue Elbow/Tony Houseman WMA is provided in the TPWD letter (Appendix G). USACE has informed TPWD that restoration measures may not be implementable because TxDOT approval is required to restore these areas, which are co-managed with USFWS as a single user mitigation bank. TPWD would consider managing any and possibly all of the private properties acquired for mitigation purposes, as long as the properties are readily accessible to TPWD staff and the public, and practically

manageable. TPWD would also be willing to divest the remainders of their property which would be isolated by levee construction.

- Several other agencies (notably NRCS, TCEQ, and TxDOT) participated in interagency meetings in which the mitigation plan was developed and reviewed. No reservations or adverse comments were expressed about the plan in these meetings.

6.4.3 Historic Properties Mitigation

Development of a mitigation plan will be deferred to the Preconstruction Engineering and Design (PED) phase when surveys and site assessments will be completed. The mitigation of historic properties may be necessary following an evaluation of impacts to determine if any of the four currently listed historic properties would be indirectly impacted. The eight archeological sites within the study area also would need to be evaluated as to their horizontal and vertical extent and eligibility for inclusion in the National Register of Historic Places (NRHP). The two cemeteries within the study may also be directly impacted and would need to be delineated and evaluated. There is also the potential for identifying cultural resources during survey investigations of high probability areas. Based on the current level of data, the mitigation of impacted historic properties might involve the construction of measures to reduce impacts on the setting of historic buildings or districts, as well as Historic American Building Survey documentation. If impacts are identified, archeological historic properties would require data recovery excavations or avoidance and cemeteries would need disinterment and interment of burials to a new location. The relocation of burials from impacted cemeteries might also involve purchasing land if other arrangements cannot be made.

6.5 COST ESTIMATE

A Class 4 parametric cost, using historical and unit costs, was applied to develop the cost estimate for screening the final array within the alternative reaches in the project areas. A Class 3 cost estimate using a Microcomputer Aided Cost Estimating System (MCACES) was developed for the Recommended Plan. The estimate was divided into 3 construction contracts mirroring the three distinct geographical locations: Orange, Port Arthur, and Freeport, Texas. The engineering design work was premised on a feasibility level of detail and analysis, consistent with the SMART planning process that is necessary to substantiate the Recommended Plan baseline cost estimate. Another key concept is to utilize existing information where applicable. Quantities and design features were developed by the Galveston District (SWG) Engineering Branch. This estimate was prepared using the latest Unit Price Books and labor rates for fiscal year 2016 (October 2015). The estimate was prepared in accordance with ER 1110-2-1302, dated 30 June 2016. The costs were escalated in accordance with the above Engineering Regulation and EM 1110-2-1304, dated 31 March 2016. All data was input into the Total Project Cost Summary Sheet (TPCS). The TPCS also incorporates a formal Cost Risk Analyses was performed with the cooperation of Cost Engineering

Directory of Expertise (DX) of the Walla Walla District. The risks were quantified and a cost risk model developed to determine a contingency at 80% confidence level (CL). The final results of the TPCS broken up by the three main project areas are shown on Table 6-9.

Table 6-9. TPCS Overview

Project Area	Total Project First Cost (Constant Dollar Basis)	Total Project Cost (Fully Funded)
Orange CSRM	$1,926,224,000	$2,304,741,000
Port Arthur and Vicinity CSRM	$729,069,000	$832,191,000
Freeport and Vicinity CSRM	$593,313,000	$677,193,000
Total	$3,248,607,000	$3,814,126,000

6.6 PROJECT SCHEDULE AND INTEREST DURING CONSTRUCTION

A project schedule was developed for all project components assuming an adequate funding stream. Also as described in section 6.3, A region wide systems approach for construction of Orange 3, Port Arthur and Freeport CSRM Plan, is being recommended to ensure that all of the benefits stated would be achieved. The project schedule included Preconstruction Engineering and Design (PED) and followed normal construction practices under USACE regulations and standards. Lands, easements, right-of-ways, relocations and borrow/disposal areas (LERRDs) were an NFS obligation and were assumed to be provided consistent with a normal construction processes. Port Arthur and Vicinity CSRM and Freeport and Vicinity CSRM project assumed a 72 month construction period and the Orange CSRM project area assumed a 120 month construction period. Interest during construction over these periods are reflected in the fully funded cost shown on Table 6-6.

6.7 DESIGN AND CONSTRUCTION CONSIDERATIONS

Significant consideration was given to the existing infrastructure that is in extremely close prominently to the work areas. Construction activities would be closely monitored to ensure that there is not any damage to industrial facilities or the existing project. Coordination with numerous different stakeholders along with the project local sponsors will be required.

6.8 DEFERRED MAINTENANCE CONSIDERATIONS

Currently the existing Freeport system is "unacceptable" in the Flood Control and Coastal Emergency Act (PL 84-99) program and not certifiable for FEMA accreditation under the National Flood Insurance Program (NFIP) Code of Federal Regulations (44 CFR. Section 65.10); therefore, the local sponsor has a System-Wide Improvement Framework (SWIF) plan in place to address

the deferred maintenance issues and issues impeding 44 CFR. Section 65.10 accreditation. The local sponsor submitted a System Wide Improvement Framework (SWIF) letter of intent (LOI) to the USACE in November 2012, and this letter of intent was accepted and approved by USACE on January 13, 2013. As part of the formulation process the final recommendation assumed all of the SWIF items, shown on Table 6-10, would be addressed and would not impact the implementation of the final recommendation.

Table 6-10. Deficiency Tabulation from the Freeport and Vicinity Hurricane Flood Protection System (HFPS) System Wide Improvement Framework (SWIF)

Deficiency	Description
Potential Shallow slope stability due to flood side seepage	North and South Barge Canal Levees. These levees were originally dredge spoil from construction of the Barge Canal and subsequently now function as levees. They contain various quantities and quality of sand and clay.
Inadequate Factor of Safety Deep Slope Stability	Old River North Deficiency is deep (circular) slope stability. This reach had marginal factor of safety in the HFPS upgrade post-Carla in 1965. Subsequent construction of 45 ft navigation channel at Port Freeport in 1985 had a negative impact on the slope stability which the DM showed was to be solved during construction by establishing a 95 ft bench(berm) seaward of the toe of the levee. Current soundings do not show evidence of that bench. A new 55 ft navigation channel project for Port Freeport has finished a feasibility study and would exacerbate the stability issue on this reach of the levee, thus, this issue will be evaluated and resolved by USACE as a part of the PED/GRR of the 55 ft. project.
Horizontal pipeline encroachment (4)	East Bank of Brazos River, Old River South, Old River North, North and South Barge Canal (approx. 100 pipelines)
Abandoned Pipelines	178 pipelines system wide (final number subject to increase)
Abandoned Structures	(1) Complex Pump structure at Barge Canal Turning Basin, (1) Old River North (Shell dock); Marine Dock A-5 Old River North, Dow Dock A-7 on South Barge Canal Levee
Potential under seepage	North and South Barge Canal Levees. Soil borings confirmed a sand seam approx. 30+ ft beneath a large portion of these levees and the adjacent Waste Water

Deficiency	Description
	and Fresh Water canals that parallel the levees on the South and North side, respectively.
Potential piping along pipelines in levee, cover unknown	Approx. 350 pipelines in North and South Barge Canal Levees, pipelines in East Bank of Brazos River Levees 1 and 2; Oyster Creek Levees
Docks – Dock design without dynamic loading.	(3) Old River South, Berth 5 (1) Old River North - Dock A-5 (also noted under Abandoned Structures). An independent preliminary dynamic analysis of Wave loading impact of realigned line of protection cause uncertainty of performance.
I-Walls Unknown condition.	Plant B Turning Basin; (1) Old River North - A 611; (3) Old River South. Visual inspection created an uncertainty in performance during design storm.
Potential Structural deficiency	Port Freeport Berth 5 (also listed under Docks), A 801 Sea Water Intake, Old River North,
Poorly maintained sea water intake structure	(1) Old River North A 801 structure, also noted under potential structural deficiency.
Damage to Closure elements	(1) East Bank of the Brazos River 2; (1) Barge Canal Turning Basin
Levee instability due to too steep protected side	(1) Old River South – Phillips Docks; (2) Old River North – at Dow Pump Station; Plant A Shell Dock;
Vertical penetrations below the standard project hurricane surge elevation	All Levees
Interior Drainage	Delineate the ponding areas behind all Levees

6.9 VALUE ENGINEERING (VE)

A VE study was conducted on the Sabine Pass to Galveston Bay Coastal Storm Risk Management Planning Study during the Alternative Formulation and Analysis phase of the SMART Feasibility Study process prior to determining the Tentatively Selected Plan (TSP) that was carried forward into project feasibility development. The VE study validated the final array of planning alternatives and reviewed their preliminary development to assure project value considerations were integrated into the process. Additional details, can be found in the Value Engineering Appendix.

6.10 SEA LEVEL AND CLIMATE CHANGE

In recognition of the uncertainty presented by sea level rise and climate change and the potential for directly proportionate impact in the design assumptions due to the coastal setting of the project,

several measures have been incorporated at this stage of the project. Consistent ER 1100-2-8162 and ETL 1100-2-1, all proposed floodwall sections will be constructed to the 50-year intermediate RSLC and will be designed for the greatest hydraulic loading out of the 50-year intermediate, the 50-year high and the 100-year intermediate. These load cases will ensure that the wall will meet all design criteria for the 50 year intermediate and still survive and not suffer a brittle failure under hydraulic loading from the 50-year high or the 100-year intermediate RSLC. All levee sections will be designed to the 50-year intermediate RSLC, with the assumption that they can be more easily adapted to future SLC than the floodwall. The recommended plan for the floodwall will allow for future increases in wall height due to its current robust structural design in the floodwall base and stem.

Drainage features will also be designed with similar considerations to those implemented on the floodwalls, allowing them to withstand the additional loads that should there be a future need to modify the project to address a changing environment. Proposed pump stations will be provided with future expansion considerations in order to be able to handle potential increments in their capacity requirements while minimizing impacts to the structure or the need for an additional one. This recommended approach allows the entire system to be adaptable to the 50-year high or the 100-year intermediate RSLC, which are the proposed performance limits of the systems.

The limits of 50-year high or the 100-year intermediate RSLC were recognized due to the constraints of high ground tie in, levee footprint impacting ultimate levee height, and adaptability constraints on closure structures, navigation gates, and pump stations. The adaptability concept for the RSLC scenarios above the 50-year intermediate will allow for limited overtopping of waves and minor still water overtopping that would then be mitigated for using interior drainage features. This approach also minimizes the initial cost of the floodwall while still allowing for adaptation. The recommended plan for the floodwall will allow for future increases in wall height due to its current robust structural design in the floodwall base and stem.

6.11 REAL ESTATE CONSIDERATIONS

The Non-Federal Sponsors will be responsible for acquiring and furnishing all lands, easements, rights-of-way, relocations (i.e., P.L. 91-646 relocations and utility/facility relocations), borrow material, and dredged or excavated material disposal areas (LERRD) for the project areas, as required. All lands needed for this project will be acquired in fee, with the exception of the land needed for the flood risk reduction levee easements, staging areas, perpetual road easements, and borrow area easements. A Real Estate Plan was developed to present the Real Estate requirements for the Recommended Plan. It is estimated that up to 252 ownerships could be impacted by the Recommended Plan. Additional details, the chart of accounts can be found in the Real Estate Appendix.

6.11.1 Lands, Easements, and Rights-of-Way

The following lists the Lands, Easements, and Rights-of-Way requirements for the Recommended Plan. For the Orange 3 New Levee, current plans indicate 15 miles of new levee (100 to 150 feet wide) and 11 miles of new floodwall (78 feet wide) would be constructed. In support of the construction activities, the following estimates were used:

- 130 acres of perpetual easement for operations and maintenance; and
- Temporary work area easement will be used for staging for three years (20 acres).

For the Port Arthur and Vicinity CSRM, certain portions of the existing 29.04-mile system of levees and floodwalls and/or closure system would be improved or replaced. There will also be a new levee section on the northeastern end of the system measuring 1,830 LF in which a perpetual easements will be needed. All work would be achieved within the existing rights-of-way. In support, the following estimates were used:

- Temporary work area easement will be used for staging areas for 3 years (33 acres)

For the Freeport and Vicinity CSRM, certain portions of the existing 43.12-mile system of levees and floodwalls and/or closure system would be improved or replaced. All work would be achieved within the existing rights-of-way. In support, the following estimates were used:

- Temporary work area easement will be used for staging areas for 3 years (20 acres).

6.11.2 Facility Removals/Utility Relocations

Multiple pipelines would be impacted by this project. An estimate of the number and location of these pipelines was developed and utilized in developing the Orange 3 alternative. Plan formulation costs were based on cost estimates prepared by engineering consultants for a very similar plan in the same general location (Hurricane Flood Protection System, Orange County, Texas (2012), a Flood Protection Planning Study prepared for the Orange County Economic Development Corporation by Carroll & Blackman, Inc., Costello, Inc., and LJA Engineers, Inc.). This cost included relocation costs for pipelines that were identified in the project area using a state database. Cost risks already identified in the risk register relate to uncertainties in the state database. Plans and costs for relocations were developed in greater detail for the Recommended Plan.

6.12 OPERATION AND MAINTENANCE, REPAIR, REHABILITATION AND REPLACEMENT (OMRR&R)

OMRR&R of these facilities would be extensive. The Recommended Plan is a complex system constructed in a marine environment. OMRR&R requirements would include, but not be limited to, biannual exercising of the systems gates and closure structures, grass mowing, painting, pump station O&M, drainage and navigation structure operation, and maintenance and alteration approvals under Section 408. The purpose of OMRR&R is to sustain the constructed project and to maintain the stated level of benefits at the completion of construction. Under 33 U.S. Code 408 (commonly referred to as Section 408), the Secretary of the Army, on the recommendations of the Chief of Engineers, may grant permission for the alteration of a USACE civil works project if it is determined that the alteration will not be injurious to the public interest and will not impair the usefulness of the project. The local sponsors would also be required to coordinate with stakeholders for OMRR&R concerns and evacuation/emergency action planning. The total estimated annual OMRR&R cost is $5,468,000 based on the current Federal Fiscal year discount rate. A majority of the annual OMRR&R costs are based upon sustaining the new levee system under Orange 3. The NFS is not obligated to address loss of risk reduction due to RSLR through future levee lifts or structure modification, but they will still be required to repair, rehabilitation or provide replacement of components to maintain the original project benefits. As part of PED, a OMRR&R manual will be developed to outline the expected OMRR&R requirements. After the District Engineer provides notice of construction completion for the project, or functional portion of the project, the NFS will commence OMRR&R responsibilities associated with the project.

6.13 ECONOMIC ANALYSIS FOR RECOMMENDED PLAN

6.13.1 Summary of Accounts

6.13.1.1 National Economic Development (NED)

Estimated net benefits for the Recommended Plans Separable Elements are listed below by project area. Overall, the estimated Equivalent Annual Net Benefits of the TSP is $300,043,000.

- Orange 3 CSRM - Equivalent Annual Net Benefits = $15,634,000
- Port Arthur and Vicinity CSRM - Equivalent Annual Net Benefits = $106,318,000
- Freeport and Vicinity CSRM - Equivalent Annual Net Benefits = $178,091,000

The Table 6-11 displays the total economic performance of Recommended Plan.

Table 6-11. Economic Performance of Recommended Plan Overview

(FY 2017 Price Level/2.875 percent interest rate)	Recommended Plan
INVESTMENT	
Estimated First Cost	**$3,248,606,000**
Annual Interest Rate	2.875%
Project Life (years)	50
Construction Period (months)	120
Interest During Construction	$368,075,000
Investment Cost	$3,616,681,000
Interest	$103,980,000
Amortization	$33,267,000
OMRR&R ($/year)	$5,467,000
TOTAL ANNUAL COSTS	**$142,713,000**
Without Project EAD	$648,349,000
Residual EAD	$205,594,000
Storm Reduction Benefits	$442,756,000
TOTAL BENEFITS	**$442,756,000**
NET BENEFITS	**$300,043,000**
BENEFIT-COST RATIO	**3.1**

6.13.1.2 Environmental Quality (EQ)

Potential impacts of the Recommended Plan on human and environmental resources have been identified and presented in this document. All factors that were be relevant to the Recommended Plan were considered, including direct and indirect impacts on wetlands, effects on essential fish habitat and listed species, air quality, water and sediment quality, hazardous materials, historic properties, socioeconomic, and environmental justice impacts. Environmental impacts on wetlands are the primary environmental effect. All potential effects are evaluated in Section 7.0.

6.13.1.3 Regional Economic Development Benefits (RED)

The proposed Recommended Plan reduces probabilities of direct damages, but also decreases the occurrence of secondary impacts, such as potential disruptions to refining capacities, which could lead to higher fuel prices.

6.13.1.4 Other Social Effects (OSE)

Based on the qualitative evaluation performed on the Orange 3 CSRM, Port Arthur and Vicinity CSRM, and the Freeport and Vicinity CSRM, the expectation for each project area would be that all plans would positively impact life-safety risk. A quantitative model was not used to determine

performance of plans against life-safety risk reduction, but it is expected that the Recommended Plan would have a positive impact and no increase in risk.

6.14 RISK AND UNCERTAINTY

6.14.1 Engineering Data and Models

This section summarizes risk and uncertainty included in some key models and methods applied in this study and documented in the report appendices in more detail.

6.14.1.1 Hydrology and Hydraulics

The hydrologic, hydraulic, and coastal information presented in this report relied heavily on available data gathered from many local, state, and national sources. Some of the information was preliminary, such as the HEC-RAS models for the Neches River, Cow Bayou, and Adams Bayou. The models had been through quality control and assessment by the entities they were acquired from, and additional Quality Assurance/Quality Control was performed by USACE. These models have relatively low risk and uncertainty but should be reevaluated again during PED. Additionally, the watersheds and waterways may change by the time PED begins and this should be addressed at that time.

For most interior drainage areas, hydrologic calculations were performed using the rational and regression methods. These are common methods of estimating rainfall runoff and discharges at outfalls, and their use is permitted by USACE. To reduce uncertainty, two separate rational method calculation formulations and two separate regression formulations were used. The results produced very similar results; typically, the difference was in the 5-10 percent range. More detailed modeling (utilizing HEC-HMS and HEC-RAS), which was not completed during the feasibility, will be performed during PED.

Relative Sea Level Change

The project must consider possible trends that affect the area. One trend that would likely impact the area is RSLC. The degree of uncertainty and values vary considerably amongst the worldwide scientific community, and this issue will likely be debated and methods will likely be improved over time. This study uses current USACE sea level change guidance as required for USACE studies. To account for the unknowns in sea level change, USACE requires evaluation of high, medium, and low scenarios of sea level change projections.

Recommendations to address RSLC scenarios are described in detail in the engineering appendix and summarized here. The entrance channel jetties at both Freeport and Sabine Neches Waterway

are high enough that there is no concern of being impacted by RSLC estimates. Levees should be constructed in an adaptable or anticipatory manner for estimated sea level rise if possible. Outfall calculations account for the predicted rise in sea level by increasing size and capacity.

This project utilizes the highest estimated sea level change value following required USACE guidance. Using the "high" estimates in the guidance reduces the risk that sea level change is underestimated or that future estimates may impact the project. Uncertainty is considered by evaluating a range of possible sea level change possibilities from "low" to "high." It is recommended that RSLC be reevaluated during PED because the understanding of sea level change and USACE guidance may change between the completion of this report and initiation of PED.

Hydrodynamics and Storm Surge

Typical Conditions. Typical conditions were assessed using previous modeling efforts, analysis of existing data, and limited salinity transport modeling. Uncertainties in collected data are transferred to the analyses presented here. ERDC-CHL utilized a Desktop Off-Channel Wetland Salinity Mitigation Model (DOWSMM) to perform an analysis to quantitatively assess the impacts of the proposed gates. DOWSMM modeling is based on previous modeling efforts without site-specific calibration or validation data.

Storm Conditions. Baseline storm surges used for the analysis were composed of the suite of storm surges produced from the Federal Emergency Management Agency (FEMA) Texas Joint Storm Surge Study (JSS). The FEMA Texas JSS used the Advanced Circulation (ADCIRC) model together with the ERDC Steady State Wave model (STWAVE) to perform storm surge and wave simulations. Statistics based on the JSS model runs were updated using the most recent Joint Probability Method-Optimal Sampling (JPM-OS) code.

In the Freeport region, without project storm model results were applied for both with- and without-project conditions. This approach includes uncertainty associated with still water level overtopping and potential adjacent impacts.

Storms at Orange County and Port Arthur were modeled for without-project conditions in the same manner as Freeport. One new with project alignment was modeled as a vertical wall in this region. This approach provides information about adjacent impacts but does not include calculation of still water level overtopping. It also does not include detailed analysis of the separable elements, since all elements were included in the sole with-project model run.

6.14.1.2 Other Engineering Risk and Uncertainty

Risk and uncertainty for the existing systems stems from the use of existing information for the initial assumptions of the feasibility-design. This risk varies from small for I-wall reconstruction/resiliency features in areas where significant information is available, to large risk in areas of levee raising where minimal existing information was available. As described in section 6.4.3 a formal Cost Risk Analyses was performed and risks and uncertainty were quantified and incorporated to the final results of the TPCS.

Other risks and uncertainties associated with the engineering data and modeling are in the assumptions that were made based on the following:

- The accuracy of available information and data collected.
- Assessment of existing physical conditions based primarily on photo imagery and LiDAR data, no on-the-ground physical survey data.
- The preliminary levee system alignments assumed for the Orange CSRM project. Alignments might adjust during feasibility-level design.
- Assessment of the foundation conditions/soil properties for the Orange CSRM project area based on very limited geotechnical investigations.
- Generic conceptual design templates for the levee embankment and floodwall uniformly applied across the new Orange CSRM alignment. Future designs will be tailored to the local conditions and will therefore vary.
- The closure structures with navigable opening and pump stations are conceptual in nature based on similar structures and pump stations that were constructed for the New Orleans Hurricane and Storm Damage Risk Reduction System. These have not been conceptually designed for the CSRM projects.

6.14.2 Economic and Life Safety Risks

The Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) Version 1.4.0 certified model was used to calculate the damages for the without project existing and future conditions. Measurable damage categories from HEC-FDA including residential and non-residential structures and automobiles are accounted for in the residual damages. Uncertainty related to economics can come from several sources. One source is the structure elevation, which has two components: the topographic ground elevation that a structure sits on, and the structure's estimated first floor elevation. Another source is the value of the structure and its contents. The final source of uncertainty is in the inundation depth/percent damage relationship (usually known as depth damage functions) used to estimate damages to a structure for a given level of flooding. Parameter settings in HEC-FDA account for these uncertainties. Residential, Commercial, and Industrial

Damages: The recommended plan would greatly reduce the equivalent annual storm surge damages in areas behind the new levee system and in areas where the existing systems would be upgraded. However, damages can still occur from project exceedance events, rainfall events, and hurricane winds and windblown debris, particularly in upland areas where drainage features are restricted by railway and roadway features. The recommended risk reduction system is only authorized to address storm surge caused by hurricane and tropical storm events. The levee system is not authorized to be closed under non-hurricane and tropical storm events. Some damages will still occur from rainfall events and from storm surge that exceeds the crest of the system.

The system is expected to withstand storm surges up to the 1% probability storm level, but the level of risk reduction afforded by the recommended plan will depend on the rate at which relative sea level change occurs. The damage analysis incorporates a rate of relative sea level rise equivalent to the intermediate curve prescribed by USACE guidance. The levee system will reduce hurricane and tropical storm surge damages by 68 percent to the existing structures behind the levee system over a 50 year period base on the intermediate RSLR conditions.

Table 6-12 shows the equivalent average annual remaining damages provided by the HEC-FDA model.

Table 6-12. Equivalent Annual Residual Damages - By Components of Recommended Plan

Component	Total Equivalent Annual Residual Damages[1] (FY 2017 Price Level)
Orange 3 CSRM	$59,228,000
Port Arthur and Vicinity CSRM	$104,674,000
Freeport and Vicinity CSRM	$41,692,000

Risk to Life and Safety: Life-safety risks are reduced through effective warnings and evacuation procedures. Warnings are expected to be issued and heeded well before hurricane landfall, thereby removing the residents from harm's way. The erratic nature and unpredictability of hurricane path and intensity requires early and safe evacuation. This policy should be continued both with and without the storm damage reduction project. Additional information on the uncertainties is contained in Appendix C, Economic Analysis, in the Risk Performance of Proposed Action section.

6.14.3 Environmental Data and Analyses

The most current available data were used for environmental analyses of the study area, augmented by brief field visits to the study areas and reviews of habitat classification using the most recent aerial photographs. Ecological modeling was required to quantify impacts or mitigation. Uncertainty is inherent in ecosystems, and therefore unavoidable when evaluating ecological processes and impacts. There is often a lack of extensive data sets for all parameters under study, and many of the physical and biological processes are not completely understood. Ecological analyses for the study utilized input from several engineering models referenced in the table above.

Impact assessments for the Orange CSRM Plan are based in part on assumptions regarding the operating plans that will be developed during PED. Resource agencies have requested to participate in the preparation of this plan to ensure that the system is operated to maintain tidal access to wetlands inside and outside of the levee system. Because of uncertainty associated with project performance, the O&M monitoring should include evaluation of the performance of the culvert system in maintaining tidal flows. Impact assessments are also based upon assumptions regarding the amount of constriction (and thus fisheries access impacts) to Adams and Cow Bayous created by placement of the surge gate structures within the bayou floodways. Impact assumptions should be reviewed when engineering design is sufficiently complete to determine if impacts have been captured appropriately.

There is risk that changes to the alignment may be needed to address unexpected HTRW discoveries during construction. Although no unresolved current or recent hazardous material releases were found near any of the CSRM Plan alignments, most of the refineries and chemical plants have had violations in the past. The HTRW facilities along the construction right-of-way should be more thoroughly investigated with visual inspections and interviews with facility managers to confirm the potential HTRW risks along the levee alignment prior to construction or more detailed design. If significant changes in the alignment are needed, environmental impacts will be reevaluated, and additional NEPA review may be needed.

6.15 CONSISTENCY WITH OTHER STATE AND FEDERAL LAWS

This FIFR-EIS has been prepared to satisfy the requirements of all applicable environmental laws and regulations and has been prepared using the Council on Environmental Quality (CEQ) NEPA regulations (40 CFR Part 1500–1508) and the USACE's regulation ER 200-2-2 - Environmental Quality: Policy and Procedures for Implementing NEPA, 33 CFR 230. In implementing the Recommended Plan, USACE would follow provisions of all applicable laws, regulations, and policies related to the proposed actions. The following sections present brief summaries of Federal environmental laws, regulations, and coordination requirements applicable to this FEIS-EIS.

6.15.1 Clean Air Act

Temporary air emission impacts resulting from construction of the Recommended Plan in the Sabine and Brazoria Regions have been calculated; the analysis is presented in Appendix I. The Sabine Region is currently designated as in attainment or unclassifiable with National Ambient Air Quality Standards (NAAQS); therefore, a General Conformity Determination is not required. Brazoria County is contained within the Houston-Galveston-Brazoria (HGB) Air Quality Control Region (AQCR); this region meets all of the NAAQS, except for ozone. The HGB area is currently classified as being in severe nonattainment for the 8-Hr ozone (1997) standard and marginal nonattainment for the 8-Hr ozone (2008) standard. Direct and indirect emissions would result from temporary construction activities. Construction of the Recommended Plan in this area would result in emissions below the *de minimis* threshold for nonattainment pollutants and thus a conformity determination is not required. In order to reduce impacts associated with emissions of particulate matter and other pollutants, the control measures specified in Section 7.8.2.1 would be included in construction contracts, as applicable and practicable.

Air emissions from the operation of internal combustion engines that produce exhaust result in Greenhouse Gas (GHG) emissions that could contribute to global climate change. The CEQ published "Draft NEPA Guidance on Consideration of the Effects of Climate Change and Greenhouse Gas Emissions", December 18, 2014. The Draft Guidance suggests that the impacts of projects directly emitting GHG in excess of 25,000 metric tons or more of carbon dioxide (CO2)-equivalent (CO2e) GHG emissions per year be considered in a qualitative and quantitative manner in NEPA reporting; however, there are no implementing regulations to direct development of these analyses for Federal projects. GHG emissions are expected to be well below the significance threshold. In order to reduce GHG emissions, emission reduction methods described in Section 7.8.2.2 would be implemented.

6.15.2 Clean Water Act

Section 404 of the CWA regulates dredge-and/or-fill activities in waters of the U.S. In Texas, Section 401 of the CWA (State Water Quality Certification Program) is regulated by the TCEQ. USACE requested and has received Section 401 State Water Quality Certification for the Recommended Plan from TCEQ. Based on the alternatives and environmental consequences analysis presented in this FIFR-EIS, TCEQ has concurred that there is a reasonable assurance that construction of the Recommended Plan would not violate water quality standards and is the least environmentally damaging practicable alternative that meets the project purpose. No impacts to special aquatic sites are anticipated in conjunction with the Port Arthur and Vicinity or Freeport and Vicinity CSRM Plans. However, two types of special aquatic sites ("wetlands" and "sanctuaries and refuges") would be impacted by construction of the Orange 3 CSRM Plan. The

alignment of the Orange 3 CSRM Plan has been carefully situated to avoid and minimize impacts to these special aquatic sites and the aquatic ecosystem to the greatest extent practicable. Unavoidable, significant impacts would be fully mitigated by the proposed Orange CSMR mitigation plan. The CWA Section 404(b)(1) Evaluation (presented in Appendix H) concludes that the discharge of fill material in conjunction with construction of the Orange CSRM plan complies with Section 404(b)(1) Guidelines.

6.15.3 Endangered Species Act

A Biological Assessment (BA) was prepared and coordinated with USFWS and NMFS describing the study area, Federally listed threatened and endangered species of potential occurrence in the study area as identified by the NMFS and USFWS, and potential impacts of the TSP on these protected species (Appendix J). The Recommended Plan results in fewer wetland impacts than the TSP, and no changes to the USACE "no effect" determination. ESA coordination correspondence is provided in Appendix G. USACE has determined that the Recommended Plan would have no effect on the following listed animal species: piping plover, red knot, whooping crane, West Indian manatee, four whale species (fin, humpback, sei, and sperm), four sea turtle species (green, Kemp's ridley, loggerhead and hawksbill), and four coral species (lobed star, mountainous star, boulder star and elkhorn). The Recommended Plan would also have no effect on the following candidate species: Sprague's pipit, and two freshwater mussel species (smooth pimpleback and Texas fawnsfoot). There is no designated critical habitat in the project areas. The USFWS concurred with the USACE "no effect" determinations.

6.15.4 Magnuson-Stevens Fishery Conservation and Management Act

The Magnuson-Stevens Fishery Conservation and Management Act (PL 94-265), as amended, establishes procedures for identifying EFH and required interagency coordination to further the conservation of Federally managed fisheries. Its implementing regulations specify that any Federal agency that authorizes, funds, or undertakes, or proposes to authorize, fund, or undertake, an activity that could adversely affect EFH is subject to the consultation provisions of the Act and identifies consultation requirements. EFH consists of those habitats necessary for spawning, breeding, feeding, or growth to maturity of species managed by Regional Fishery Management Councils in a series of Fishery Management Plans.

Submittal of the DIFR-EIS and its assessment of S2G impacts on EFH to NMFS initiated EFH consultation. Direct and indirect impacts associated with construction of the Orange-Jefferson CSRM Plan would result in the loss of about 203.0 acres of estuarine emergent marsh over the period of analysis. Marsh acres include water within the marsh and small drainages; some SAV in the estuarine marsh areas would also be lost. The Cow and Adam Bayous surge gate structures

would constrict flows in these bayous while in their normal open condition, resulting in functional fisheries access impacts on a total of about 2,137 acres of estuarine emergent marsh in the bayou floodplains upstream of the gated structures. Direct and indirect impacts would be fully compensated with the restoration of approximately 453 acres of estuarine emergent marsh and shallow water as described in the mitigation plan. NMFS has determined that USACE has satisfactorily addressed NMFS EFH Conservation Recommendations and no further EFH consultation is required. A summary of the Conservation Recommendations and the USACE response is provided below. The full record of USACE EFH consultation with NMFS is presented in Appendix G.

NMFS provided six Conservation Recommendations (CR) by letter dated October 26, 2015. USACE fully concurs with the CR with the exception of two (Recommendations 2 and 5), as explained further below. NMFS recommended that USACE: 1) develop a complete mitigation plan in consultation with the NMFS Habitat Conservation Division (HCD), 2) complete mitigation within 18 months of the start of construction of the Orange CSRM system, 3) conduct additional modeling and environmental analysis if the Adams and Cow Bayous surge gates constrict bayou cross sections by more than 50 percent; 4) develop an Operations Plan in consultation with resource agencies that ensures that surge gates and culverts remain open except during surge events; 5) reassess functional fisheries access impacts if closures exceed assumptions; and 6) use construction fill material from approved, upland borrow sources.

USACE cannot comply with CR 2. Due the scale of the marsh mitigation features and beneficial use of dredged material from the adjacent Sabine-Neches Waterway (SNWW), it would not be possible to establish tidal elevations and plant wetland vegetation within 18 months of the initiation of levee construction. Construction of the mitigation areas would begin as soon as possible after levee system construction is initiated, and would be complete within 8 years.

USACE provided clarification of the estimated surge gates and culverts closure times in regard to CR 5. At this time, it is assumed that the return interval for storm surges high enough to threaten the project area would be 10 to 15 years. Gates or water control structures would need to be closed for large storm events, even if the storms occur more frequently than this predicted return period. The operating plan for the gates has not yet been developed, but an estimated closure time (one week for each storm event closure or up to two weeks for periodic maintenance) would result in only minor and temporary impacts to fisheries access. The details and schedule of these closures would be determined during preparation of the Operation Plan in consultation with NMFS HCD and the other state and federal resource agencies.

6.15.5 Coastal Zone Management Act

Under the Texas Coastal Management Program (TCMP), enacted under the Coastal Zone Management Act in 1972, the GLO reviews Federal activities to determine whether they are consistent with the policies of the TCMP. USACE prepared a Consistency Determination that evaluated the TSP for consistency with the TCMP and concluded that it was fully consistent to the maximum extent practicable with the enforceable policies of the Texas program. GLO confirmed the USACE consistency determination and recommended no conditions. The Recommended Plan results in fewer wetland impacts than the TSP, and no changes to the USACE consistency determination. TCMP coordination correspondence is provided in Appendix M.

6.15.6 Fish and Wildlife Coordination Act

The Fish and Wildlife Coordination Act (FWCA) provides for consultation with the USFWS and, in Texas, with TPWD whenever the waters or channel of a body of water are modified by a department or agency of the U.S. USFWS and TPWD have actively participated in the extensive resource agency meetings conducted to evaluate impacts and develop mitigation measures for the Recommended Plan.

The CAR's 30 Final Recommendations and USACE responses are summarized in the Table 6-13. The recommendations were followed in developing the Recommended Plan, engineering design considerations and the Mitigation Plan. Readers should refer to Appendix K to see the complete CAR document; CAR recommendations have been integrated in the description of the Recommended Plan throughout the report.

Table 6-13. USFWS Final CAR Recommendations

USFWS Final CAR Recommendations	USACE Response
1. Situate flood risk reduction features to minimize wetland and bottomland hardwood impacts. Fully compensate for any unavoidable losses caused by project features.	Concur.
2. Minimize enclosure of wetlands with levee alignments. Maintain hydrologic connections with unavoidable enclosures or establish non-development easements in those areas.	Concur.
3. Avoid adverse impacts to bald eagle nesting locations and wading bird colonies through careful design risk reduction features and timing of construction.	Concur.
4. Conduct forest clearing associated with project features during the fall or winter to minimize impacts to nesting migratory birds, when practicable.	Concur.

USFWS Final CAR Recommendations	USACE Response
5. Develop a complete mitigation plan to compensate for direct and indirect habitat impacts in consultation with the Service and other state and federal natural resource agencies during final feasibility planning, and implement mitigation construction concurrently with project construction.	Concur. See mitigation plan presented in FIFR-EIS.
6. Include language in the project's first Project Cooperation Agreement (or similar document) specifying the responsibility of the local-cost sharer to provide operational and construction monitoring, and maintenance funds for mitigation features.	Concur.
7. Coordinate PED planning of project features with the Service and other Federal/State resource agencies and provide 30 days for review.	Concur.
8. Avoid impacts to state and federal lands. If not feasible, coordinate with affected agencies until construction of that feature is complete and prior to any subsequent maintenance.	Concur.
9. If mitigation lands are purchased for inclusion within a National Wildlife Refuge (NWR), those lands must meet certain requirements; a general summary of some of the requirements is provided in Appendix A.	Concur.
10. If applicable, a General Plan should be developed by the Corps, through coordination with the Service, and the natural resource agencies in accordance with Section 3(b) of the FWCA for mitigation lands.	Concur.
11. Initiate consultation pursuant to Section 7 of the Endangered Species Act if the proposed project features change, the status of species change, or the project is not implemented within three years of the date of our Endangered Species Act coordination.	Concur.
12. Incorporate larger, numerous openings within a diversity of locations in a risk reduction levee aimed at maintaining estuarine dependent fishery migration.	Concur.
13. Flood protection water control structures in any watercourse should maintain pre-project width and depth to the maximum extent practicable, especially structures located in tidal passes.	Concur.
14. To the extent possible, water control structure sited in canals, bayous, or navigation channels that do not maintain the pre-project cross section should be designed and operated with multiple openings within the structure.	Concur.
15. Should final surge gate structure designs reduce the cross section of Adams or Cow Bayous more than 50 percent, additional modeling and environmental analysis will be performed to characterize potential hydrologic and fish passage impacts and determine additional mitigation requirements.	Concur.

USFWS Final CAR Recommendations	USACE Response
16. Flood risk reduction surge gates, sluice gates, culverts, and any other water control structures should remain completely open except during storm events or regularly scheduled maintenance or inspections. O&M and management plans for structures should be developed in coordination with the Service and other resource agencies.	Concur.
17. The O&M plan should include a schedule of maintenance events for each gate and culvert and proposed closure times for said maintenance activities. A worst case closure scenario is estimated to be 5-7 days every 10-15 years based on predicted storm surge return intervals high enough to threaten areas targeted for risk reduction. However, in years where more than one storm event occurs, we expect the gates to remain closed (5-7 days) for each storm event. Periodic maintenance of the gates and culverts (not included in the worst case scenario) may result in additional closures estimated of not more than two weeks for each instance. Any proposed operational deviation from the estimated frequency or duration of structure closures must be assessed in coordination with the Service and other resource agencies at which time additional mitigation would be required to offset such operational impacts.	Concur.
18. The number and siting of openings in flood risk reduction levees should be optimized to minimize the migratory distance from the opening to enclosed wetland habitats.	Concur.
19. Flood risk reduction structures within a waterway should include shoreline baffles and or ramps (e.g., rock rubble, articulated concrete mat) that slope up to the structure invert to enhance organism passage. Coordinate structure design with the resource agencies.	Concur.
20. To the maximum extent practicable, structures should be designed and/or selected and installed such that average flow velocities during peak flood or ebb tides do not exceed 2.6 feet per second. However, this may not necessarily be applicable to tidal passes or other similar major exchange points.	Concur.
21. To the maximum extent practicable, sluice gates or culverts (round or box) should be designed, selected, and installed such that the invert elevation is equal to the existing water depth and flows are sufficient to prevent siltation.	Concur.
22. Temporary culverts or sluice gates should be installed in construction access roads unless otherwise recommended by the natural resource agencies. Culvert spacing should be optimized on a case-by-case basis in consultation with resource agencies. At a minimum, there should be one, 24-inch culvert or sluice gate placed every 500 feet and one at natural stream crossings.	Concur.

USFWS Final CAR Recommendations	USACE Response
23. Water control structures should be designed to allow rapid opening in the absence of an off-site power source after a storm passes and water levels return to normal.	Concur.
24. Levee alignment and water control structure alternatives should be selected to avoid the need for fishery organisms to pass through multiple structures (i.e., structures behind structures) to access an area.	Concur.
25. Operational plans for water control structures should be developed to maximize the cross-sectional area open for as long as possible.	Concur.
26. Any proposed change in mitigation features or plans should be coordinated in advance with the Service, NMFS, EPA, TPWD, TCRQ, and TGLO.	Concur.
27. A report documenting the status of mitigation implementation and maintenance should be prepared every three years by the managing agency and provided to the Corps, the Service, NMFS, EPA, TPWD, TCEQ, and TGLO.	Concur.
28. Fill material used during the construction of the levees or its associated features should come from an approved upland borrow source that has undergone contaminant testing criteria approved by the EPA.	Concur.
29. The Corps shall fully compensate for any unavoidable losses of wetland habitat (including forested wetlands) or non-wet bottom hardwoods caused by project features as dictated by the Wetland Value Assessment modeling.	Concur.
30. Acquisition, habitat development, maintenance, and management of mitigation lands should be allocated as a first-cost expense of the project to ensure mitigation obligations are met on behalf of the public interest.	Non-Concur. See response in this section.

USACE fully concurs with the USFWS Final Recommendations with one exception. The allocation of mitigation construction, monitoring and maintenance costs are governed by WRDA 1986 and USACE guidance. First costs, which include all costs of acquisition, habitat construction and construction monitoring, are apportioned between the Federal government and the non-Federal sponsor as stipulated by law and USACE policy. Periodic inspections would be conducted as part of normal Operations and Maintenance. Monitoring to determine the success of mitigation measures is primarily the responsibility of the non-Federal sponsor, as specified in the Project Partnership Agreement.

6.15.7 Marine Mammal Protection Act of 1972

The Marine Mammal Protection Act was passed in 1972 and amended through 1997. It is intended to conserve and protect marine mammals and establish the Marine Mammal Commission, the International Dolphin Conservation Program, and a Marine Mammal Health and Stranding Response Program. The Recommended Plan would have no effect on marine mammals.

6.15.8 National Historic Preservation Act

Compliance with the National Historic Preservation Act of 1966, as amended (54 U.S.C. § 306108), requires the consideration of effects of the undertaking on all historic properties in the project area and development of mitigation measures for those adversely affected properties in coordination with the SHPO and the Advisory Council on Historic Preservation. It has been determined that there is a potential for new construction, improvements to existing facilities, and maintenance of existing facilities to cause effects on historic properties. Therefore, in accordance with 36 CFR 800.14, USACE has executed a Programmatic Agreement among USACE, the Texas SHPO, and non-Federal implementation sponsors to address the identification and discovery of cultural resources that may occur during the construction and maintenance of proposed or existing facilities. USACE invited the ACHP and Native American tribes to participate as signatories to the Programmatic Agreement, but both groups declined the invitation. The executed Programmatic Agreement is provided in Appendix L.

6.15.9 Federal Water Project Recreation Act

This 1995 Act requires consideration of opportunities for outdoor recreation and fish and wildlife enhancement in planning water-resource projects. The Recommended Plan is not expected to have any long-term effects on outdoor recreation opportunities in the area.

6.15.10 Farmland Protection Policy Act of 1981 and the CEQ Memorandum Prime and Unique Farmlands

In 1980, the CEQ issued an Environmental Statement Memorandum "Prime and Unique Agricultural Lands" as a supplement to the NEPA procedures. Additionally, the Farmland Protection Policy Act, passed in 1981, requires Federal agencies to evaluate the impacts of Federally funded projects that may convert farmlands to nonagricultural uses and to consider alternative actions that would reduce adverse effects of the conversion. The TSP would have directly impacted approximately 178 acres of prime or otherwise important farmlands. Elimination of levee system reaches and reductions in the width of the construction and permanent rights-of-way for the Orange 3 CSRM Plan reduced these impacts significantly. The Orange 3 CSRM element of the Recommended Plan would permanently convert approximately 36 acres of prime

farmland, as defined by the NRCS Web Soil Survey (USDA 2015), into a CSRM levee system. Approximately 61 additional acres would be temporarily unavailable for agriculture while in use as construction staging areas. No prime and unique farmlands would be impacted by construction of the Port Arthur and Vicinity or Freeport and Vicinity CSRM Plans.

Orange 3 CSRM Plan impacts on prime and important farmlands have been minimized to the greatest extent possible by locating the alignment at the upland/floodplain transition. Existing drainage patterns would be maintained, and surrounding land uses would remain compatible with agriculture in so much as they are today. The NRCS evaluated the impacts of the TSP and concluded that the sites would receive a total score of less than 160, and therefore need not be given further consideration for protection. The NRCS impact evaluation is consistent with impacts of the Recommended Plan, which results in fewer prime farmland impacts. NRCS coordination correspondence is provided in Appendix G.

6.15.11 Executive Order 11988, Floodplain Management

This Executive Order (EO) directs Federal agencies to evaluate the potential effects of proposed actions on floodplains. Such actions should not be undertaken that directly or indirectly induce growth in the floodplain unless there is no practicable alternative. The Water Resources Council Floodplain Management Guidelines for implementation of EO 11988, as referenced in USACE ER 1165-2-26, require an eight-step process that agencies should carry out as part of their decision making on projects that have potential impacts on or within the floodplain. The eight step assessment, presented later in this report, concludes that all practicable alternatives have been considered in developing the Recommended Plan, and that the main Federal objective of reducing coastal flood risk cannot be achieved by alternatives outside the floodplain. The Recommended Plan does not support direct or indirect floodplain development within the base floodplain. USACE and the study's NFS have lead public outreach efforts to local communities starting with the NEPA scoping meeting, and will continue throughout the study process.

6.15.12 Executive Order 11990, Protection of Wetlands

This EO directs Federal agencies to avoid undertaking or assisting in new construction located in wetlands, unless no practicable alternative is available. Construction of the Orange CSRM Plan would result in the conversion of about 160 acres of wetlands to a levee system. All practicable measures have been taken to minimize the loss of wetlands. Alternatives to avoid the loss of wetlands were evaluated, and the levee alignment was carefully located to minimize the loss. The alignment was reviewed during the final feasibility phase and impacts were reduced significantly from those presented in the DIFR-EIS. The DIFR-EIS afforded the public an opportunity for review prior to completion of the FIFR-EIS and the selection of a Recommended Plan. Based on these actions and considerations, it has been determined that the Recommended Plan is the only

practicable alternative. These impacts will be fully compensated by the mitigation plan so that there will be no net loss of wetlands.

6.15.13 Coastal Barrier Improvement Act of 1990

This Act is intended to protect fish and wildlife resources and habitat, prevent loss of human life, and preclude the expenditure of Federal funds that may induce development on coastal barrier islands and adjacent nearshore areas. The Coastal Barrier Improvement Act of 1990 was enacted to reauthorize the Coastal Barrier Resources Act (CBRA) of 1982. The Gulf shoreline area south and west of the existing Freeport HFP is designated as unit T05. Improvements to the existing levee system would be made within the existing levee right-of-way, which is not included in the CBRA unit. CBRA units in the Sabine Region are more than 10 miles south of the project area. No construction would occur within any of the CBRA zone units in the general area of the Recommended Plan in the Sabine and Brazoria regions.

6.15.14 Executive Order 12898, Environmental Justice

This EO directs Federal agencies to determine whether the Preferred Alternative would have a disproportionate adverse impact on minority or low-income population groups within the project area. Based on a demographic analysis of the study area presented in Appendix R and findings of an environmental justice review, the Recommended Plan would not have a disproportionately high and adverse impact on any low-income or minority population.

6.15.15 Executive Order 13186, Responsibilities of Federal Agencies to Protect Migratory Birds and the Migratory Bird Treaty Act

The Migratory Birds and the Migratory Bird Treaty Act (MBTA) of 1918 (as amended) extends Federal protection to migratory bird species. Among other activities, nonregulated "take" of migratory birds is prohibited under this Act in a manner similar to the ESA prohibition of "take" of threatened and endangered species. Additionally, EO 13186 "Responsibilities of Federal Agencies to Protect Migratory Birds" requires Federal agencies to assess and consider potential effects of their actions on migratory birds (including, but not limited to, cranes, ducks, geese, shorebirds, hawks, and songbirds). The effect of the Recommended Plan on migratory bird species has been assessed, and no impacts are expected on migratory birds or their habitat in the project area. Construction contracts would include instructions to avoid impacts on migratory birds and their nests from construction-related activities.

6.15.16 Executive Order 13045, Protection of Children from Environmental and Safety Risks

This EO requires Federal agencies to make it a high priority to identify and assess environmental health and safety risks that may disproportionately affect children and to ensure that policies, programs, activities, and standards address these risks. This report has evaluated the potential for the Recommended Plan to increase these risks to children, and it has been determined that children in the project areas would not likely experience any adverse effects from the proposed project.

6.15.17 Hazardous Wildlife Attractants On or Near Airports

In accordance with FAA AC 150/5200-33 and the Memorandum of Agreement among the FAA, the USACE, and other Federal agencies (July 2003), the Recommended Plan was evaluated to determine if proposed land uses could increase wildlife hazards to aircraft using public use airports in the study area. Only one element of the Recommended Plan (the Orange 3 CSRM Plan) included features which could be considered wildlife attractants. Potential attractants (three marsh mitigation features) were found to be located beyond the 5-mile perimeter of the Southeast Texas Regional Airport in Beaumont, Texas. No change in land use is proposed in conjunction with construction of two mitigation measures within the five-mile perimeter of the Orange County Airport. USACE provided this information to the FAA concluding that construction of the Recommended Plan would not constitute a change in land-use incompatible with airport operations. At the request of FAA, the TXDOT Aviation Division reviewed the impact analysis and concurred that the Recommended Plan is compatible with operation of the Orange County and Southeast Texas Regional airports. FAA made this request because evaluation of potential environmental impacts to these airports is the responsibility of TXDOT under terms of the FAA State Block Grant Program.

6.15.18 Consultation with Federally-recognized Indian Tribes

In accordance with the USACE Tribal Policy Principles, Presidential Memorandum (April 29, 1994) Government to Government Relations with Native American Tribal Governments, Executive Order 13175 (Consultation and Coordination with Indian Tribal Governments (November 06, 2000), and President Obama's Memorandum of November 5, 2009 – Tribal Consultation, USACE has contacted and coordinated with Federally-recognized Indian Tribes which have demonstrated an interest in the study to obtain their views and assess the impact of the proposed CSRM plans on tribal lands, resources and concerns. The Alabama Coushatta Tribe of Texas, the Comanche Nation of Oklahoma, the Coushatta Tribe of Louisiana, the Kiowa Indian Tribe of Oklahoma, the Mescalero Apache Tribe, and the Tonkawa Tribe of Oklahoma were contacted by letter in November, 2014, to inform them of the upcoming S2G study, invite them to

participate as cooperating agencies, coordinate the study schedule, and initiate consultation regarding any concerns the tribes may have regarding potential project impacts to sites, areas or resources of religious, cultural or other tribal interest. No responses were received from the tribes and no concerns or potential impacts were identified. The DIFR-EIS was provided to the same tribes in September 2015, and the tribes were notified that USACE intended to execute a Programmatic Agreement to govern the scope of cultural resource investigations, to be determined in concert with the Texas SHPO and Indian tribes. No comments on the DIFR-EIS or the Draft Programmatic Agreement were received from the tribes. The FIFR-EIS will be provided to the tribes during State and Agency Review.

7 ENVIRONMENTAL CONSEQUENCES*

Environmental consequences of the No Action Alternative and Recommended Plan are compared below. Impacts described below apply to all of the optimization heights of the alternatives in the Final Array. The right-of-way was sized to include lands needed to construct a levee or floodwall suitable for at least the Intermediate RSLC scenario plus additional lands needed for construction. A comparison of all factors compared in evaluating the Final Array of Alternatives, including environmental effects, is presented in Section 5.4 of this report.

7.1 PROTECTED LANDS

7.1.1 Orange 3 CSRM Plan

No Action Alternative. State-managed lands in the vicinity would continue to be conserved and managed for the benefit of fish of wildlife resources through the period of analysis. The Tony Houseman WMA is located at northeast end of the Orange CSRM Plan, north and south of Interstate 10. The Lower Neches River WMA includes three separate properties along the central section of the CSRM Plan in Orange County.

Recommended Plan. Impacts to TPWD property were avoided and minimized to the greatest extent practicable by modifying the new levee system's alignment location. Remaining unavoidable impacts of the Orange 3 CSRM plan would consist of approximately 80.1 total acres; 1.7 and 78.4 acres, respectively, in the Tony Houseman and Lower Neches River WMAs. Details of these impacts are shown in Table 7-1. Approximately 34.6 acres would be right-of-way impacts, while approximately 45.5 acres are remainders that would be not affected by construction, but cut-off from the rest of TPWD property in the area. In the Tony Houseman WMA, approximately 1.5 acres of the right-of-way impacts are forested wetlands and adjacent waters. In the Lower Neches WMA, approximately 19.8 acres of the right-of-way are wetlands, with the majority of impacts occurring to coastal marsh. The wetland impacts have been evaluated and quantified with the WVA model along with the other impacts of this plan. The plan would not impact any TPWD structures. All impacts are fully compensated by the overall mitigation plan described for the Orange 3 CSRM project. TPWD has agreed that the feasibility-level impact analysis is sufficient at this time, pending additional study and consultation during the PED phase as planned by USACE. Final approval or concurrence by TPWD cannot occur until requirements of Chapter 26 of the Parks and Wildlife Code are met, and that would occur after the project is authorized. At this time, no obstacles to this approval have been identified.

Table 7-1: Impacts on TPWD Property

	Acres of TPWD Property Impacts								
Property Name	BH	Swamp	Fresh	Intmd	Brackish	Water	Other	Remnants	Total
Tony Houseman WMA	0.5	0.4				0.7	0.0	0.2	1.7
Lower Neches River WMA									
Adams Bayou Unit		1.4	4.8	1.5		0.3	3.6	7.2	18.8
Old River Unit	0.2	0.0	3.9	0.0	2.8	0.2	10.0	37.3	54.5
Nelda Stark Unit	2.6		0.5				1.1	0.8	5.0
Total	3.3	1.8	9.2	1.6	2.8	1.1	14.8	45.5	80.1

7.1.2 Port Arthur and Vicinity CSRM Plan

No Action Alternative. State-managed lands in the vicinity would continue to be conserved and managed for the benefit of fish and wildlife resources through the period of analysis. The Big Hill Unit of the J.D. Murphree WMA is located on the west bank of Taylor Bayou, adjacent to the southwest levee of the existing Port Arthur HFP system.

Recommended Plan. No direct or indirect impacts on TPWD property or other protected lands are expected in conjunction with improvements to the Port Arthur CSMR Plan.

7.1.3 Freeport and Vicinity CSRM Plan

No Action Alternative. State-managed lands in the vicinity of the Freeport HFP system would continue to be conserved and managed for the benefit of fish and wildlife resources through the period of analysis. The Brazoria NWR and Justin Hurst WMA are located near the east and west boundaries, respectively, of the existing Freeport HFP system. These lands would continue to be managed for conservation and the benefit of fish of wildlife resources through the period of analysis.

Recommended Plan. No direct or indirect impacts on USFWS or TPWD property are expected in conjunction with improvements to the Freeport CSRM Plan.

7.2 PHYSICAL AND HYDROLOGICAL CHARACTERISTICS

7.2.1 Orange 3 CSRM Plan

No Action Alternative. The existing Sabine-Neches Waterway (SNWW) 40-foot deep-draft navigation channel passes through the study area, following the Orange-Jefferson County line.

Deepening of the existing channel to -48 feet MLLW was authorized by the Water Resources Reform and Development Act (WRRDA) of 2014. Deepening the channel would allow the saltwater wedge in the deep draft navigation channel to reach further inland and increase salinity in the lower Neches and Sabine River channels, as well as Sabine Lake (USACE, 2011). Since construction of the deeper channel is likely in the foreseeable future, projected FWP salinities from the SNWW feasibility study have been utilized as the FWOP salinities for impact evaluation in this study.

Future rates of freshwater inflow and RSLC are likely to result in significant changes in the FWOP condition for the study area (National Research Council [NRC], 1987; Intergovernmental Panel on Climate Change [IPCC], 2013; Milliken et al., 2008a). FWOP forecasts of salinity, marsh loss, and related impacts on plant and animal communities in the study area are important in establishing the baseline condition against which FWP impacts are measured. Project impacts and costs have been assessed against 50-year projections of the three potential rates of RSLC calculated for Sabine Pass, TX (Low – 1.63 feet; Intermediate – 2.32 feet; and High – 4.51 feet).

The high, generally flat terrace between the Sabine and Neches Rivers is on average 10 feet higher than the surrounding floodplains of the two rivers. Similarly, on the west bank of the Neches River, the flat coastal plain averages 10 to 15 feet higher than the floodplain. Extensive marshes line the Neches River floodplain on both sides of the river; however, the majority occur on the east side in Orange County. On the Sabine River, extensive marshes extend east from the river into Louisiana. In Texas, the narrow floodplains of Cow and Adams Bayous are lined with narrow fringes of forested wetlands, which give way to large marshes where they reach the Sabine River. These are the largest drainages in the Orange County area and are nearly the only drainages flowing east into the Sabine River. The western edge of the Orange County upland is drained by numerous, evenly spaced, small drainages, which cut from the upland to the large marshes in the Neches River floodplain. A few even smaller drainages flow into the Neches floodplain from the Jefferson County side. A map of the Sabine regions drainages and sub-basins is shown in Figure 7-1.

In the existing condition, freshwater inflows from the upland areas to marshes and forested wetlands in the floodplain are being conveyed primarily through existing stream channels. The majority of the time, flows are directed toward channels and ditches that discharge into the floodplain through existing drainages. Water flows into the Sabine and Neches Rivers through channels with incised beds, and in some cases flows spread out directly into wetland areas. Overland sheet flow is generally temporary, occurring during intense or long duration rain events. The degree to which shallow groundwater aquifers may contribute flows to the floodplain is unknown, but groundwater flows are assumed to be a minor contributor. It is believed that marshes in the floodplain rely primarily on rainfall and tidal push for inundation.

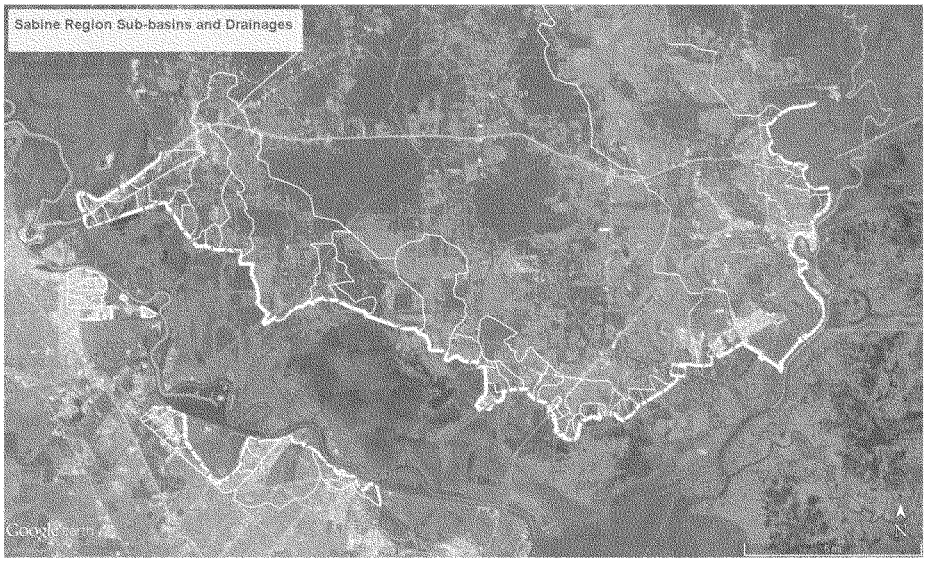


Figure 7-1: Sabine Regions Sub-basins and Drainages

The relatively high difference in elevation between the floodplain and the uplands will protect most of the developed upland areas from the effects of RSLC for the period of analysis. However, the larger tidal prism and higher water elevations will result in higher water levels in the large and small drainages, which cut from the uplands to the river valleys. Marshes may migrate further inland along these drainages as a result of the higher RSLC conditions.

Recommended Plan. Construction of the Orange CSRM Plan would result in a new levee/floodwall system around the southern upland/floodplain margin of Orange County . Such a system could potentially affect freshwater inflows to the floodplain downstream of the levee system by blocking or redirecting flows, and by inhibiting tidal flows into marshes located upstream of the levee system. The design of the levee/floodwall system would minimize these impacts to the greatest extent possible through the inclusion of an extensive culvert system that would allow flows through the levee at essentially FWOP conditions. Since discharge patterns and flows through the proposed Orange 3 CSRM system should be similar to future without-project conditions, impacts to sediment transport would be minimal. In addition, an analysis of potential effects of the Adams and Cow Bayou surge gates (presented in Appendix D), indicates that these gates would have little impact on sediment transport if designed to maximize flows during storm events. Flows in those bayous are very slow and the tidal prisms are very limited, so

even a constriction as large as 50 percent would have negligible impacts on water surface elevations and salinities, even during large storm events. Under median flows and the maximum constriction assumed for the modeling, some impacts to maximum inlet velocity and wetland water surface elevation are possible if surge coincides with a large freshwater inflow event. These impacts can and will be mitigated by inclusion of design elements, such as vertical lift gates next to the surge gates and gated culverts in the adjacent levee system.

7.2.1.1 Design Accommodations to Minimize Impacts

Gated culverts would be placed everywhere the red drainage lines intersect the yellow levee alignment shown in Figure 7-1. Sluice gate culverts are planned for use everywhere there are tidal flows; flap gate culverts may be utilized in upstream areas above tidal influence. The levee alignment, drainage basins and proposed culvert locations were evaluated in detail using aerial images to check for smaller, secondary drainages where culverts would also be needed to maintain flows to adjacent wetlands. Approximately 13 new culverts, recommended as a result of this analysis, have been incorporated into the project design where additional connectivity appeared to be needed.

Culverts have been designed to maintain existing flows for a 100-year rainfall event, with an additional 10 percent to account for the predicted increase in rainfall due to climate change over the period of analysis. The sluice gates would remain open except when surge risk reduction is needed; they would be closed temporarily for a short period before and after a storm occurs. Flap gate culverts would provide for one-way flow downstream from the levee system. Both culvert types will be designed with longer spans and lower heights than would typically be used in an attempt to replicate the natural drainage profile.

In the existing condition, freshwater inflows from the upland areas to marshes and forested wetlands in the floodplain are being conveyed primarily through existing stream channels. The majority of the time, flows are directed toward channels and ditches that discharge into the floodplain through existing drainages. A channel would be constructed along the inside of the levee system to collect flows and direct them into the existing stream channels, replicating the flow pattern of the majority of flows entering the floodplain. Impacts from overland flows are expected to be minimal because these flows are minor and temporary.

During a surge event, the sluice gates in the culverts would be closed; pumps would be used to pump rainfall runoff from the interior to the exterior. The pumps are being conservatively sized to avoid floodplain impacts on the interior of the levee system, and to allow overbank flooding in the streams in the floodplain outside of the levee during high flow events. Hydrologic flows in the

FWP condition would thus be very similar to FWOP flows in location, duration, and magnitude, both inside and outside of the levee system.

Based on these assumptions, it was determined that the levee would have negligible impacts on the general hydrology of the floodplain both inside and outside of the levee system. Because this determination rests heavily on these assumptions, resource agencies have requested to be involved in the development of the Operation Manual during the PED phase and during subsequent periodic reviews when the Operation Plan is reevaluated to determine project performance under future conditions, including potentially higher than anticipated rates of RSLC.

The potential for hydrologic impacts of proposed surge gates on Adams and Cow Bayous was evaluated using ERDC's DOWSMM desktop hydrologic model. This modeling indicates negligible impacts on the water surface elevation and salinity within Adams and Cow Bayous from potential constrictions to the channel cross-section with the proposed surge gates in their normal open condition. This was determined by a sensitivity analysis conducted on the inlet size for each bayou, based on the assumption that construction of the gates would result in some reduction of the cross-section while open to daily flows. In the analysis, bayou cross-sections were reduced by a wide range of estimated parameters, up to a maximum 75 percent constriction. It was determined that the limited tidal prism associated with the bayous results in minimal energy loss across the connection between the bayous and the Sabine River, and therefore, constriction of this access point results in little change in the tidal energy passing into the bayou. The insensitivity of the water surface elevation and the salinity impacts gives high confidence that the general conclusion associated with this study is robust; constriction of the inlet, even significant constriction, results in minimal impacts on water surface elevation and salinity within the bayous.

The extent to which these constrictions would impound stormwater within the bayous was also examined by evaluating the effects of a significant rainfall event (Tropical Storm Allison) that had been captured in the median flow simulation. Once again, this analysis applies to the normal, open condition of the gate and evaluated the impacts of rainfall not associated with a significant storm surge event. Given the type of structures currently being evaluated (sector gates on the navigation channels with one or more flanking vertical lift gates to maintain flows on one or both sides of the navigation gates), it is estimated that existing flows may be reduced by a maximum of 50 percent. The DOWSMM analysis showed that, even for a 50 percent constriction, the volume of water resulting from such a storm could still pass through the constriction with little impact on upstream stage. There was no attempt made to determine if this storm event represented a project flood, and hence a larger storm could have a more significant impact.

Impacts related to the temporary closure of the gates were also considered to determine whether fisheries migration would be impacted with short-term surge-related gate closures. The degree of impact would be influenced by the timing and duration of a structure closure relative to peak migration seasons. At this time, it is assumed that the return interval for storm surges high enough to threaten the project area would be 10 to 15 years. Gates and culverts would need to be closed for large storm events, even if the storm occur more frequently than this predicted return period. The Operating Plan for the gates and culverts has not yet been developed, but the estimated closure time (one week for each storm event or up to two weeks for periodic maintenance) would result in only minor and temporary impacts to fisheries access. It is not anticipated that the gates, once closed, would remain closed for an extended period. The project design includes a pump system that would significantly reduce the flood duration upstream of the structures after when the gates are closed. It must be noted, however, that should the final structure design of the Cow and Adams surge gates reduce the cross section of the bayous by more than 50 percent, additional modeling and environmental analysis would be needed to more thoroughly characterize potential hydrologic impacts of the gate structures.

7.2.1.2 Unavoidable Indirect Impacts

Despite all efforts to minimize impacts, some indirect functional impacts of the Orange 3 CSRM Plan remain. These are related to fisheries access impacts on the extensive marshes in the lower Cow and Adams Bayous floodplains from the Cow and Adams Bayou surge gate structures, and to localized hydrologic impacts caused by levee system location and construction.

Based on all of the above analyses and assumptions, it appears that the only significant impact of the Cow and Adam Bayous surge gate structures would be reductions in fisheries access to estuarine marshes associated with the day-to-day operation in the open condition. The fisheries impacts are discussed in detail in the section on fish and wildlife impacts below.

A few localized indirect hydrologic impacts remaining after avoidance and minimization efforts were also identified. An analysis of the location of the levee system alignment identified small areas that would be impounded between the new levee and terrace bluff. These impoundments would result in the loss of small stands of swamp and bottomland hardwood. Construction of the Cow Bayou gate structure and levee system would indirectly affect a few areas both inside and outside the levee system by permanently disrupting tidal connections. Tidal access to one bottomland hardwood area outside of the levee would also be permanently disrupted by levee construction activities. Indirect impacts in the vicinity of the Cow Bayou structure could be higher under the Intermediate and High RSLC, as wetlands could have persisted and migrated further inland in without the hydrologic disruptions caused by gate construction. Specific information on these losses is provided in the Coastal Marsh and Forested Wetland impact sections below.

The indirect wetland impacts described above have been captured and quantified with WVA modeling that is described in detail in Appendix O. Impacts calculated for the Intermediate RSLC condition were utilized to determine compensatory mitigation.

7.2.2 Port Arthur and Vicinity CSRM Plan

No Action Alternative. The area served by the existing Port Arthur HFP System is densely covered with residential, commercial, and industrial development with a few isolated wetland areas. Drainages flow primarily into the Neches River to the north, the Sabine-Neches Canal to the east, and Taylors Bayou to the west. The configuration of the HFP would continue to be maintained at the existing dimensions. Higher water levels associated with Intermediate and High RSLC could result in overtopping during future storm surges.

Recommended Plan. The Port Arthur CSRM Plan improvements would not result in physical impacts on the floodplain or hydrology; no changes in the general layout of the right-of-way are planned. Interior drainage would be managed in the same manner as the Orange CSRM Plan, such that improvements would have negligible impacts on the general hydrology of the floodplain both inside and outside of the levee system. No impacts on the large marsh systems west of the Port Arthur CSRM Plan are expected.

7.2.3 Freeport and Vicinity CSRM Plan

No Action Alternative. The existing Freeport Harbor Project (FHP) 45-foot deep-draft navigation channel extends from deep water in the Gulf of Mexico into the south-central area of the existing Freeport HFP system. Freeport Harbor is located on the Old Brazos River Channel, which dead-ends near State Highway 288. The waterway is heavily developed with industrial and commercial properties, including petrochemical manufacturing and storage terminals, warehousing, and related businesses. Deepening of the existing channel to 56 feet MLLW was authorized by the Water Resources Reform and Development Act (WRRDA) of 2014. Deepening the channel is not expected to have significant effects on salinity or circulation since proximity to the Gulf and lack of freshwater inflows make existing salinities in the channel very high.

Future rates of freshwater inflow and RSLC are likely to result in significant changes in the FWOP condition for the study area (National Research Council [NRC], 1987; Intergovernmental Panel on Climate Change [IPCC], 2013; Milliken et al., 2008a). FWOP forecasts of salinity, marsh loss, and related impacts on plant and animal communities in the study area are important in establishing the baseline condition against which FWP impacts are measured. Project impacts and costs have

been assessed against 50-year projections of the three potential rates of RSLC calculated for Freeport, TX (Low – 1.26 feet; Intermediate – 1.94 feet; and High – 4.13 feet).

The area within the Freeport HFP system is dense industrial and commercial development, with small residential areas. No natural wetlands are present in the majority of this area; however, marsh and forested wetlands are present in areas adjacent to Oyster Creek on the northeastern side of the system. Existing interior drainage systems have maintained sufficient flows to allow these areas to persist despite their location within the levee system.

Recommended Plan. The Freeport CSRM Plan would replace floodwalls, raise levees, and install resiliency features. Improvements would be made within the existing project right-of-way and thus would have little impact on physical characteristics of the system. A surge gate structure, similar to those proposed for Cow and Adams Bayous in the Sabine region, is proposed for the DOW Barge Canal. This is a man-made, dead-end, industrial canal lying in the center of the existing Freeport HFP system; no wetlands lie along the canal. The gate would normally remain open, being closed for short periods before and after expected storm surges. Construction of the gate would result in some degree of flow constriction, but effects on salinity and water surface elevation would be low because of the limited tidal prism associated with the canal.

7.3 COASTAL PRAIRIE

7.3.1 Sabine Region CSRM Plans

The Orange 3 and Port Arthur and Vicinity CSRM Plans are combined for this impact evaluation.

No Action Alternative. No remnant tracts of native tall grass or salty prairies have been identified in the Sabine region project areas.

Recommended Plan. Recommended Plan improvements would be contained within the existing right-of-way; no impacts on coastal prairie are anticipated.

7.3.2 Freeport and Vicinity CSRM Plan

No Action Alternative. Coastal prairie would continue to be critically imperiled in the Brazoria region. No remnant tracts of native tall grass or salty prairies have been identified in the study area. The nearest known prairie restoration sites are located in the Brazoria and San Bernard NWRs, located east and west of the Brazoria study area.

Recommended Plan. Improvements would be contained within the existing right-of-way. No impacts to coastal prairie are anticipated.

7.4 COASTAL MARSH

7.4.1 Orange 3 CSRM Plan

No Action Alternative. Tens of thousands of acres of coastal marsh are present in the study area, located primarily in the floodplains of the Sabine and Neches Rivers, as well as Cow and Adams Bayous. These marshes would be expected to persist, with some areas undergoing slow wetland loss and conversion to open water over the period of analysis. In the lower Neches River Valley, this conversion is caused by subsidence and faulting (sometimes related to oil and gas production), dredged canals, alteration of hydrologic regime (due to channelization and placement of dredged material), decreased input of fluvial sediment (due to upstream dams), and construction of artificial levees (White and Tremblay 1995). Similar factors are responsible for marsh loss in the Sabine River Basin. Recent wetland loss rates (1984-2014) have been calculated by USGS for 12 subunits of the study area by analyzing multiple dates of cloud-free Landsat imagery from 1984-2014 (USGS 2014). The loss rates range from a low of 0.0052 percent per year in the Bessie Heights area on the Neches River, to a high of 0.0982 percent per year in the Old River Cove area along the north shore of Sabine Lake. These rates would be expected to increase under the Intermediate and High RSLC scenarios. This expectation is based on the negative relationship between RSLC and wetland loss rates that has been observed in coastwide non-fresh marshes outside of active deltaic influences in Louisiana (USACE, 2013).

Recommended Plan. Direct impacts from construction of the 27-mile-long levee/floodwall system in Orange County would result in the loss of about 105.3 acres of coastal marsh (fresh – 24.3 acres; intermediate – 6.8 acres; brackish – 74.2.0 acres) and 49.0 AAHUs. The right-of-way was sized to include lands needed to construct a levee or floodwall suitable for the Intermediate RSLC scenario plus additional lands needed for construction, and it was assumed that all wetlands within the right-of-way would be permanently lost due to construction. The plan currently calls for all earthen material for the levee system to be obtained from approved, commercial, upland borrow sources. If new borrow areas are identified during final feasibility planning or prior to construction, these areas will be evaluated for impacts in coordination with the resource agencies and the appropriate NEPA document will be prepared. Staging areas needed to support construction have been located in previously disturbed or non-wetland upland areas.

Construction of the new levee system would also result in some indirect impacts resulting in the loss of marsh. A careful examination of the proposed alignment identified several areas where marsh would be impounded between the levee or floodwall and the upland bluff, or where

hydrologic connections would be permanently disrupted by levee system construction. These indirect impacts would result in the loss of about 97.7 acres of intermediate and brackish marsh and 43.7 AAHUs.

The direct and indirect coastal marsh impacts described above have been illustrated, captured, and quantified with WVA modeling that is described in detail in Appendix O. Impacts calculated for the Intermediate RSLC condition were utilized to determine compensatory mitigation.

7.4.2 Port Arthur and Vicinity CSRM Plan

No Action Alternative. Fresh and intermediate wetlands are located within the existing levee system, with the majority clustered in a low-lying central area. Some wetlands are located along the exterior perimeter of the levee system, along the Neches River and Taylor Bayou. The floodplain marshes are experiencing wetland loss rates similar to marshes in Orange County, but would be expected to persist through the period of analysis.

Recommended Plan. Improvements from the Port Arthur CSRM Plan would result in no impacts on coastal marsh. All construction activities would be confined to the existing right-of-way or immediately adjacent industrial areas.

7.4.3 Freeport and Vicinity CSRM Plan

No Action Alternative. No natural wetlands are present in the majority of the area served by the existing Freeport HFP system; however, marsh and forested wetlands are present in areas adjacent to Oyster Creek on the northeastern side of the system. These areas would be expected to persist through the period of analysis.

Recommended Plan. No coastal marsh would be impacted by construction of the Freeport CSRM Plan. Recommended Plan improvements would be made within the existing project right-of-way and thus will have no impact on coastal marsh. BMPs would be utilized to ensure no inadvertent filling of adjacent marsh areas during construction.

7.5 FORESTED WETLANDS

7.5.1 Orange 3 CSRM Plan

No Action Alternative. Thousands of acres of forested wetlands are present in the study area, located primarily in the upper floodplains of the Sabine and Neches River, and along Cow and Adams Bayous. Isolated stands of bottomland hardwoods are also scattered across the undeveloped interior of Orange County. Swamps would be subject to increasing stress due to

salinity increases associated with RSLC. It is expected that some of the forested wetlands would be lost to development over the period of analysis. Generally, development activities are regulated under Section 404 of the Clean Water Act, and these losses would likely be replaced by required compensatory mitigation. Other unregulated losses would also be expected, especially in relation to silviculture and borrow area activities that are expected to continue in the study area. Depending upon specific circumstances, these activities may not be regulated and forested wetland losses would not be replaced.

Recommended Plan. Direct impacts during construction of the new levee system would result in the loss of about 54.9 acres of forested wetland (swamp –10.6 acres; bottomland hardwood – 44.3 acres), resulting in the loss of 37.4 AAHUs. The right-of-way was sized to include lands need to construct a levee or floodwall suitable for the Intermediate RSLC scenario plus additional lands needed for construction, and it was assumed that all wetlands within the right-of-way would be permanently lost due to construction.

Construction of the new levee system would also result in some indirect forested wetland impacts. Approximately 14.6 acres of swamp and bottomland hardwoods would be impounded between the levee or floodwall and the upland bluff, or would be adversely affected by disrupted tidal access. These impacts are expected to result in the eventual loss of the forested wetlands, represented by a loss of 5.2 AAHUs.

The direct and indirect coastal marsh impacts described above have been captured and quantified with WVA modeling that is described in detail in Appendix O. Impacts calculated for the Intermediate RSLC condition were utilized to determine compensatory mitigation.

7.5.2 Port Arthur and Vicinity CSRM Plan

No Action Alternative. Small pockets of forested wetlands (primarily bottomland hardwoods) are scattered through the less densely developed areas within the levee system. A few small bottomland hardwood areas are located adjacent to the levees along the Neches River. It is expected that some of the forested wetlands would be lost to development over the period of analysis. Generally, development activities are regulated under Section 404 of the Clean Water Act, and these losses would likely be replaced by required compensatory mitigation.

Recommended Plan. Recommended Plan improvements would result in no impacts on forested wetlands. All construction activities would be confined to the existing right-of-way or immediately adjacent industrial areas.

7.5.3 Freeport and Vicinity CSRM Plan

No Action Alternative. Small pockets of forested wetlands (primarily bottomland hardwoods) are scattered through the less densely developed areas within the levee system. The greatest concentration is scattered along the levees adjacent to Oyster Creek. It is expected that some of the forested wetlands would be lost to development over the period of analysis. Generally, development activities are regulated under Section 404 of the Clean Water Act, and these losses would likely be replaced by required compensatory mitigation.

Recommended Plan. All improvements would be made within the existing project right-of-way and thus would have no impact on forested wetlands. Best management practices would be utilized to ensure no inadvertent impacts on adjacent wetland forests during construction.

7.6 IMPACTS TO FISH AND WILDLIFE AND THEIR HABITATS

7.6.1 Fish and Wildlife Impacts

7.6.1.1 Sabine Region CSRM Plans

The Orange 3 and Port Arthur and Vicinity CSRM Plans are combined for this impact evaluation.

No Action Alternative. Natural habitats within the Orange 3 CSRM Plan construction right-of-way would continue to provide cover, roosting, foraging, and nesting habitat for fish and wildlife during the period of analysis. Some marsh may convert to open water in the Sabine and Neches River floodplains, but most of the wetland habitats would be expected to persist over the 50-year period of analysis. In Orange County on the Sabine River and in the vicinity of Bridge City, the majority of the upland/floodplain transition in the area considered for the new levee alignment is lined by development or placement areas. Between Bridge City and Rose City, most of the upland/floodplain transition is undeveloped.

In Jefferson County, the transition from the uplands to the Neches floodplain in the area affected by the CSRM plan is lined with continuous urban or industrial development. Wildlife accesses the floodplain using narrow corridors through development or crossing over leveed placement areas, in addition to passing through natural areas. Fishery access is unobstructed in most streams and bayous. Fish and wildlife access is unobstructed across the levees of the existing Port Arthur HFP levee system, on the northeast and southwest sides of the system. The right-of-way of the existing system is maintained as cleared, grassy levee with side slopes, and as floodwall systems. Existing culverts are open in their normal, operating condition; they are closed for short periods before and after storm surge events.

Recommended Plan. Direct impacts of construction of the Orange 3 CSRM Plan would result in the destruction of approximately 160.2 acres of natural fish and wildlife habitat over the 50-year period of analysis; indirect impacts described above would result in the loss of approximately 112.3 acres of forested wetlands and marsh. No direct or indirect impacts on fish and wildlife habitat would be expected from construction of the Port Arthur and Vicinity CSRM Plan. During construction, fish and wildlife would be able to move out of construction corridors into adjacent habitat and avoid harm; however, competition for remaining habitat might result in a small reduction in wildlife productivity. BMPs would be enforced to prevent fill material from entering nearby wetlands or waters. Forest clearing during construction would be conducted during the fall or winter to minimize impacts on nesting migratory birds, when practicable. Forested areas in the construction right-of-way would be surveyed prior to construction to avoid impacting nesting bald eagles. Adverse impacts to bald eagle nesting locations would be avoided in accordance with the National Bald and Golden Eagle Management Guidelines, as recommended by the USFWS CAR for this project. Terrestrial wildlife would be able to cross-earthen levee segments to access remaining habitat on either side, as it does now across the levees of the Port Arthur HFP. Floodwall segments would generally be located in developed areas and limited in length; wildlife would be able to utilize nearby levee segments for access as needed. Fisheries access would be maintained at FWOP levels with only negligible impacts as described in the physical and hydrological impacts section.

The Cow and Adam Bayous surge gate structures would result in functional impacts to fisheries access and minor effects on sediments, nutrients and organic matter transfer in extensive marshes in the bayou floodplains upstream of the gated structures (Figures 7-2 and 7-3) from day-to-day operation in the open condition. These impacts could be expected to affect approximately 1,300 and 900 acres of coastal marsh in the Cow and Adams Bayou floodplains, respectively, resulting in the loss of 50.5 AAHUs over the period of analysis. The upstream limit of the affected areas, defined to include all upstream marshes in the bayou floodplains, is approximately 7.7 stream miles upstream of the Cow Bayou structure and 4.4 stream miles upstream of the Adams Bayou structure.

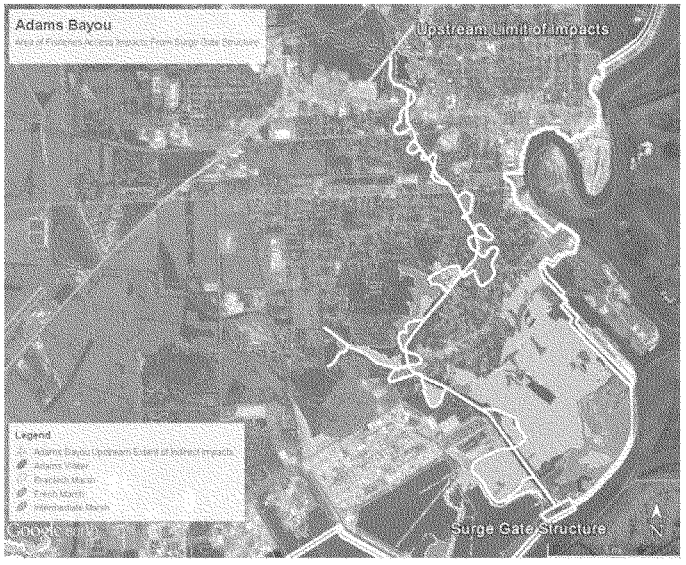


Figure 7-2: Adams Bayou Indirect Fisheries Impact of Surge Gate Structure

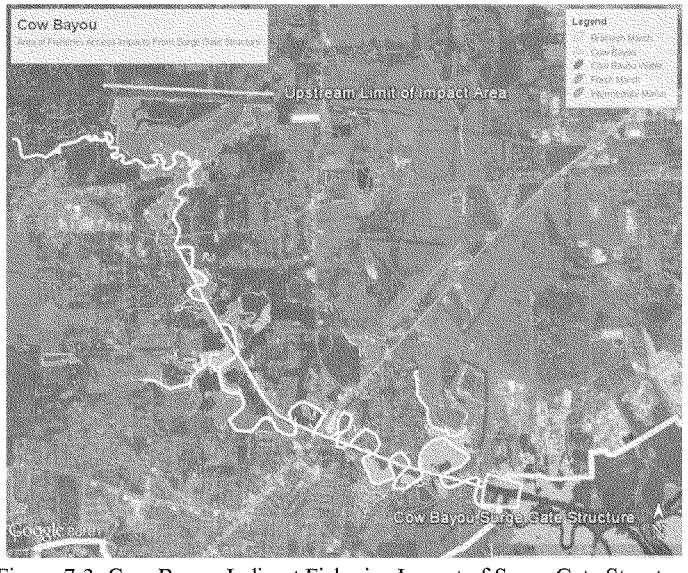


Figure 7-3: Cow Bayou Indirect Fisheries Impact of Surge Gate Structure

According to the NMFS (2008), the ability of estuarine dependent marine fishery organisms to migrate to and from coastal habitats decreases as structural restrictions increase, thereby reducing fishery production (Hartman et al. 1987; Rogers et al. 1992; Rozas and Minello 1999). The physical ability (i.e., swimming speed) to navigate through a structure is not the only factor influencing fish passage. Both behavioral and physical responses govern migration and affect passage of fishery organisms through structures. These responses may vary by species and life stage. In addition, most marine fishery species are relatively planktonic in early life stages and are dependent on tidal movement to access coastal marsh nursery areas. For this reason, in general, the greater the flow through a structure into a hydrologically affected wetland area, the greater the marine fishery production functions provided by that area. It should not be assumed that structures that have been determined to provide sufficient drainage capacity also optimize or provide adequate fishery passage. Structures constructed along the sides of Cow and Adams Bayou would interfere with organism movement into and out of the bayou, but this impact could be minimized by following specific NMFS design recommendations.

Since only preliminary information on the Cow and Adams gate structures is available at this time, the WVA indirect impacts analysis assumed that the structures would reduce the cross-sectional area of the bayous by 50 percent. Final structural designs would incorporate fisheries-friendly considerations recommended by NMFS (2008) to the greatest extent possible. If it is determined during PED that the final feasibility design would reduce the cross-sectional area of the bayou inlets by more than 50 percent, impacts will be reevaluated and additional investigations conducted as needed. The direct and indirect coastal marsh impacts described above have been captured and quantified with WVA modeling that is described in detail in Appendix O.

7.6.1.2 Freeport and Vicinity CSRM Plan

No Action Alternative. The right-of-way of the existing Freeport HFP system is maintained as cleared, grassy levee and side slope areas, and as floodwall systems. Natural habitats adjacent to the construction right-of-way would continue to provide cover, roosting, foraging, and nesting habitat for wildlife during the period of analysis. The exterior levees follow Oyster Creek on the east and the Brazos River Diversion Channel on the west. Wildlife access is unobstructed across the levees along these levee segments.

Recommended Plan. Freeport and Vicinity CSRM Plan improvements would be accomplished within the existing right-of-way. During construction, fish and wildlife would be able to move out of construction corridors into adjacent habitat and avoid harm. BMPs would be enforced to prevent fill material from entering nearby wetlands or waters. Forest clearing during construction would be conducted during the fall or winter to minimize impacts on nesting migratory birds, when practicable. Terrestrial wildlife would be able to cross-earthen levee segments to access remaining

habitat on either side. Floodwall segments would generally be located in developed areas and limited in length; wildlife would be able to utilize nearby levee segments for access as needed. There is little potential for bald eagle nests in the vicinity of the levee system because of the low quality and size of forested wetlands in the area.

7.6.2 Essential Fish Habitat Impacts

7.6.2.1 Sabine Region CSRM Plans

The Orange 3 and Port Arthur and Vicinity CSRM Plans are combined for this impact evaluation because EFH conditions and impacts are similar.

No Action Alternative. Estuarine habitats in the study area (estuarine emergent marsh, estuarine submerged aquatic vegetation, and estuarine mud/soft bottoms) would continue to be open and available for use by fish and shellfish through the period of analysis. Shallow open water estuarine areas are likely to increase and estuarine emergent marsh is likely to decrease as a result of RSLC.

Recommended Plan. Direct and indirect impacts associated with construction of the Orange 3 CSRM Plan would result in the loss of about 203.0 acres of estuarine emergent marsh over the period of analysis. Marsh acres include water within the marsh and small drainages; some SAV in the estuarine marsh areas would also be lost. These acres would be replaced by in-kind mitigation in the amount determined using the WVA model and the CE/ICA incremental analysis; all impacts would be fully compensated with the restoration of estuarine emergent marsh and shallow water.

Construction of the Cow and Adams Bayous surge gates would result in the loss of approximately 11 acres of estuarine soft bottom EFH. This is the area estimated for the footings of the gate structures. This water area has been included in the WVA impact analysis, and the loss will be fully compensated by shallow water restoration in association with marsh mitigation.

Construction would result in the temporary burial of benthic organisms and temporary increases in water column turbidity in the vicinity of the Cow and Adams Bayous gates. Recovery of benthic macroinvertebrates following burial is typically rapid (recovering within months rather than years) (VanDerWal et al., 2011; Wilber et al., 2006; Wilber and Clarke, 2001), and consequently no long-term effects are expected. The displacement of finfish and shrimp species (including estuarine dependent organisms that serve as prey for Federally managed species) during levee system construction would be temporary and individuals should move back into these specific areas once the project is completed.

The Cow and Adam Bayous surge gate structures would constrict flows in these bayous while in their normal open condition, resulting in functional fisheries access impacts on a total of about 2,137 acres of estuarine emergent marsh in the bayou floodplains upstream of the gated structures. These impacts could be expected to affect approximately 1,235 and 902 acres of coastal marsh in the Cow and Adams Bayou floodplains, respectively, resulting in the loss of 50.5 AAHUs over the period of analysis. The functional loss to these marsh systems would be replaced by the mitigation plan's marsh restoration, in the amount determined using the WVA model and the CE/ICA incremental analysis; all impacts would be fully compensated with the restoration of estuarine emergent marsh and shallow water.

No impacts on EFH are expected from the Port Arthur CSRM Plan. In most areas, construction would take place within the existing right-of-way and from barges in adjacent waterways. No improvements are proposed in the vicinity of the two gates along Taylor Bayou on the southwest side of the system.

7.6.2.2 Freeport and Vicinity CSRM Plan

No Action Alternative. Estuarine habitats in the study area (estuarine emergent marsh, estuarine submerged aquatic vegetation, and estuarine mud/soft bottoms) would continue to be open and available for use by fish and shellfish through the period of analysis. Shallow open water estuarine areas are likely to increase and estuarine emergent marsh is likely to decrease as a result of RSLC.

Recommended Plan. EFH would not be significantly affected by construction of the Freeport CSRM Plan. Construction of a surge gate at the mouth of the DOW Barge Canal would permanently affect up to 3 acres of soft bottom. However, there is no estuarine emergent marsh or other natural habitat lining the canal, tidal energy and flushing is low, water quality is poor, and the canal provides little benefit to shell or finfish that may enter it. Therefore, impacts on EFH would be negligible. The displacement of finfish and shrimp species (including estuarine dependent organisms that serve as prey for Federally managed species) during gate construction would likely be temporary and individuals should move back into these specific areas once the project is completed. The potential harm to some individual finfish and shellfish from temporary turbidity-related impacts would be minimal and would not reduce any populations of Federally managed species or their prey.

7.6.3 Threatened and Endangered Species Impacts

This evaluation was combined for the Sabine and Brazoria regions, as listed species are generally the same for both.

No Action Alternative. Hopper dredging at the SNWW and Freeport Entrance Channels would continue with potential for takes of threatened and endangered green, Kemp's ridley, loggerhead, and hawksbill sea turtles. These potential impacts are addressed in the November 19, 2003, Gulf Regional Biological Opinion (GRBO) to USACE on Hopper Dredging of Navigation Channels and Borrow Areas in the U.S. Gulf of Mexico, and Revision 2 to the GRBO, issued January 9, 2007, for USACE dredging projects on the Gulf Coast. Existing threats to the twelve remaining listed and three candidate species described below would be expected to be minor, as most of the species rarely occur, and some do not occur, in the project areas.

Recommended Plan. The Orange 3 CSRM Plan and the Port Arthur and Freeport and Vicinities CSRM Plans would have no effect on the following listed animal species: piping plover, red knot, whooping crane, the West Indian manatee, four whale species (fin, humpback, sei, and sperm), four sea turtle species (green, Kemp's ridley, loggerhead, and hawksbill), and four coral species (lobed star, mountainous star, boulder star, and elkhorn). The CSRM plans would also have no effect on the following Candidate species: Sprague's pipit, and two freshwater mussel species (smooth pimpleback and Texas fawnsfoot). No critical habitat is located in the project areas. The details of this assessment may be found in the USACE Biological Assessment (Appendix J).

7.7 WATER AND SEDIMENT QUALITY IMPACTS

7.7.1 No Action Alternative

7.7.1.1 Sabine Region CSRM Plans

No Action Alternative. Several stream segments in the Sabine region have been classified by TCEQ (2014) as non-supporting for aquatic life, recreation, fish consumption, and general uses. Sampling of tidal segments of the Sabine and Neches Rivers and the GIWW (ID # 501, 702) has identified undesirable levels of bacteria (Enterococcus and E-coli) and PCB's in edible fish tissues. Tidal segments of small streams such as Little Cypress, Adams Bayou, Gum Gully, Cow Bayou, Coon Bayou, and Cole Creek (ID #'s 501B, 508, 508B, 511, 511B, and 511C) have low flows, little tidal energy, high dissolved solids, and high turbidity due to a heavy clay substrate and forest detritus; they generally report depressed levels of dissolved oxygen and undesirable levels of bacteria and certain nutrients. Little Cypress Bayou also exhibits water toxicity, as do the lower segments of the Neches River and Star Lake Canal, near the confluence of the Neches River and Sabine Lake. Freshwater stream segments in the Sabine region generally have higher water quality than do tidal segments, with a few, such as Adams Bayou, Gum Gully, Cow Bayou, Taylor Bayou/North Fork, and Alligator Bayou (ID # 508A, 508B, 511A, 701, and 702A, reporting depressed levels of dissolved oxygen and high bacteria levels.

An implementation plan has been developed to improve water quality for support of recreational and aquatic life uses for the Cow and Adams Bayou watersheds (Orange County Stakeholder Advisory Group, 2015). The plan addresses nonpoint discharges from failing onsite sewage facilities, pastures, forests, and urban runoff, as well as primary point sources such as wastewater treatment facilities and illicit discharges. Water quality will improve marginally over the period of analysis if the stakeholders are successful in reducing existing discharges. Circulation and tidal flows may increase as RSLC increases tidal flows into the region.

Shoaled sediments in the Sabine region are fine-textured (mean percent clay is 76 percent) and generally of good quality, as evidenced by testing of water and sediments in conjunction with maintenance dredging of existing navigation channels and proposed modifications for the SNWW (USACE, 2011; SOL, 2012). A routine water and sediment testing contract is planned in the near future to support USACE maintenance dredging of the Neches River Channel; sediment testing for dioxin has been added due to the historic presence of paper mills in the region.

7.7.1.2 Freeport and Vicinity CSRM Plan

In the Brazoria region, only one stream has been classified as impaired; Oyster Creek (ID # 1109) is identified as non-supporting for recreation use due to undesirable levels of bacteria. Shoaled sediments in the navigation channels are generally of good quality, a evidenced by testing of water and sediments in conjunction with maintenance dredging of existing navigation channels and proposed modifications for the Freeport Harbor Channel (USACE 2012), and the mouth of the San Bernard River (USACE 2008).

7.7.2 Recommended Plan

7.7.2.1 Sabine Region CSRM Plans

Fill material required to construct the Orange 3 CSRM Plan would be obtained from approved, upland, commercial borrow sources that have undergone contaminant testing. If it is necessary, during the PED or Construction Phase, to designate new borrow areas, these areas would be evaluated for environmental impacts prior to use. If adverse effects to the environment would occur with their development, the proposed action would be coordinated with resource agencies and NEPA documents prepared as required by CEQ regulations.

A Clean Water Act Section 404(b) (1) Evaluation is presented in Appendix H. The majority of the fill material would be placed in upland areas; however, approximately 160 acres of marsh and forested wetlands would be directly impacted by the placement of fill material by bulldozers and possibly drag-line cranes, or excavation to construct floodwalls. The proposed alignment has been located to minimize, to the greatest extent practicable, impacts on the Neches and Sabine River

floodplains and to avoid and minimize impacts on the aquatic ecosystem. Unavoidable, significant impacts would be fully mitigated. A detailed description of these wetland impacts is provided in Appendix O.

Construction of the Cow and Adams Bayou surge gates would result in temporary increases in water column turbidity in the vicinity of the Cow and Adams Bayou gates. These bayous are normally turbid due to the high clay content of bayou sediments. No long-term effects from temporary turbidity increases are expected. However, because of the potential for contaminants in the Sabine and Neches Rivers, the areas to be disturbed by construction of the Adams and Cow Bayous surge gates will be tested prior to construction during the PED phase. In addition, the right-of-way for other locations where construction would require significant disturbance in aquatic environments would be reviewed, and sediment testing would be conducted in those locations if warranted. If contaminated sediments are identified by testing, a plan to avoid or remediate will be developed by USACE and the non-Federal sponsor, and a new National Environmental Policy Act (NEPA) document would be prepared if needed.

Discharges of fill material into wetlands and waterways adjacent to the upland fill or excavation areas would be minimized by the use of silt curtains to minimize turbidity impacts; forestry BMPs, such as water bars and diversion ditches, would be utilized if needed to stabilize disturbed forest floors and prevent erosion. Potential impacts on flows and interior flooding were described above in the section on impacts on physical and hydrological characteristics of the Sabine Region. The potential for hydrologic impacts on Adams and Cow Bayous was evaluated, and modeling indicates negligible impacts on the water surface elevation and salinity within Adams and Cow Bayous from potential constrictions to the channel cross-section with the proposed surge gates in their normal open condition. Hydrologic flows in the FWP condition would be very similar to FWOP flows in location, duration, and magnitude, both inside and outside of the levee system. Culverts have been designed to maintain existing flows for a 100-year rainfall event, with an additional 10 percent to account for the predicted increase in rainfall due to climate change over the period of analysis. The negligible indirect impacts would not be expected to exceed established Total Maximum Daily Loads (TMDLs) for Adams and Cow Bayous and their tributaries.

Shoaled sediments from the SNWW are proposed for use in constructing the marsh mitigation features of the Orange 3 mitigation plan. Shoaled sediments in the Sabine region are fine-textured (mean percent clay is 76 percent) and generally of good quality, as evidenced by testing of water and sediments in conjunction with maintenance dredging of existing navigation channels and proposed modifications for the SNWW (USACE, 2011; SOL, 2012). SNWW sediments are routinely used for beneficial use projects, both on private and TPWD properties in the region. A routine water and sediment testing contract is planned in the near future to support USACE

maintenance dredging of the Neches River Channel; sediment testing for dioxin has been added due to recent information confirming the historic presence of paper mills in the region. The USACE would evaluate the results of O&M sediment testing of the Neches River Channel maintenance material, and if warranted based upon the results of this testing and evaluation, conduct additional sediment testing prior to construction to confirm the suitability of SNWW sediments for use in marsh mitigation features. The risk of identifying insufficient quantities of suitable sediment for the mitigation features is considered to be low based on the large quantity of shoaled sediments available in adjacent navigation channels, routine O&M water and sediment testing results, and the acceptability of this material for several recent Neches River beneficial use projects.

Construction of improvements to the Port Arthur CSRM Plan would have minimal impacts on water quality. No changes would occur to the existing alignment and pump facilities would be improved or maintained to provide for future daily flows and flood waters. At this time, it is assumed that fill material for the levee improvements would be obtained from commercial borrow sources. Discharges of fill material into adjacent wetlands and waterways would be minimized by the use of silt curtains and other BMPs.

7.7.2.2 Freeport and Vicinity CSRM Plan

Recommended Plan. Fill material required to construct the Freeport and Vicinity CSRM Plan would be obtained from commercial borrow sources. Testing to ensure that the material is free of contaminants will be conducted prior to use if the commercial facility has not already done so. If it is necessary, during the PED or Construction Phase, to designate new borrow areas, these areas would be evaluated for environmental impacts prior to use. If adverse effects to the environment would occur with their development, the proposed action would be coordinated with resource agencies and NEPA documents prepared as required by CEQ regulations. Construction would have minimal impacts on water quality as construction would occur within the existing project right-of-way. No changes would occur to the existing alignment and pump facilities would be improved or maintained to provide for future daily flows and flood waters. Hydraulic and hydrologic effects of the proposed surge gate on the DOW Barge Canal are expected to minimal because it is a dead-end, man-made channel with no freshwater inflows. Discharges of fill material into adjacent wetlands and waterways will be minimized by the use of silt curtains and other BMPs. A Clean Water Act Section 404(b)(1) Evaluation is presented in Appendix H.

7.8 AIR QUALITY IMPACTS

7.8.1 No Action Alternative - All CSRM Plans

The Sabine Region is located in the BPA AQCR. According to EPA Region 6, this region has been re-designated as in attainment for the 1997 8-hour Ozone NAAQS (EPA 2015). Further, the Sabine region is designated as in attainment for all other criteria pollutants.

Brazoria County is located within the HGB AQCR as defined in the Texas State Implementation Plan (SIP), adopted in 1972 and revisions thereafter. The area is currently designated as severe nonattainment for the 8-hour ozone (1997) standard and marginal nonattainment for the 8-hour ozone (2008) standard. The HGB AQCR is in attainment for all other criteria pollutants.

7.8.2 Recommended Plan

7.8.2.1 Air Emission Impacts

Air emissions of the Orange 3, Port Arthur and Vicinity, and Freeport and Vicinity CSRM Plans were modeled and the results are presented in Appendix I. The air emission impacts assessed in this report are based on preliminary construction estimates and schedules for alternatives evaluated for the TSP. The impact assessments utilized conservatively-high duration and quantity estimates to ensure that all potential impacts were identified and disclosed for review. The construction estimates and schedules for the Recommended Plan fall below the estimates used for the modeling presented below. The EPA software package Motor Vehicle Emissions Simulator (MOVES) 2014 was utilized to generate emission factors based on the types of construction equipment and vehicles anticipated. Air quality impacts would be expected to be temporary and confined to the duration of the construction events. Sources of air quality changes from the Recommended Plan are expected to result from direct emissions from construction and demolition equipment, such as cranes, excavators, bulldozers, concrete pumps, saws, and generators, and indirect emissions from commuting workers and delivery vehicles such as cars, pickup trucks, flatbed trucks, dump trucks, and concrete trucks. The equipment lists, along with their proposed operations, are quite lengthy; they have not been included in the appendix but are available upon request.

Total modeled emissions (tons/year) for each CSRM Plan in the BPA AQCR are provided in Table 7-2, and the total modeled emissions for the Freeport and Vicinity CSRM Plan in the HGB ACQR are provided in Table 7-3. Per 40 CFR Part 93, Chapter 153, a conformity determination would be required for each criteria pollutant or precursor where the total of direct and indirect emissions of the criteria pollutant or precursor in a nonattainment or maintenance area caused by a Federal action would equal or exceed minimum thresholds defined in the regulation. These General Conformity thresholds are presented in Appendix I.

Table 7-2: Air Quality Impacts in the BPA AQCR

Year	Alternatives	Airshed	Pollutant (tons/year)						
			CO	NOx	PM-10	PM-2.5	SO_2	VOC	Lead
2020	Orange	Sabine	21.0	25.7	2.1	2.0	0.1	5.8	0.0
2021	Orange	Sabine	21.0	25.7	2.1	2.0	0.1	5.8	0.0
2022	Orange	Sabine	21.0	25.7	2.1	2.0	0.1	5.8	0.0
2023	Beaumont	Sabine	30.6	37.4	2.9	2.8	0.1	9.0	0.0
2023	Orange	Sabine	21.0	25.7	2.1	2.0	0.1	5.8	0.0
2024	Port Arthur	Sabine	17.9	44.4	2.8	2.7	0.1	6.6	0.0
2024	Orange	Sabine	21.0	25.7	2.1	2.0	0.1	5.8	0.0
2025	Port Arthur	Sabine	17.9	44.4	2.8	2.7	0.1	6.6	0.0
2025	Orange	Sabine	21.0	25.7	2.1	2.0	0.1	5.8	0.0
2026	Port Arthur	Sabine	17.9	44.4	2.8	2.7	0.1	6.6	0.0
2026	Orange	Sabine	21.0	25.7	2.1	2.0	0.1	5.8	0.0
2027	Port Arthur	Sabine	17.9	44.4	2.8	2.7	0.1	6.6	0.0
2027	Orange	Sabine	21.0	25.7	2.1	2.0	0.1	5.8	0.0
2028	Jefferson	Sabine	16.9	26.3	1.8	1.8	0.1	4.9	0.0
2029	Jefferson	Sabine	16.9	26.3	1.8	1.8	0.1	4.9	0.0

CO=carbon monoxide, NOx=nitrous oxides, PM-10=particulate matter less than 10 microns, PM-2.5=particulate matter less than 2.5 microns, SO_2=Sulphur dioxide, VOC=volatile organic carbons

Table 7-3: Air Quality Impacts in the HGB AQCR

Year	Alternative	Airshed	Pollutant (tons/year)						
			CO	NOx	PM-10	PM-2.5	SO_2	VOC	Lead
2020	Freeport	HGB	12.2	3.0	0.5	0.4	0.0	2.3	0.0
2021	Freeport	HGB	12.1	3.0	0.5	0.4	0.0	2.3	0.0
2022	Freeport	HGB	12.1	3.0	0.5	0.4	0.0	2.3	0.0

CO=carbon monoxide, NOx=nitrous oxides, PM-10=particulate matter less than 10 microns, PM-2.5=particulate matter less than 2.5 microns, SO_2=Sulphur dioxide, VOC=volatile organic carbons

The BPA ACQR is classified as in attainment for all NAAQS pollutants and, therefore, the General Conformity Rule does not apply. The single greatest increase of any criteria pollutant from all projects within the region is 70.1 tons/year of nitrous oxides (NOx) (2024 – 2027). Since the General Conformity Rule *de minimis* thresholds do not apply and the total emissions from all activities are demonstrated to be below the significance thresholds, the Recommended Plan would not have significant impacts on ambient air quality within the region.

The HGB AQCR is classified as marginal nonattainment for the 2008 ozone NAAQS, and severe Nonattainment for the 1997 ozone NAAQS. Therefore, the General Conformity Rule applies to

the precursors of ozone (NOx and volatile organic compounds or VOC) resulting from the TSP. The *de minimis* thresholds are 25 tons/year for NOx and VOC. Emissions of NOx and VOC are estimated to increase by 3.0 tons/year and 2.3 tons/year, respectively, for years 2020 to 2022; therefore, the *de minimis* thresholds are not exceeded and a conformity determination is not required. Emissions from the other criteria pollutants are demonstrated to be below the significance thresholds identified above. Because the TSP levels fall below the *de minimis* thresholds for non-attainment pollutants and are below significance levels for attainment pollutants, the Recommended Plan would not have significant impacts on ambient air quality within the HGB region.

In order to reduce impacts associated with emissions of particulate matter and other pollutants, the following control measures will be included in construction contracts, as applicable and practicable.

Fugitive Dust Source Controls:

- Stabilize heavily used unpaved construction roads with a non-toxic soil stabilizer or soil weighting agent. This agent cannot result in the loss of vegetation or increase other environmental impacts.
- During grading, use water as necessary on disturbed areas in construction sites to control visible plumes.
- Vehicle Speed:
  Limit speeds to 25 miles per hour on stabilized unpaved roads as long as such speeds do not create visible dust emissions.
  Limit speeds to 10 miles per hour or less on unpaved areas within construction sites on un-stabilized (and unpaved) roads.
  Post visible speed limit signs at construction site entrances.
- Inspect and wash construction equipment vehicle tires, as necessary, so they are free of dirt before entering paved roadways, if applicable.
- Provide gravel ramps of at least 20 feet in length at tire washing/cleaning stations, and ensure construction vehicles exit construction sites through treated entrance roadways, unless an alternative route has been approved by appropriate lead agencies, if applicable.
- Use sandbags or equivalent effective measures to prevent run-off to roadways in construction areas adjacent to paved roadways. For those contracts in which one is required, ensure consistency with the Storm Water Pollution Prevention Plan.
- Sweep the first 500 feet of paved roads exiting construction sites, other unpaved roads en route from the construction site, or construction staging areas whenever dirt or runoff from construction activity is visible on paved roads, or at least twice daily or less during period of precipitation.

- Cover or treat soil storage piles with appropriate dust suppressant compounds and disturbed areas that remain inactive for longer than 10 days. Provide vehicles, which are used to transport solid bulk material on public roadways and that have potential to cause visible emissions, with covers. Alternatively, sufficiently wet and load materials onto the trucks in a manner to provide at least one foot of freeboard.
- Use wind erosion control techniques (such as windbreaks, water, chemical dust suppressants, and/or vegetation) where soils are disturbed in construction, access and maintenance routes, and materials stock pile areas. Keep related windbreaks in place until the soil is stabilized or permanently covered with vegetation.

Mobile and Stationary Source Controls

- Plan construction scheduling to minimize vehicle trips.
- Limit idling of heavy equipment to less than 5 minutes and verify through unscheduled inspections.

Administrative Controls

- Develop a construction traffic and parking management plan that maintains traffic flow and plan construction to minimize vehicle trips.
- Identify any sensitive receptors in the project area, such as children, elderly, and the infirm, and locate construction equipment and staging zones away from sensitive receptors and building air intakes.

7.8.2.2 Greenhouse Gas Impacts

Air emissions from the operation of internal combustion engines that produce exhaust result in GHG emissions that could contribute to global climate change. The Council on Environmental Quality (CEQ) published Final Guidance on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change on National Environmental Policy Act Reviews, August 1, 2016 (CEQ 2016). The guidance recommends that Federal agencies use projected GHG emissions associated with proposed actions as a proxy for assessing potential effects on climate change. GHG emissions per year should be considered in a qualitative and quantitative manner in NEPA reporting; however, there are no implementing regulations to direct development of these analyses for federal projects. All emissions would come from individual mobile internal combustion engines in on-road and non-road equipment, and it is likely that the total GHG emissions from mobile sources for the three elements of the Recommended Plan would exceed 25,000 metric tons per year of carbon dioxide (CO2)-equivalent (CO2e) per year.

Except for the NAAQS pollutants emitted by these mobile sources as indicated above, the same GHG emissions would occur for every mobile vehicle and piece of equipment regardless of whether the Recommended Plan is implemented. The vehicles and equipment would be used elsewhere by the project contractors on other construction projects, but not necessarily in the two airsheds affected by the Recommended Plan. Since GHG are not listed as NAAQS pollutants subject to regulation under the Texas SIP, and no listed pollutants are generated above *de minimis* levels, and the Recommended Plan would not result in any new stationary emission sources, detailed analysis of GHG emissions was not performed.

However, based on comparison to a similar waterfront construction project, temporary GHG emissions from construction and commuting vehicles are expected to vary between 4,500 and 14,000 tons of CO^2 and CO^2 equivalents per year in the Sabine airshed and approximately 3,200 tons of CO^2 and CO^2 equivalent per year in the Brazoria airshed. Emissions reduction practices could be implemented.

Non-road diesel and gasoline engines can contribute significantly too many pollutant loads, including GHGs. In recent years, EPA has set standards for engines used in most new construction equipment. However, because construction equipment can last 25-30 years, it will take many years before existing equipment is fully replaced by newer, cleaner-burning equipment. With this in mind, EPA developed the Clean Construction USA program to assist operators of heavy non-road, diesel-powered equipment to reduce emissions from older engines that are in operation today. Emission reduction methods include:

- Idle-reduction practices that save money, reduce emissions, add fuel savings, extend engine life, and provide a safer and better work environment for equipment operators;
- Switching to ultra-low-sulfur fuel, which in addition to reducing sulfur (non-GHG) emissions, improves engine efficiency by reducing wear, deposits, and oil degradation;
- Retrofitting equipment to reduce emissions; and
- Installing catalysts and filters verified by EPA to ensure emissions reduction and durability of retrofit technologies. Engine upgrade kits are also available and can be installed during routinely scheduled engine rebuilds.

Roughly one-third of the temporary annual GHG emission impacts are estimated to come from delivery vehicles and worker commuter vehicles. As an additional mitigation measure, construction contractors and the USACE can encourage alternate transportation means. The encouragement of alternative transportation methods, including carpooling, public transportation, and use of local labor could potentially reduce these GHG emissions by as much as 40 percent. Incentives for these initiatives can include preferred parking for carpoolers.

With implementation of these reduction measures, total GHG emissions may reasonably be reduced by up to 25 percent over the lifespan of the projects, resulting in emission rates as low as between 3,375 and 10,500 tons of CO^2 and CO^2 equivalents per year in the Sabine airshed and approximately 2,400 tons of CO^2 and CO^2 equivalent per year in the Brazoria airshed.

7.9 NOISE IMPACTS

The No Action Alternative will be discussed separately for each of the CSRM Plans, but the Recommended Plan condition discussion has been combined for all the Sabine and Brazoria region plans since the impacts will be similar for all.

7.9.1 No Action Alternative for all CSRM Plans

7.9.1.1 Orange CSRM Plan

Ambient noise levels in the vicinity of the proposed Orange CSRM Plan vary from natural noise levels found in undeveloped, rural areas of southwest Orange County to noise levels associated with urban areas and industrial sites in south Orange County. The Orange 3 CSRM Plan construction area contains about 190 residences located adjacent to the proposed Orange 3 right-of-way. About 25 residences are located 30-40 feet from the right-of-way, 80 are located from 100-600 feet away, and the remainder are located between 50 and 100 feet from the proposed right-of-way. Numerous schools are located in the general area in southern Orange County; the closest is located one-third of a mile from the right-of-way and the rest are more than 0.5 mile away. Only one hospital is located in Orange and it is more than 2 miles from the proposed right-of-way.

7.9.1.2 Port Arthur and Vicinity CSRM Plan

In the vicinity of the existing Port Arthur HFP project, ambient noises are associated with dense urban and industrial development, and barge and ship traffic on the deep draft navigation channels. Residents along the ship channels are also exposed to temporary noise levels associated with occasional maintenance dredging of these channels.

Approximately 180 residences are located adjacent to the existing HFP system. Most of these are located about 100 feet from the existing levee or floodwall centerline. Numerous schools are located in the general area, with the closest four located at least one-half mile away. None of the area hospitals are located closer than 1 mile from the project, and three are located 2 or more miles distant.

7.9.1.3 Freeport and Vicinity CSRM Plan

In the vicinity of the existing Freeport HFP project, ambient noises are associated with industrial development and minor residential urban development, in addition to noises associated with ship traffic on the deep- and shallow-draft navigation channels. Residents near the ship channels are also exposed to temporary noise levels associated with occasional maintenance dredging of these channels.

Approximately 105 residences are located adjacent to the existing Freeport HFP system, divided roughly equally between Freeport and Oyster Creek. The existing right-of-way passes immediately adjacent to the Freeport Public Library, Brazosport High School, Freeport Intermediate, and one large apartment complex. None of these are located near the levee system segments to be reconstructed by the CSRM Plan. Numerous other schools in the area are located at least one-half mile away. There are no major hospitals located in the area protected by the existing HFP system. The majority of the structures are located over 200 feet away.

7.9.2 Recommended Plan

None of the CSRM Plans are expected to result in significant long-term noise impacts. No new permanent noise sources would be installed as part of the Recommended Plan; noise impacts would be temporary, occurring during construction only. The Plans would, however, create short-term noise level increases for noise-sensitive receivers located close to the construction zone. Construction activities near sensitive receptors such as residences, schools, and hospitals would be conducted solely during normal daylight working hours; no construction activities would occur during evening or night hours. All of the residences located adjacent to the Orange 3 and Port Arthur and Vicinity CSRM Plans temporary right-of-way, and all of the residences located adjacent to the Oyster Creek, East Storm Levee and Tide Gate Levee portion of the Freeport temporary right-of-way would be exposed to the construction-related noise levels described below. No construction is proposed for the part of the existing Freeport system that passes immediately adjacent to the Freeport Public Library, Brazosport High School, Freeport Intermediate, and one large apartment complex.

EPA identifies a 24-hour exposure level of 70 logarithmic A-weighted decibels (dBA) as the maximum level of environmental noise, which will prevent any measurable hearing loss over a lifetime (U.S. EPA 2015). This is an average over a 24-hour period. Occasional higher noise levels can be consistent with a 24-hour average of 70 dBA if a sufficient amount of relative quiet is experienced for the remaining period of time.

Noise levels related to construction would be based upon the actual number and type of equipment operating in one location at a specific time, and would also fluctuate as equipment is maneuvered throughout the construction right-of-way. Some of the temporary construction activities associated with levee system improvements are expected to generate noise above the 70-dBA level at times during each day. Typical temporary noise levels that could be associated with construction include 73 dBA for large front end loaders from a distance of 100 feet, 86 dBA for off-road haul trucks at 50 feet, 88 dBA for unloading crane at 50 feet, and 90 dBA for vibratory sheet piling at 100 feet (Epsilon Associates 2006). For comparison, typical interior home noise levels are about 50 dBA. Construction activities would be limited to daylight hours to reduce average daily impacts to nearby residents. Contractors would be required to comply with local noise ordinances during construction. There is potential for vibrations associated with construction of some floodwall improvements to affect nearby structures. These effects would be evaluated during detailed design.

Construction of the surge gates in Adams and Cow Bayous (Orange 3 CSRM Plan) and the Dow Barge Canal (Freeport and Vicinity CSRM Plan) would result in temporary and minor noise impacts on aquatic life. It is anticipated that coffer dams would be constructed to facilitate gate construction and thus noise impacts on aquatic life from construction of the gates themselves would be minimal. Pile drivers and draglines could be used to construct the coffer dams and open channels around the coffer dams would be maintained at all times. Fish and other aquatic life would be able to move away from the area of noise impacts, thus minimizing the temporary effects. Similar types of noise impacts, though smaller in scale, would expected with construction of floodwalls at the Alligator Bayou, Lakeside and Port Acres pump stations as part of the Port Arthur and Vicinity CSRM Plan.

7.10 HAZARDOUS, TOXIC, AND RADIOACTIVE WASTE IMPACTS

The construction rights-of-way for the three CSRM plans evaluated for the Recommended Plan have been investigated for the presence of hazardous materials, hazardous waste, and the potential for contamination by current or past industrial or other activities. A detailed report of this investigation is provided as Appendix N. The locations of HTRW areas of concern discussed below are limited to those in the Recommended Plan alignments. All are identified in Appendix N by latitude and longitude. For the purposes of this investigation, a risk to the proposed levee and floodwall alignments is defined as the presence of an HTRW contamination site or HTRW generation site on or adjacent to an alignment, the presence of an activity with the potential for contamination adjacent to or within 0.25 mile of an alignment, or the presence of a past HTRW contamination site or activity adjacent to or within 0.25 mile of an alignment. Except for large oil

refining and chemical plants, small HTRW sites such as commercial gas stations in excess of 0.25 mile from the alignment corridor do not pose an environmental risk to the project.

HTRW concerns were investigated through a review of state and Federal databases maintained to monitor permits and activities regulated by state and Federal agencies, such as the TCEQ and the EPA. Envirosite Corporation was contracted to search relevant environmental databases for sites and activities on or near the levee and floodwall alignments. The EPA's Enforcement and Compliance History Online website was visited to identify past HTRW incidents or permit noncompliance violations for sites identified in the Envirosite Corporation database reviews, primarily violations of the Clean Air Act (CAA), CWA, and RCRA. In addition, historical USGS topographic maps and historical aerial photographs were obtained along the levee and floodwall alignments to identify former industrial or other activities that may have contributed to HTRW contamination in the project areas. The volume of material examined for this report is too large to include in the appendix (over 28,500 pages of reports and maps), but the data are available in electronic format from USACE for further review.

7.10.1 Orange CSRM Plan

7.10.1.1 No Action Alternative

Facilities which store or produce hazardous materials are described for the Orange 3 CSRM Plan's construction area in Appendix N. In addition to these facilities, numerous pipelines transporting hazardous materials for shipment or further processing cross the proposed alignment. The locations of all identified HTRW sites and pipeline crossings discussed here are shown on maps in Appendix N.

The proposed construction right-of-way for the Orange 3 CSRM Plan runs near numerous chemical manufacturing and other industrial facilities, including the Port of Orange and several ship-building yards. Research identified seven major HTRW sites and facilities near or adjacent to the proposed alignment. "Major" refers to size; it refers to an HTRW site that is a large plant with a mapable footprint, as opposed to a minor facility that can only be indicated by a point on a map. All are currently operating industrial facilities and listed in databases identifying the generation, handling, or release of hazardous materials and waste. The largest of these, DuPont-Invista (Sabine River Works), maintains several large wastewater treatment and cooling ponds along the proposed alignment. The other operating HTRW facilities are Signal International (Front Street Yard), Conrad Orange Shipbuilding, Lanxess, Honeywell, Chevron Phillips Chemical Company, and Firestone Polymers (Firestone Synthetic Rubber and Latex Company). One former industrial hazardous waste disposal site, owned by WMW Holding Company, has been closed by TCEQ and classified as clean.

The Orange 3 CSRM project area would continue to be subject to future risks of storm surge impacts, and related potential impacts of petrochemical spills from the facilities identified in this report. These industries have emergency operating plans, which help reduce the risks of spills caused by tropical storm impacts, but impacts can occur with storms of great magnitude or when storms spin up quickly and come ashore with little advance warning.

7.10.1.2 Recommended Plan

The general HTRW risk associated with construction of the levee alignment in Orange County is classified as low, since no unresolved current or recent hazardous material releases in about the last 15 years were found, and no significant recent RCRA or CWA permit violations were identified in the proposed construction right-of-way. Most of the refineries and chemical plants had numerous CAA violations in the past or currently in effect due to stack emissions, but these do not raise the risk of ground-based HTRW contamination. One facility which stores hazardous materials (Chemical Storage and Loading) is located outside the Orange 3 CSRM Plan; it would need to continue to provide its own risk reduction from surge impacts. The other facilities, which store crude oil, or manufacture gasoline and other petrochemicals such as industrial polymers, synthetic rubber, and other chemicals would experience lower risks of spills associated with storm surge impacts if the CSRM Plan is implemented.

Some of the construction areas for the Orange 3 CSRM Plan are located in or immediately adjacent to industrial sites that have a history of generating, handling or storing hazardous or toxic materials. Because of this proximity, additional HTRW risk information would be collected with a Phase I assessment during the PED phase to determine if there is potential for construction to disturb previously unknown contaminated sediments or groundwater. In addition, submerged water bottoms to be disturbed by construction of the Adams and Cow Bayou sector gates would be tested for contaminants prior to construction.

7.10.2 Port Arthur and Vicinity CSRM Plan

7.10.2.1 No Action Alternative

The Port Arthur CSRM alignment lies adjacent to three large petroleum and petrochemical facilities – Texaco Chemical Company (Neches Plant), Total Refinery-BASF Chemicals, and the Valero Port Arthur Refinery. A smaller chemical facility, Calabrian Corporation, is located about 900 feet away. Motiva Enterprises - Port Arthur Refinery, currently with the largest refining capacity in the U.S., is located in Port Arthur, but is over 1 mile away from the construction right-of-way. One National Priority List (NPL) Superfund area on Star Canal is located adjacent to the

northwestern most HFPP alignment. EPA is currently preparing an agreement to implement remediation, which will involve removal of sediment from Star Bayou (EPA 2015).

The project area would continue to be subject to future risks of I-wall overtopping due to storm surge, and related potential impacts of petrochemical spills. These industries have emergency operating plans, which help reduce the risks of spills caused by tropical storm impacts, but impacts can occur with storms of great magnitude or when storms spin up quickly and come ashore with little advance warning.

7.10.2.2 Recommended Plan

Total Refinery-BASF Chemicals and Valero have had numerous CAA violations in the past or currently in effect due to stack emissions, but these do not raise the risk of ground-based HTRW contamination. No currently active spills or land/water releases of hazardous materials were found for these facilities or others in the area. Therefore, the Port Arthur project area is classified as a generally low risk for HTRW impacts associated with reconstruction of portions of the levee system. The facilities in the Port Arthur area, which store crude oil, or manufacture gasoline, petrochemicals, and liquid sulfur dioxide, would experience lower risks of spills associated with storm surge impacts if the CSRM Plan is implemented.

Some of the construction areas for the Port Arthur CSRM Plan are located in or immediately adjacent to industrial sites that have a history of generating, handling or storing hazardous or toxic materials. Because of this proximity, additional HTRW risk information would be collected with a Phase I assessment during the PED phase to determine if there is potential for construction to disturb previously unknown contaminated sediments or groundwater. No CSRM Plan construction activities are proposed for the alignment in the vicinity of this NPL site.

7.10.3 Freeport and Vicinity CSRM Plan

7.10.3.1 No Action Alternative

The Freeport and Vicinity CSRM Plan alignment lies adjacent to six operating chemical and petroleum industrial facilities: Nalco Freeport Plant, Chemical Specialties, Air Liquide Freeport HYCO Plant, and three separate sites associated with Dow Chemical Company (the Texas Operations Plant, the Oyster Creek plant, and Dow Chemical Shipping). Other chemical and refining facilities are located in close proximity to the alignment, including numerous shipping points along the Port of Freeport and GIWW shipping corridors. The alignment lies adjacent to petroleum bulk stations, storage tanks, and pipelines. It passes adjacent to Freeport Liquid Natural Gas (LNG) Receiving Storage and the Tejas Power natural gas transmission pipeline and a natural gas gathering system (Galveston Island Gathering System). The proposed alignment corridor also

crosses the Bryan Mound Strategic Petroleum Reserve facility located on the Brazos River. There is a large, 48-inch buried pipeline connecting the Bryan Mound facility to the refineries at Texas City to the northeast, but the exact location of this pipeline is not known. There are numerous pipeline crossings along the proposed levee and floodwall alignments. Many of the pipeline crossings transport hazardous materials between processing facilities, and others transport finished products to shipping terminals. The project area would continue to be subject to future risks of levee system overtopping impacts, and related potential impacts of petrochemical spills. These industries have emergency operating plans, which help reduce the risks of spills caused by tropical storm impacts, but impacts can occur with storms of great magnitude or when storms spin-up quickly and come ashore with little advance warning.

7.10.3.2 Recommended Plan

The general risk level for the Freeport area is indicated as low, since no current or recent unresolved RCRA or CWA releases were identified for any of the industrial facilities in the Freeport area in about the last 15 years. Many of the facilities have ongoing CAA violations due to stack emissions. The facilities in the Freeport area, which store crude oil, or manufacture petrochemicals, industrial gases, and other chemicals, would experience lower risks of spills associated with storm surge impacts if the CSRM Plan is implemented. Some of the construction areas for the Freeport CSRM Plan are located in or immediately adjacent to industrial sites that have a history of generating, handling or storing hazardous or toxic materials. Because of this proximity, additional HTRW risk information would be collected with a Phase I assessment during the PED phase to determine if there is potential for construction to disturb previously unknown contaminated sediments or groundwater. Pipeline crossings are identified as points of concern along the proposed alignments where special caution should be exercised during construction to avoid damage to the pipelines and release of hazardous materials into the environment.

7.11 CULTURAL RESOURCE IMPACTS

7.11.1 No Action Alternative – All CSRM Plans

The proposed project area for the S2G Study is located along the upper Texas coast and has been occupied by humans since the Paleoindian period dating to around 11,500 BP. The study area is characterized by upland coastal prairies dissected by streams and rivers and extensive bay and estuarine systems along the coast. The study area is primarily drained by the Sabine River, the Trinity River, the San Jacinto River, Buffalo Bayou, and the Brazos River. Sediments in the region are generally fluvial sandy and silty clays overlying Pleistocene-aged clay. Prehistoric sites are commonly found within these upper sediments along streams and rivers and along the shorelines of the bays and gulf coast, close to prime areas for resource exploitation. These sites include

campsites, dense shell middens, and cemeteries containing projectile points, stone, bone, and shell tools, aquatic and terrestrial faunal remains, hearth features, ceramics, and in some cases human remains and associated funerary objects. Historic-age resources in the region consist of farmsteads and ranches, houses, buildings, bridges, tunnels, oil industry structures, cemeteries, lighthouses, shipwrecks, and the ruins of these buildings and structures. Although historic-age resources can occur anywhere, these sites tend to be concentrated in small towns and urban areas, along roads, and within current and historic navigation paths. Shipwrecks may also occur in numerous locales due to the dynamic nature of the sea floor and bay bottoms and the lack of navigation improvements until the latter part of the nineteenth century. These dynamic conditions can result in shifting shoals and reefs that endanger ships, as well as bury their wrecks as shorelines and bars migrate through time.

A preliminary assessment of the cultural resources within the region was conducted using a desktop review of the databases maintained by the Texas Historical Commission and the Texas Archeological Research Laboratory for terrestrial and marine cultural resources, as well as the shipwreck and obstruction databases of the National Oceanic and Atmospheric Administration and the Bureau of Ocean Energy Management. There are over 3,600 cultural resources located within this region of the upper Texas Coast. These cultural resources include National Historic Landmarks, NRHP listed properties, archeological sites, cemeteries, historical markers, and shipwrecks and submerged resources. The National Historic Landmarks in the six-county study area are all located in the Galveston Region. These are the San Jacinto Battlefield, the Battleship Texas, and the Tall Ship Elissa, as well as National Historic Landmark Districts, the Galveston Strand Historic District and the Galveston East End Historic District. The NRHP Properties are generally located in urban areas and consist of historic houses, commercial and government buildings, and structures. NRHP Properties in the Sabine Region include the Navy Park Historic District, W.H. Stark House, Sims House, and Woodmen of the World Lodge. These are all located in the area that would be protected by the Port Arthur and Vicinity CSRM Plan. NRHP Properties in the Galveston Region include the Main Street/Market Square Historic District, Pomeroy Homestead, Ross S. Sterling House, Ashbel Smith Building, Fort Travis, Washburn Tunnel, and others. NRHP Properties in Brazoria are generally located in more inland areas of the county, with the southernmost property located in Lake Jackson, just inland of the Freeport and Vicinity CSRM project area.

Within the areas of the proposed Orange 3 CSRM Plan, the study area was examined within 200 feet of the proposed work for archeological resources and cemeteries and 1,500 feet for historic structures and buildings. There are a total of eight archeological sites (41OR15, OR39, OR59, OR60, OR70, BO4, BO119, and BO121), four NRHP Properties (Navy Park Historic District, W.H. Stark House, Sims House, and the Woodmen of the World Lodge), and three cemeteries

(Evergreen, Thomas, and an unknown cemetery) within this study area. There are also 25 historical markers within the study area; however, only one of these, the Niblett's Bluff marker in Orange, is more than 50 years old, having been erected in 1964.

7.11.2 Recommended Plan – All CSRM Plans

The primary considerations concerning cultural resources are threats from direct impacts on intact terrestrial archeological sites and indirect impacts on historic structures and buildings from new construction and improvements. A large portion of the study area has been altered for industrial and commercial use, especially in the cities of Orange, Port Arthur, and Freeport. As such, these urban areas have a low probability for intact prehistoric archeological sites to occur. However, there is a moderate to high potential for encountering historic-age archeological sites and cemeteries, as well as historic-age structures and buildings. In those areas outside of the urban centers, the potential for encountering prehistoric archeological sites is moderate to high. There are no proposed actions within marine environments and therefore no potential to impact submerged cultural resources.

The Area of Potential Effect (APE) for this project will be the footprint of the Recommended Plan for direct impacts on archeological resources plus a 1,500-foot buffer for indirect impacts on standing structures or buildings. The Orange 3 CSRM Plan construction right-of-way overlaps with five archeological sites and two cemeteries. Additionally, there are four National Register Properties within 1,500 feet of the proposed levee system (Navy Park Historic District, W.H. Stark House, Sims House, and the Woodmen of the World Lodge), all of which would experience reduced risk of storm surge damages with construction of the new levee system. The five archeological sites in Orange County (41OR15, OR39, OR59, OR60, and OR70) are all prehistoric sites that have poorly delineated boundaries, insufficient documentation, and have not been evaluated for NRHP eligibility. All of these sites have the potential to be directly impacted by construction activities. The two cemeteries also have a potential to be directly affected by levee construction as their recorded boundaries overlap with the proposed project area. These cemeteries, the Thomas cemetery and an unknown cemetery, are not well documented and their locations may not be accurate within the existing state databases.

There are numerous cultural resources that occur near the APE for the Port Arthur and Freeport CSRM Plans; however, most of these resources occur outside of the areas proposed for improvements. In Port Arthur, there are no cultural resources that overlap with the areas for proposed improvements along the existing hurricane risk reduction system. However, there are three archeological sites (41BO4, BO119, and BO121) that are within proximity to the proposed improvement areas along the Freeport hurricane protection system. These three sites all occur

along Oyster Creek, are poorly delineated, lack sufficient documentation, and have not been evaluated for NRHP eligibility.

Based on the current information for the proposed levee construction and improvements, there is a potential to affect historic properties and cemeteries. These effects consist of direct impacts from earth moving and excavation activities related to construction and potential indirect effects on historic structures such as diminished viewshed from the raising of levees and floodwalls. The USACE recommends intensive cultural resources investigations to identify and evaluate any historic properties within proposed construction areas. The scope of these investigations will be determined in concert with the Texas SHPO and Native American Tribes and in accordance with the Programmatic Agreement for this project (Appendix L).

7.12 PRIME AND UNIQUE FARMLANDS

Prime and other unique farmlands in the CSRM plan areas were mapped using the NRCS Web Soil Survey website (USDA 2015). Custom Soil Reports and soil maps were downloaded for each area and area available upon request. Soils were clipped from the USDA database to calculate prime farmland impacts of CSRM Plan construction right-of-ways.

7.12.1 Orange 3 CSRM Plan

7.12.1.1 No Action Alternative

Mapped soil units identified as prime, unique, statewide, or locally important farmlands (hereafter referred to as prime or otherwise important farmland) under the Farmland Protection Policy Act (FPPA) occur within the proposed construction rights-of-way in Orange County. Units identified by the NRCS in the construction area are, in descending order of prevalence, Ijam clay, Orcadia-Urban land complex, Orcadia-Anahuac complex, Aris-Spindletop complex, Orcadia-Aris complex, Neches coarse sand, Leton loam, Neel-Urban Land Complex, Orcadia silt loam, and Franeau clay (U.S. Department of Agriculture [USDA] 2015). Impacts on prime farmland during the FWOP condition would occur primarily from industrial, commercial and/or residential development, and continue according to expected trends of population growth and development in each area.

7.12.1.2 Recommended Plan

The Orange 3 CSRM Plan would permanently convert approximately 36 acres of prime farmland, as defined by the NRCS Web Soil Survey (USDA 2015), into a CSRM levee system. Approximately 61 additional acres would be temporarily unavailable for agriculture while in use as construction staging areas. About 78 percent of the area to be impacted by construction (about

125 acres) is classified as prime farmland. Recent aerial photographs were reviewed to determine the current status of mapped units located within the right-of-way, and approximately 22 percent (28 acres) were found to be developed or in use as pipeline right-of-ways or roadways. Therefore, about 36 acres of prime or otherwise important farmland would be converted to a non-agricultural use. This represents less than 0.1 percent of the total "land in farms" reported by the Orange County 2012 agriculture census (USDA 2012). The undeveloped prime farmland areas that would be impacted are fragmented, surrounded by development, and not currently used for agriculture. The proposed alignment has been designed to follow the upland/wetland margin to the greatest extent possible. Almost all of the lands north of the alignment are developed urban, suburban, and industrial areas. Almost all of the lands south of the alignment are bottomland wetlands, which are not farmed; other areas are industrial cooling ponds or placement areas. The westernmost 2.3 miles of the alignment extends inland away from the upland/wetland margin, with a few tracts south of the alignment which appear to be used for pasture. Only one small area of the construction right-of-way itself (about 6 acres in size) appears to have been farmed recently; levees for rice farming are present in the area.

Construction of the Orange 3 CSRM Plan would not make areas outside of the alignment unfarmable; interior drainage patterns would be maintained at FWOP conditions and access across the levee system would be possible. Any areas compatible with agricultural use that occur in the vicinity of the proposed alignment would remain fully compatible with agricultural use after project construction. Impacts on prime and otherwise important farmlands have been minimized to the greatest extent practicable.

7.12.2 Port Arthur and Vicinity CSRM Plan

7.12.2.1 No Action Alternative

No prime or otherwise important farmlands are located within the proposed construction right-of-way of the existing HFP project in Jefferson County, Texas.

7.12.2.2 Recommended Plan

The Port Arthur and Vicinity CSRM Plan would have no impacts on prime and unique farmlands. Construction activities would be restricted to the existing levee system right-of-way, with the exception of a few small areas within existing industrial complexes.

7.12.3 Freeport and Vicinity CSRM Plan

7.12.3.1 No Action Alternative

No prime or otherwise important farmlands are located within the right-of-way of the existing HFP project in Brazoria County, Texas. Mapped soil units identified as prime or otherwise important farmland are present in one small area on Oyster Creek proposed for right-of-way expansion under the Freeport and Vicinity CSRM Plan. These soils are Asa silt loam and Asa silty loam (USDA 2015).

7.12.3.2 Recommended Plan

The Freeport and Vicinity CSRM Plan would have no impacts on prime and unique farmlands. Construction activities would be restricted to the existing levee system right-of-way.

7.13 FLOODPLAIN IMPACTS

7.13.1 EO 11988

EO 11988 (Floodplain Management) requires Federal agencies to avoid "to the extent possible the long and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct and indirect support of floodplain development wherever there is a practicable alternative." In accomplishing this objective, "each agency shall provide leadership and shall take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health, and welfare, and to restore and preserve the natural and beneficial values served by floodplains in carrying out its responsibilities" for:

- Acquiring, managing, and disposing of Federal lands and facilities;
- Providing Federally undertaken, financed, or assisted construction and improvements; and
- Conducting Federal activities and programs affecting land use, including but not limited to water and related land resources planning, regulation, and licensing activities.

USACE ER 1165-2-26 contains the USACE's policy and guidance for implementing EO 11988. Per ER 1165-2-26, the USACE must first determine whether there are practicable alternatives to placing a proposed project in a floodplain. In addition, ER 1165-2-26 specifies that all reasonable factors should be taken into consideration when determining practicability. These factors are conservation, economics, visual elements, natural and beneficial values served by floodplains, impact of floods on human safety, locational advantage, the functional need for locating the development in the floodplain, historic values, fish and wildlife habitat values, endangered and

threatened species, Federal and state designations of wild and scenic rivers, refuges, etc., and, in general, the needs and welfare of the people.

7.13.2 EO 11988 Eight-Step Analysis

To assist in complying with EO 11988, the USACE has issued guidance (USACE ER 1165-2-26), as it pertains to planning, design, and construction of USACE projects. The Water Resources Council Floodplain Management Guidelines for implementation of EO 11988, as referenced in USACE ER 1165-2-26, requires an eight-step process that agencies should carry out as part of their decision-making on projects that have potential impacts on, or are sited within, the floodplain. The eight steps reflect the decision-making process required in Section 2(a) of EO 11988. In order to demonstrate the Proposed Action complies with EO 11988 and to address related public safety concerns, the following documentation is provided. The existing floodplain management activities, including National Flood Insurance Program related actions and requirements are described. This is followed by a response to the eight-step process.

1. *Determine if the proposed action is in the base floodplain.*

Yes, the Proposed Action lies within the base floodplain. The proposed action includes three separate project areas. Two of the areas currently have existing hurricane flood risk reduction systems that lie in the base floodplain. The proposed action for the third project area includes the construction of new levee and floodwalls, which will also lie in the base floodplain.

2. *If the action is in the base floodplain, identify and evaluate practicable alternatives to the action or to location of the action in base floodplain.*

Alternatives have been evaluated and not carried forward, as they were either not practicable or did not meet the goals of the Proposed Action. Coastal storm flood risks are addressed by the Proposed Action. The proposed coastal flood risk management plan is located within the base floodplain and includes modifications to two existing hurricane flood risk reduction systems. A coastal flood risk analysis followed the "Principles and Guidelines for Water and Related Land Resources," dated March 1983, including evaluation of contributions to NED and reducing potential life-safety risk. Plan formulation and screening of plans described in this Feasibility Report, Chapter 5, is the basis for concluding there are no practicable alternatives to locating the proposed flood risk management plan in the base floodplain. The main Federal objective of reducing coastal flood risk cannot be achieved by alternatives outside the floodplain. All structural alternatives considered were located in the base floodplain.

Practicable nonstructural alternatives like flood proofing, structure relocation, permanent evacuation, and instrumentation were considered. Flood proofing, structure relocation and permanent evacuation were removed from consideration because they were not viable for broad application across the three project areas and were not economically viable.

3. *State whether the proposed action would induce development in the base floodplain.*

The Proposed Action would not induce development in the base floodplain. The Proposed Action would occur in areas that are highly urbanized among the three counties, all of which have substantial industrial investment. Urban development would remain behind the existing hurricane flood risk reduction systems and behind the proposed new levees and floodwalls. The cities of Beaumont, Port Arthur, and Freeport all participants in the National Flood Insurance Program (NFIP) which specifies how cities that participate should manage floodplain development, particularly through zoning ordinances and building codes. No indication exists that these cities have any intention of opting out of the NFIP at any point in the future.

4. *Identify the impacts in the base floodplain of the proposed action and any induced development.*

Impacts within the base floodplain are presented in Chapter 4. Potential impacts on the base floodplain are described for the Proposed Action. Impacts on fish and wildlife, cultural resources, recreation, sediment flow, and other floodplain resources are considered in the Feasibility Report and Engineering Appendix. Avoidance and minimization of impacts on existing floodplain resources has been considered in the development of the Proposed Action. Most of the expected losses or impacts on existing floodplain resources are expected to be compensated by the benefits provided by the Proposed Action. Mitigation requirements for the Proposed Action are described in Section 6.1.3.

5. *Describe measures available to minimize adverse impacts on the natural and beneficial floodplain values.*

Avoidance and minimization efforts for all resources are described in Section 6.1.3. A summary of the potential environmental impacts of the Proposed Action are described in Section 6.1.3. Direct impacts of the Proposed Action would result in the loss of approximately 160 wetland acres from construction of the new levee-floodwall system. Approximately 112 acres would be lost over time due to indirect hydrologic effects, and indirect, functional fisheries access impacts to 2137 acres of the extensive marshes in the lower Cow and Adams Bayous floodplains. In total, 69.5 acres of forested wetland and 2,340 acres of coastal marsh would be impacted. Mitigation

would be needed to compensate for a loss of 42.7 AAHUs from forested wetlands and 143.3 AAHUs from coastal wetlands.

6. *Describe the effect of the above topics on any reevaluation of alternatives and on the final plan selection*

A re-evaluation of alternatives was not required because of considering the topics listed above. There are no remaining unmitigated adverse effects on natural and beneficial floodplain due to implementation of the Proposed Action.

7. *Finding and Explanation*

EO 11988 requires Federal agencies to avoid, to the extent possible, the long- and short-term adverse impacts associated with the occupancy and modification of flood plains and to avoid direct and indirect support of floodplain development wherever there is a practicable alternative. The Proposed Action does not support direct or indirect floodplain development within the base floodplain. As stated in Section 6.2 "Description Of The Recommended Plan" the current design does obtain a 1% level of risk reduction throughout the length of the system, but the system is only authorized to address storm surge caused by hurricane and tropical storm events, not rainfall events or riverine events. The federal action would only change the more recent base flood advisory maps (post Ike) and future flood advisory maps if they were are based on storm surge impacts. FEMA Floodplain management guidelines would still require updates to the base flood elevations based on changing rainfall impacts and day-to-day tidal impacts from changes in RSLR.

The action is not likely to induce development in low lying areas due to the fact that there would still be a significant economic costs to overcome for developing in these areas under both the FWOP and FWP conditions. Many of these areas are wetlands and would still flood from rainfall and riverine events. As stated in Chapter 6, the levee system would only be closed for storm surge events. Existing local building codes would still require developments to build above the 100 yr stage for rainfall/riverine impacts, and with an open levee system, the stage is still going to increase over time because of RSLR impacts. Existing local building codes would require significant amounts of fill material for new developments in low lying areas. These areas would still be in jurisdictional wetland and would require compensatory mitigation for impacting these areas. These two factors and the existing available upland areas for development, at a much lower cost, would limit the development in these areas.

In addition, the loss of natural and beneficial flood plain values would also be minimized through future floodplain management plan and zoning rules since the NFS has an obligation relating to

the operation of the project, specifically pump station capacities, to prevent encroachments that would impact the utility of the project when the pump station is operating. The NFS will be required to comply with flood plain management requirements and ensure that project features such as pump stations would not be impacted by developments in the areas behind the risk reduction system. The pump system is designed to match the existing gravity drainage capacity when the system is closed. The NFS would have a responsibility to ensure that this operation of the project features is maintained.

USACE and the study's NFS have led public outreach efforts to make local communities aware of actions in the floodplain, starting with the NEPA scoping meeting, and will continue throughout the study process. These scoping meetings are described in Section 9.1. A public and agency review of the DIFR-EIS have been conducted and relevant public and agency comments have been considered in preparing the FIFR-EIS.

8. Critical Actions

The Proposed Action is the most responsive to the planning objectives established in the Feasibility Report and is consistent with the requirements of this Executive Order. The Proposed Action is the most practicable alternative to minimize both short- and long-term adverse impacts associated with modification and occupancy of the base floodplain while maintaining the avoidance of direct and indirect development in the floodplain. The Proposed Action also seeks to minimize impacts on health and human safety and, where possible, to preserve the natural and beneficial uses of the floodplain.

Although the project is intended to prevent damages to structures and infrastructure and is not intended to reduce the risk to loss of life during major storm events, the project does continue to enhance community resilience and better protect critical federal assets from the impacts of flooding. Even under exceedance events (>1%), the system's resilient design, will allow for reduced damages when compared to the FWOP conditions.

7.14 SOCIOECONOMIC IMPACTS (ENVIRONMENTAL JUSTICE)

EO 12898 directs Federal agencies to determine whether the Preferred Alternative would have a disproportionate adverse impact on minority or low-income population groups within the project area. Based on the findings of an environmental justice review, presented earlier in this report and based on data presented in Appendix R, the Sabine and Brazoria elements of the Recommended Plan would not significantly disproportionately affect low-income or minority populations.

7.14.1 No Action Alternative – All CSRM Plans

The population in Orange County within the Orange 3 CSRM Plan area has been identified as being approximately 79 percent white in the aggregate, but with at least seven census blocks showing populations in which minorities make up more than 50 percent. Jefferson County, for the Port Arthur and Vicinity CSRM Plan, by contrast has an aggregate white population of 45 percent and 20 census blocks showing minority populations over 50 percent. The population in Brazoria County for the Freeport and Vicinity CSRM Plan has an aggregate racial makeup of 61 percent white and 39 percent minority. Ten census blocks have populations that have minority populations that are over 50 percent. No evidence exists showing concentrations of low-income populations that could potentially be disproportionately impacted by a Federal action in any of the project areas for the three counties.

7.14.2 Recommended Plan – All CSRM Plans

The Orange 3 CSRM Plan involves the construction of new levees and floodwalls, thereby potentially impacting the population in Orange County. Based on the proposed footprint, one Census block with over 50 percent minority population would be impacted with the construction of the levee/floodwall. Public involvement will need to continue to ensure no disproportionate impacts occur for these residents. The other two project areas consist of existing hurricane flood risk reduction systems where impacts from construction activities would be less intrusive; therefore, the potential for disproportionate adverse impacts is considered to be negligible.

7.15 PROTECTION OF CHILDREN FROM ENVIRONMENTAL AND SAFETY RISKS

EO 13045 requires that Federal agencies evaluate their programs or activities to determine if they would result in disproportionate environmental health and safety risks to children. Children may be more or less sensitive than adults to equivalent levels of exposure to environmental pollutants. In addition, there may be age-related differences in types and levels of exposure.

7.15.1 No Action Alternative – All CSRM Plans

All of the CSRM project areas (Orange 3, Port Arthur and Freeport) would continue to be subject to existing and increasing future risks of storm surge impacts, and related potential impacts of petrochemical spills. These industries have emergency operating plans, which help reduce the risks of spills caused by tropical storm impacts, but impacts can occur with storms of great magnitude or when storms spin up quickly and come ashore with little advance warning. Given the high density of petrochemical industries in these areas, FWOP risks of storm surge impacts

would continue to place children living in the project areas at risk to environmental pollutant exposures.

7.15.2 Recommended Plan – All CSRM Plans

All three of the CSRM Plans would reduce potential risks to children's health and safety associated with contaminant spills resulting from storm surge impacts on industrial facilities in the project area. Children residing in Orange County would receive risk reduction that does not exist at this time, and risks to residents residing within the existing Port Arthur and Freeport CSRM project areas would be reduced. Construction of the CSRM plans is not expected to increase risks to children's health and safety.

7.16 HAZARDOUS WILDLIFE ATTRACTANTS ON OR NEAR AIRPORTS

7.16.1 No Action Alternative

Due to the increasing concern about aircraft-wildlife strikes, the FAA has implemented standards, practices, and recommendations for holders of Airport Operating Certificates issued under Title 14, CFR Part 139, Certification of Airports, Subpart D (Part 139), to comply with the wildlife hazard management requirements of Part 139. Airports that have received Federal grant-in-aid assistance must use these standards.

When considering proposed dredged material placement, BU features, and mitigation areas, developers must take into account whether the proposed action would increase wildlife hazards. The FAA recommends minimum separation criteria for land use practices that attract hazardous wildlife to the vicinity of airports. These criteria include land uses that cause movement of hazardous wildlife onto, into, or across the airport's approach or departure airspace or air operations area (AOA).

These separation criteria include:

- Perimeter A: For airports serving piston-powered aircraft, hazardous wildlife attractants must be 5,000 feet from the nearest AOA;
- Perimeter B: For airports serving turbine-powered aircraft, hazardous wildlife attractants must be 10,000 feet from the nearest AOA; and
- Perimeter C: 5-mile range to protect approach, departure, and circling airspace.

7.16.1.1 Sabine Region CSRM Plans

Airports within the Sabine region that must comply with these standards are the Orange County and Southeast Texas Regional airports.

7.16.1.2 Freeport and Vicinity CSRM Plan

The Texas Gulf Coast Regional Airport is the closest airport serving the Freeport area. It is located 7 miles northwest of the northernmost extent of the Freeport and Vicinity CSRM Plan, between Lake Jackson and Angleton.

7.16.2 Recommended Plan

7.16.2.1 Sabine-Region CSRM Plans

No features of the Port Arthur and Vicinity CSRM Plan fall within any of the separation perimeters for either airport. None of the Orange 3 CSRM Plan features fall within any of the separation perimeters for the Southeast Texas Regional Airport.

Two potential wildlife attractant features (proposed marsh mitigation areas 28 and 29) of the Orange 3 CSRM Plan fall within Perimeter C of the Orange County Airport, but are well outside of Perimeters A and B. The lands proposed for mitigation sites 28 and 29 are currently undeveloped. Almost all of the area is owned by TPWD and managed for fish and wildlife habitat. A small strip of land along the northern edge of proposed mitigation area 29 is privately-owned. It is comprised of submerged lands and emergent estuarine marsh that also serves as fish and wildlife habitat. Marsh restoration in these areas would not change the land use of this area, and therefore land-use after construction would be compatible with airport operations.

7.16.2.2 Freeport and Vicinity CSRM Plan

No features of the Freeport and Vicinity CSRM Plan fall within any of the separation perimeters, and thus construction would have no effect on airport operations.

7.17 CUMULATIVE IMPACTS

Cumulative impacts are defined in 40 CFR 1508.7 as . . . " the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." Cumulative impacts for the TSP were assessed in accordance with CEQ guidance.

7.17.1 Sabine Region

7.17.1.1 Sabine Region Past or Present Actions

Past, present, and reasonably foreseeable projects/activities within the study area were compared to the Recommended Plan to determine whether the Recommended Plan, when combined with the impacts of other actions, could have cumulatively significant impacts on the environment.

Sabine-Neches Waterway 40-foot Channel. Channel and port improvements began in 1885 when Army Engineers completed construction of the east and west jetties (Alperin, 1977). Relying on an artificial channel dredged from Sabine Pass and following the western shore of Sabine Lake, the Port Arthur International Public Port was established in 1899. A 9-foot-deep canal was later dug in the Neches River from the Port Arthur Ship Channel to Beaumont in 1908. Multiple subsequent channel improvement projects have resulted in the current 40-foot mean low tide (MLT) authorized depth and a 77-mile-long channel from Port Arthur to Beaumont. In 1912, a 25-foot MLT navigation channel was constructed from the mouth of the Neches River, across the northern edge of Sabine Lake, and up the Sabine River to near the City of Orange, Texas. Also part of the SNWW, the Sabine River Channel was deepened to 30 feet MLT in 1922 and remains at that depth today.

GIWW – Texas Section, Main Channel and Tributaries. Construction of the GIWW between the Sabine River and Galveston Bay began in 1925. Originally 9 feet MLT by 100 feet wide, it was later enlarged to its current authorized dimensions of 12 feet MLT by 125 feet. As it leaves Louisiana, the GIWW follows the Sabine River and connects with the SNWW approximately 3 miles below Orange, Texas. The GIWW then follows the Sabine River Channel and the Sabine-Neches Canal to the head of the Port Arthur Canal, where it exits the SNWW and continues westward to Galveston Bay.

Port Arthur and Vicinity HFPP. Hurricane-flood protection projects at Freeport and Port Arthur were authorized in 1962 (USACE 2005). The Port Arthur HFFP includes approximately 33.1 miles of protective works, including about 27.8 miles of earthen levees and 5.3 miles of concrete and steel sheet pile floodwalls. The system includes 12 pump stations, which remove accumulated rainfall from the protected area. The system surrounds a 60-square-mile area around Port Arthur and nearby smaller cities such as Groves, Lakeview, and Port Acres.

Port of Beaumont Intermodal Improvement Projects. Extensive capital improvements to the Port of Beaumont have recently been completed on both sides of the Neches River (Port of Beaumont 2015). A new 250-acre petroleum terminal has been constructed north of the Neches River in Orange County; intermodal connections include new roadways, ship, and barge docks. Rail lines

and storage have been expanded on both sides of the river. More than 80 acres of all-weather, open storage has been constructed south of the Port. Other Port improvements include a general cargo wharf, repairs of bulkheads and upgrades of lots, a new double layberth for military vessels and a new 90,000-square-foot transit shed in Orange County, and an extension of the main Harbor Island east wharf on the Beaumont side. A new office-building complex has been erected to house the U.S. Surface Deployment and Distribution Command's 842nd Transportation Battalion.

Various Neches River Marsh Restoration Projects. TWPD has restored large areas of marsh in the Old River and Nelda Stark units of the Lower Neches WMA with the beneficial use of dredged material (BUDM) from the SNWW. Marsh has also been created in the Rose City and Old River areas as part of mitigation for private projects or National Resource Damage Assessments. In addition, the Sabine-Neches Navigation District and USACE restored marsh in the Bessie Heights area under a Section 204 Continuing Authorities Program project. In all, hundreds of acres of marsh have been restored along the north shore of Neches River south of Interstate 10.

7.17.1.2 Sabine Region Reasonably Foreseeable Future Actions

SNWW Channel Improvement Project (48-Foot MLLW). The 48-Foot SNWW Channel Improvement Project was authorized by the 2014 Water Resources Reform and Development Act (WRRDA). The SNWW to Beaumont would be deepened to 48 feet MLLW and the Sabine Bank Channel would be extended an additional 13.2 miles into the Gulf. In addition, the Taylor Bayou channels and turning basins would be deepened and widened, and three new anchorage/turning basins would be constructed on the Neches River. Beneficial use features and mitigation measures have been developed that effectively avoid or mitigate all environmental impacts. Extensive BUDM features would be constructed with new work and maintenance material along the lower Neches River as part of this project.

Port Arthur LNG and Pipeline. Sempra LNG, through its affiliate Port Arthur LNG, L.L.C., has amended a previous proposal for a liquefied natural gas (LNG) import facility to propose construction of a new natural gas liquefaction and export terminal and pipeline system in Jefferson County, Texas (Port Arthur LNG 2015). Located southwest of the junction of the GIWW and SNWW south of Port Arthur, the facility would include two liquefaction trains, a natural gas liquids (NGL) loading/unloading facility and storage area, marine berths, and three storage tanks. The project would interconnect with intra- and interstate pipelines lying north and south of this area. Port Arthur LNG has obtained U.S. Department of Energy (DOE) approval for export of domestically produced LNG to Free Trade Agreement countries. Completion of the Federal Energy Regulatory Commission pre-filing process is pending. If approved, commercial operations could possibly begin in 2021.

7.17.1.3 Sabine Region Resource Impact Evaluation

Land use and cumulative environmental impacts in the Sabine Region are related historically to the development of three major industries in East Texas: commercial lumbering, shipbuilding and crude oil/petrochemical production/refining. The spread of railroads into the forests of east Texas in the last quarter of the nineteenth century spurred the growth of the commercial timber industry throughout the region, which experienced such rapid growth that by the turn of the twentieth century, logging was the primary economic activity in the Sabine Region (Texas Beyond History, 2015). This changed quickly with the advent of the twentieth century. In 1901, the discovery of the Spindletop oilfield south of Beaumont stimulated the explosive growth of the oil industry, which remains a primary economic driver in the region to this day (Texas State Historical Association, 2015). Storage facilities, pipelines, and major refining units were built in Beaumont, Port Arthur, and Orange; these facilities have grown and spread, generally located close to navigation channels and highways throughout the area. By 1920, most of the forests on lands acquired by the big lumber mills had been harvested, and tangled thickets of second growth hardwoods began to grow in their place. Although the majority of forested wetlands in the study area are secondary growth, many stands are mature enough that they provide medium to high habitat values. The commercial lumber industry's dominance has declined but the commercial lumber industry remains active; managed timber stands are prevalent in the area today. Construction of deep-draft navigation channels into the area by 1908 and the accessibility of timber stimulated the growth of ship building industries in Orange, which were expanded rapidly to meet demands during both world wars. This industry was a primary driver in the growth of the City of Orange but only remnants remain along the Sabine River Channel today.

Agricultural production, recreation and conservation areas have also influenced this area's land use history. One part of the extensive J.D. Murphree WMA is located southwest of the Port Arthur HFPP, and several units (Nelda Stark, Old River and Adams Bayou) of the Lower Neches WMA are scattered along the Neches and Sabine River bottomland areas. The Tony Houseman WMA is located in the bottomlands of the Sabine River near the City of Orange. These state-owned lands will be protected and managed to provide fish and wildlife habitat for the foreseeable future. Agriculture, dominated by cattle grazing and rice production, is not a major economic driver in the area.

The existing SNWW 40-foot navigation project has increased salinity intrusion by providing an avenue for the salt-water wedge to travel further inland than it would have otherwise (USACE 2011). Subsidence, exacerbated by oil/gas/water withdrawal, has also led to permanent inundation and loss of forested wetlands and marsh, and smaller access canals for oil/gas exploration have opened interior marsh areas to salinity intrusion and marsh loss. Construction of PAs lining the

banks of the SNWW and construction of the GIWW have altered natural channel and overland flows, blocking or diverting freshwater flows into large areas of interior marsh. All of these factors collectively have resulted in the widespread conversion of fresh marshes to brackish marshes, and the loss of thousands of acres of marsh in the lower reach of the Neches River.

Nationally, wetland impacts and losses in coastal watersheds are directly tied to population pressures and wetland conversion (Stedman and Dahl 2008). Estuarine emergent mash of the U.S. Gulf Coast decreased by 5.2 percent from 2004 to 2009, with about 2,211,674 acres remaining in 2009. Palustrine emergent marsh decreased by 0.1%, with about 2,788,005 acres remaining. Freshwater forested wetlands decreased by 3.4 percent, with about 7,063,638 acres remaining in 2009.

In the Texas coastal zone, changes in wetland and aquatic habitats have been evaluated for the period from 1955 to 1992 (Moulton et. al., 1997). Overall, Texas coastal wetlands sustained an estimated net loss of 210,590 acres over this period. Estuarine emergent marsh decreased by 8.2 percent, with about 355,632 acres remaining in 1992. Palustrine emergent wetlands decreased by 29 percent, with about 571,867 acres remaining. Palustrine forested wetlands decreased by 10.9 percent with about 789,808 acres remaining.

Changes in wetland and aquatic habitats between 1956 and 2004 have been evaluated for the Orange County area (Tremblay and Calnan, 2009). The study area was divided into separate geographic areas, including the portions of the Sabine and Neches River watersheds that would be affected by the proposed Orange 3 CSRM Plan. For the entire study area, emergent wetlands increased at the average rate of 27 acres/year and estuarine open water increased at an even greater average rate of 106 acres/year. Forested and scrub/shrub wetlands decreased over the same time period by 370 acres/year. Part of the expansion of open water was due to subsidence and RSLC. While palustrine marsh was replaced primarily by uplands, roughly 78 percent of the increase in estuarine marsh was in areas previously mapped as palustrine marsh. Forested wetlands suffered the largest losses in this period, being harvested and cleared for agricultural and residential purposes, primarily in the upper reaches of the river valleys and bayous.

Based upon the mapped acres of estuarine, palustrine and forest wetlands in the Sabine and Neches River areas, the S2G project would result in the loss of about 3.8 percent of the remaining estuarine marsh, 0.2 percent of the remaining palustrine marsh, and about 0.8 percent of remaining forested wetlands in the affected Orange County area. When compared to the coastal zone of Texas, the project would result in the loss of about 0.05 percent of estuarine emergent, 0.002 percent of palustrine emergent, and 0.01 percent of forested wetlands. Even though percentages would be expected to increase when compared to more recent data, the percentage losses of the

Recommended Plan would be very small. Percentage impacts when compared to the coterminous United States are much smaller. The project would result in the loss of about 0.008 percent of estuarine emergent, 0.0004 percent of palustrine emergent, and 0.001 percent of forested wetlands.

Significant environmental impacts of public and private projects constructed after passage of NEPA have been addressed by compensation plans that fully mitigated impacts on the environment. Implementation of the SNWW 48-foot project would result in extensive BUDM marsh restoration in the Neches River floodplain, as will continued marsh restoration efforts by TPWD in the Lower Neches WMA.

Impacts of the Recommended Plan in the Sabine Region would not be sufficient, when combined with past, present, and reasonably foreseeable future impacts, to lead to significant degradation of the region's environment. Construction of the Port Arthur and Vicinity CSRM Plan would result in negligible environmental impacts. Direct and indirect impacts of the Recommended Plan on wetlands from construction of the Orange 3 CSRM Plan would be fully mitigated with a plan that compensates for both the quantity and quality of impacts to forested wetlands and marshes. Loss of about 178.7 acres of estuarine marsh would be mitigated by restoration of about 390 acres of brackish and intermediate marsh. Loss of about 24.3 acres of palustrine marsh would be mitigated by restoration of about 63 acres of fresh marsh. Loss of about 69.5 acres of forested wetland would be mitigated by preservation in perpetuity of about 559 acres of bottomland hardwoods and cypress-tupelo swamp. Marsh mitigation efforts would complement current and future marsh restoration efforts by TPWD and USACE.

The Orange 3 CSRM Plan would add a total of 27 miles of new levee/floodwall system in Orange County along the upland terrace/floodplain margin. The Port Arthur and Vicinity CSRM Plan would primarily focus on improvements to the existing 31 mile-long levee system, but it would also construct about one-third of a mile of new levee in Jefferson County; this new segment would have negligible wetland impacts. About 58 miles of placement area or hunting/fishing club dikes in Orange and northern Jefferson counties have created freshwater impoundments in the floodplains of the Sabine and Neches Rivers. About 18 miles of dikes in Orange County, and in Jefferson County along the Neches River surround industrial ponds.

For the Orange 3 CSRM Plan, levee and culvert design would maintain future tidal connectivity, resulting in negligible impacts on floodplains both inside and outside of the levee system. It would not impound wetlands upstream of the system. The new Orange CSRM system would have no impacts on threatened and endangered species. With the exception of fisheries access impacts on Adams and Cow Bayous, existing circulation, salinity, and sediment transport patterns would not be affected; water quality would be expected to remain generally the same. The indirect functional

fisheries access impacts would be mitigated by restoration of marsh systems in the Neches River bottomland outside of the levee system, which are discussed above.

7.17.2 Brazoria Region

7.17.2.1 Brazoria Region Past or Present Actions

Freeport Harbor Jetties. The Rivers and Harbors Act (RHA) of June 14, 1880, provided for construction of jetties for controlling and improving the channel over the bar at the mouth of the Brazos River (Alperin, 1977). Currently, the jetties extend approximately 7,700 feet and 8,640 feet on the north and south sides of the channel, respectively.

GIWW Texas Section, Main Channel and Tributaries. Construction of the Federally authorized GIWW between Galveston Bay and the Brazos River began in the 1907 with a 5-foot-deep by 40-foot-wide channel (Alperin 1977). Subsequent improvements have resulted in its current authorized dimensions of 12 feet by 125 feet. The GIWW crosses the existing Freeport Harbor Channel near Mile 1.5.

Brazos River Diversion Channel. Due to excessive siltation and flooding problems at Freeport, this project was authorized by Congress on March 3, 1925, and USACE completed the project in 1929 (Alperin, 1977). A diversion dam was constructed about 7.0 miles above the original mouth of the Brazos River and a diversion channel was excavated to reroute the Brazos River from the new dam to an outlet in the Gulf about 6.5 miles southwest of the original mouth.

Freeport Harbor Channel 45-Foot Project. Originally authorized by the Rivers and Harbors Act of 1935, the navigation channel was deepened to its existing authorized 45-foot depth in 1978. The Freeport Harbor Channel Jetty and Outer Bar channels are currently maintained by USACE to a depth of 48 feet MLT at a width of 400 feet. These existing channels are approximately 6.3 miles long. The North Jetty was relocated north of its original location as part of these improvements; approximately 3,500 feet were added onshore to protect against flanking, and it was lengthened seaward by 500 feet. The South Jetty was also rehabilitated concurrent with the North Jetty improvements.

Freeport and Vicinity HFPP. The Freeport HFPP is a Federal project authorized in 1962 (USACE 2005). Approximately 42 square miles (including areas of Freeport, Velasco, Lake Jackson, Clute, Lake Barbara, and Oyster Creek) were enclosed by approximately 43 miles of levees, wave barriers, floodwalls, drainage structures, pumping plants, and a vertical-lift tide gate on the navigation channel.

Bryan Mound Strategic Petroleum Reserve (SPR). Constructed in 1979, the Bryan SPR storage facility occupies 500 acres at the southeast corner of the Freeport and Vicinity HFPP, close to port and terminal facilities at Freeport and the ConocoPhillips tank farm. The site has a total DOE-authorized storage capacity of approximately 232 million barrels as part of the United States' emergency oil supply (DOE, 2004). Two principal crude oil pipelines extend from the Bryan Mound salt dome: a 4-mile, 30-inch-diameter line to the ConocoPhillips terminal and docks; and a 46-inch line to the ARCO Pipeline Company terminal in Texas City, Texas.

Freeport LNG Phase I. Freeport LNG Development, LP was permitted to construct the new Freeport LNG Import Terminal Project on Quintana Island, across the GIWW from Freeport (FERC, 2004). The project included LNG ship docking and unloading facilities with a protected single berth equipped with mooring and breasting dolphins, unloading and return arms, reconfiguration of a storm risk reduction levee and a permanent access road, two 26-inch-diameter LNG transfer lines, one 16-inch-diameter vapor return line, and service lines, two double-walled LNG storage tanks, ancillary utilities, buildings, and service facilities at the LNG terminal, and 9.6 miles of 36-inch-diameter natural gas pipeline extending from the LNG import terminal to a proposed Stratton Ridge Meter Station (FERC, 2004). This first phase of the Freeport LNG Project was completed in April 2008 and is currently operational.

Port Freeport - Velasco Terminal. The Velasco Terminal is a large cargo terminal improvement project under construction at Port Freeport. With a total 2,400 linear feet of new berths planned, 800 feet have been built thus far (Port Freeport, 2012). The facility is designed to handle new-generation gantry cranes and vessels up to 48-foot draft. It will handle containerized and break-bulk cargo, with 90 acres of developable land with rail access. The new 800-foot-long Berth 7 with 20 acres for containerized and/or break-bulk cargo activity has been completed.

Freeport Harbor Channel Widening Project (Widening Project). Port Freeport has recently widened the Freeport Harbor Entrance Channel. The project site is located along the northern edge of the Freeport Harbor Jetty and Outer Bar channels. These are maintained by the USACE to a depth of 48 feet MLT and approximate length of 6.3 miles. The project widened, but did not deepen, the Jetty and Outer Bar Channels an additional 150 to 200 feet. The length of channel that was widened is 6.1 miles, of which 5.7 miles were widened by 200 feet, to a total 600-foot width.

7.17.2.2 Brazoria Region Reasonably Foreseeable Future Actions

Freeport Harbor Channel Improvement Project (Deepening Project) and General Reevaluation Report. Authorized by WRRDA 2014, the Freeport Harbor CIP would deepen the Outer Bar Channel from the Gulf of Mexico to 58 feet MLLW; deepen the Jetty Channel through the Lower Turning Basin to 56 MLLW; deepen the Main Channel from the Lower Turning Basin to the

Brazosport Turning Basin to 56 feet MLLW; deepen through the Upper Turning Basin to 51 feet MLLW; deepen and widen the lower 3,700 feet of the Stauffer Channel at a depth of 51 feet MLLW and width of 300 feet; and dredge the remainder of the Stauffer Channel to a depth of 26 feet MLLW. Mitigation measures have been developed to compensate for all unavoidable environmental impacts. A General Reevaluation Report is currently underway to reanalyze the completed study in response to changed conditions and assumptions. Completion of the draft integrated General Reevaluation Report and environmental assessment is currently scheduled for June 2018.

Freeport LNG Phase II. In July 2014, FERC authorized Freeport LNG Development, L.P. to site, construct and operate facilities to liquefy and export domestic natural gas from its existing LNG import terminal near Freeport, Texas (FERC 2014). In addition, FERC authorized Freeport LNG's Phase II Modification Project that will revamp the previously authorized but unconstructed Phase II Project. The Phase II Modification Project comprises three major components: reorientation of the Phase II dock, modification of the transfer facilities, and modification of access roads to the terminal.

7.17.2.3 Brazoria Region Resource Impact Evaluation

Historical land use and cumulative environmental impacts in the study area are dominated by the growth of petro-chemical, LNG, and other industrial facilities. This growth has been facilitated by the growth of the deep-draft port and shallow-draft navigation channels in the study area. Significant environmental impacts of public and private projects constructed after passage of NEPA have been addressed by compensation plans that mitigated impacts on the environment. The petro-chemical and other shipping-dependent industries, as well as recreation and conservation areas (NWRs, State Parks, State Historic Sites, and WMAs), have influenced this area's land use history, navigation channel development and maintenance, coastal transportation trends, and regional economic significance. Older projects and, in particular, the Brazos River Diversion Channel and the GIWW have modified the natural hydrology, changing tidal circulation, freshwater flows, and sedimentation patterns in significant ways.

Construction of the Brazos River Diversion Channel left the existing Freeport Harbor Channel navigation channel as a dead-end channel in the bed of the Old Brazos River channel, extending from the Gulf to a dam near State Highway 288. This segment of the Freeport Harbor Channel is relatively low in biological productivity and largely devoid of natural habitats. Existing vegetation is sparsely distributed, and no significant or sensitive terrestrial or aquatic habitats exist within or along the project area. The navigation channel is heavily developed with industrial and commercial properties, including petrochemical manufacturing, storage terminals, warehousing, and related businesses. The extensive levee system of the Freeport and Vicinities HFPP lines most

of the waterways in this system and prevents overland flow from the entering the channel. Water quality in the navigation channel system is affected by high dissolved oxygen levels, and salinities approach Gulf levels because of proximity to the Gulf and lack of freshwater inflows.

The heavy sediment load of the Brazos River, which once nourished the Old Brazos River delta, is now being diverted through the Brazos River Diversion Channel to a point about 6 miles southwest of the old delta. Without this sediment source, the Old Brazos River delta is collapsing and is no longer serving as a nearshore sand source for nearby beaches, contributing to Gulf shoreline erosion in the area (Watson 2003). The Freeport Jetties and the offshore portion of the Freeport Harbor Navigation Channel also contribute to shoreline erosion by blocking or trapping longshore sediment transport along the Gulf shoreline.

The landlocked GIWW was constructed generally parallel to and inland of the Gulf shoreline to provide a protected channel for coastwide shallow draft navigation. It intersects the Freeport Harbor Navigation Channel (the Old Brazos River Channel) and the Brazos River Diversion Channel, as well as many other natural rivers near their debouchment into the Gulf. Freshwater flows from the river systems and tidal inflows divert into the GIWW, disrupting normal circulation and salinity patterns in the area near the GIWW and the Gulf shoreline.

Recreation and conservation areas (NWRs, State Parks, and WMAs), have influenced this area's land use history as well. The Brazoria and San Bernard NWR's border the Brazoria study area to the northeast and southwest of the project area. The Justin Hurst WMA and Quintana State Park are located along the Gulf shore, outside of the project area. These Federally and state-owned lands will be protected and managed to provide fish and wildlife habitat for the foreseeable future.

Impacts of the Recommended Plan in the Brazoria Region would not be sufficient, when combined with past, present and reasonably foreseeable future impacts, to lead to significant degradation of the region's environment. Modifications to the existing Freeport HFPP proposed as part of the Freeport and Vicinity CSRM Plan would have negligible environmental impacts. Modifications to the levee system would occur within the existing, disturbed right-of-way. No impacts on wetlands are anticipated. Existing circulation, salinity, and sediment transport patterns would not be affected; water quality would be expected to remain generally the same. No impacts on fish and wildlife, threatened or endangered species, or essential fish habitat are anticipated.

7.18 ANY ADVERSE ENVIRONMENTAL IMPACTS THAT CANNOT BE AVOIDED SHOULD THE RECOMMENDED PLAN BE IMPLEMENTED

The Recommended Plan would result in direct adverse impacts on benthos from construction of surge gates in Cow and Adams Bayous, but the majority of these impacts would be minor and temporary. The same gate structures would also result in functional impacts to fisheries access in these bayous. Construction of the new Orange 3 CSRM Plan would result in the loss of about 272.5 acres of marshes and forested wetlands. No other long-term environmental impacts are expected to occur as a result of the Recommended Plan.

7.19 ANY IRREVERSIBLE OR IRRETRIEVABLE COMMITMENTS OF RESOURCES INVOLVED IN THE IMPLEMENTATION OF THE RECOMMENDED PLAN

The labor, capital, and material resources expended in the planning and construction of this project are irreversible and irretrievable commitments of human, economic, and natural resources. Approximately 272.5 acres of marsh and forested wetlands would be lost from construction and operation of proposed improvements over the period of analysis, but these losses would be fully compensated with in-kind mitigation.

7.20 RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

The construction of the Recommended Plan would result in the loss of 272.5 acres of wetlands over the 50-year period of analysis. These impacts would be fully mitigated in the same general area, resulting in no net loss of wetlands and preservation of the areas long-term productivity.

7.21 ENERGY AND NATURAL OR DEPLETABLE RESOURCE REQUIREMENTS AND CONSERVATION POTENTIAL OF VARIOUS ALTERNATIVES AND MITIGATION MEASURES

NEPA regulations in 40 CFR 1502.16 (e) and (f) require a discussion of project energy requirements and natural or depletable resource requirements, along with conservation potential of alternatives and mitigation measures in an EIS. Energy (fuel) would be required to construct the new levee system, and construct and reconstruct improvements to existing systems, but these are a short-term impacts. Electricity and fuel would be expended to operate and maintain the new Orange 3 CSMR Plan. However, most of the system is a passive levee/floodwall/culvert system which requires little to no energy to operate. Energy required to operate and maintain the Cow and Adams Bayou surge gates would be minor except during episodic surge and maintenance events.

Energy required to operate and maintain the Port Arthur and Vicinity and Freeport and Vicinity CSRM Plans would be essentially equivalent to that expended for the existing systems. Construction of the Recommended Plan would not result in a significant depletion of depletable energy or natural resources. They would, however, reduce the risk of serious disruptions in the Nation's energy and petrochemical supplies by reducing storm surge impacts on areas with a high density of large petrochemical facilities.

8 IMPLEMENTATION REQUIREMENTS

This chapter provides a summary of the implementation requirements for the project in the final format.

8.1 DIVISION OF PLAN RESPONSIBILITIES AND COST-SHARING REQUIREMENTS

The Project Partnership Agreement (PPA) is a binding agreement between the Federal Government and the non-Federal sponsor, which must be approved and executed prior to the start of construction. The PPA sets forth the obligations of each party. The non-Federal sponsors must agree to meet the requirements for non-Federal responsibilities, which will be identified in future legal documents. Some of the likely responsibilities are:

- Provide 35 percent of initial project costs assigned to hurricane and storm damage reduction, and 100 percent of initial project costs assigned to protecting undeveloped private lands and other private shores which do not provide public benefits, as further specified below:
  1. Enter into an agreement that provides, prior to construction, 35 percent of design;
  2. Provide all lands, easements, and rights-of-way, and perform or ensure the performance of any relocations determined by the Federal Government to be necessary for the initial construction or the operation and maintenance of the project;
  3. Provide, during construction, any additional amounts as are necessary to make the total contribution equal to 35 percent of initial project costs assigned to hurricane and storm damage reduction, and 100 percent of initial project costs assigned to protecting undeveloped private lands and other private shores which do not provide public benefits;
- Do not use Federal funds to meet the non-Federal share of total project costs unless the Federal granting agency verifies in writing that the expenditure of such funds is authorized;
- Not less than once each year, inform affected interests of the extent of risk reduction afforded by the project;
- Agree to participate in and comply with applicable Federal floodplain management and flood insurance programs;
- Comply with Section 402 of the WRDA of 1986, as amended (33 U.S.C. 701b-12), which requires a non-Federal interest to prepare a floodplain management plan within one year after the date of signing a project cooperation agreement, and to implement such plan not later than one year after completion of construction of the project;
- Publicize floodplain information in the area concerned and provide this information to

zoning and other regulatory agencies for their use in adopting regulations, or taking other actions, to prevent unwise future development and to ensure compatibility with risk reduction levels provided by the project;

- Prevent obstructions or encroachments on the project (including prescribing and enforcing regulations to prevent such obstructions or encroachments) such as any new developments on project lands, easements, and rights-of-way or the addition of facilities which might reduce the level of risk reduction the project affords, hinder operation and maintenance of the project, or interfere with the project's proper function;
- Comply with all applicable provisions of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, Public Law 91-646, as amended (42 U.S.C. 4601-4655), and the Uniform Regulations contained in 49 CFR Part 24, in acquiring lands, easements, and rights-of-way required for construction, operation, and maintenance of the project, including those necessary for relocations, the borrowing of materials, or the disposal of dredged or excavated material; and inform all affected persons of applicable benefits, policies, and procedures in connection with said Act;
- For so long as the project remains authorized, operate, maintain, repair, rehabilitate, and replace the project, or functional portions of the project, including any mitigation features, at no cost to the Federal Government, in a manner compatible with the project's authorized purposes and in accordance with applicable Federal and state laws and regulations and any specific directions prescribed by the Federal Government;
- Give the Federal Government a right to enter, at reasonable times and in a reasonable manner, upon property that the non-Federal sponsor owns or controls for access to the project for the purpose of completing, inspecting, operating, maintaining, repairing, rehabilitating, or replacing the project;
- Hold and save the U.S. free from all damages arising from the construction, operation, maintenance, repair, rehabilitation, and replacement of the project and any betterments, except for damages due to the fault or negligence of the U.S. or its contractors;
- Keep and maintain books, records, documents, or other evidence pertaining to costs and expenses incurred pursuant to the project for a minimum of three years after the final accounting, and assure that such materials are reasonably available for examination, audit, or reproduction by the Federal Government;
- Comply with all applicable Federal laws and regulations, including, but not limited to: Section 601 of the Civil Rights Act of 1964 (42 U.S.C. 2000d) and Department of Defense Directive5500.11 issued pursuant thereto; the Age Discrimination Act of

1975 (42 U.S.C. 6102); the Rehabilitation Act of 1973, as amended (29 U.S.C. 794) and Army Regulation 600 7 issued pursuant thereto; and 40 U.S.C. 3141-3148 and 40 U.S.C. 3701-3708 (labor standards originally enacted as the Davis-Bacon Act, the Contract Work Hours and Safety Standards Act, and the Copeland Anti-Kickback Act);

- Perform, or ensure performance of, any investigations for hazardous substances that are determined necessary to identify the existence and extent of any hazardous substances regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Public Law 96-510, as amended (42 U.S.C. 9601-9675), that may exist in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for construction, operation, and maintenance of the project. However, for lands that the Federal Government determines to be subject to the navigation servitude, only the Federal Government shall perform such investigations unless the Federal Government provides the non-Federal sponsor with prior specific written direction, in which case the non-Federal sponsor shall perform such investigations in accordance with such written direction;
- Assume, as between the Federal Government and the non-Federal sponsor, complete financial responsibility for all necessary cleanup and response costs of any hazardous substances regulated under CERCLA that are located in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for construction, operation, and maintenance of the project;
- Agree, as between the Federal Government and the non-Federal sponsor, that the non-Federal sponsor shall be considered the operator of the project for the purpose of CERCLA liability, and to the maximum extent practicable, operate, maintain, repair, rehabilitate, and replace the project in a manner that will not cause liability to arise under CERCLA; and
- Comply with Section 221 of Public Law 91-611, Flood Control Act of 1970, as amended (42 U.S.C. 1962d-5b), and Section 103(j) of the WRDA of 1986, Public Law 99-662, as amended (33 U.S.C. 2213(j)), which provides that the Secretary of the Army shall not commence the construction of any water resources project or separable element thereof, until each non-Federal interest has entered into a written agreement to furnish its required cooperation for the project or separable element.

8.2 COST FOR THE RECOMMENDED PLAN

The cost estimate included here is intended to provide an estimate of total costs of the Recommended Plan. The Recommended Plan cost is included in Table 8-1.

Table 8-1: Estimate of Total First Costs of the Recommended Plan

Recommended Plan Feature	Estimated First Cost (Fiscal Year 2017) (October 2016)
Orange- CSRM Plan	$1,926,224,000
Port Arthur and Vicinity CSRM Plan	$729,069,000
Freeport and Vicinity CSRM Plan	$593,313,000
Total	$3,248,607,000

8.3 VIEWS OF NON-FEDERAL SPONSOR AND OTHERS

The existing Port Arthur and the Freeport HFPPs local sponsors have expressed interest in cost sharing for the Recommended Plan identified for the Port Arthur and Vicinity CSRM and the Freeport and Vicinity CSRM. The local sponsors responsible for operation and maintenance are the Jefferson County Drainage District No. 7 and the Velasco Drainage District (VDD), respectively. The local sponsor for Orange CSRM would be Orange County. They have also expressed interest in cost sharing for construction. A region wide systems approach for construction of Orange 3, Port Arthur and Freeport CSRM Plan, is being recommended to ensure that all of the benefits stated would be achieved.

8.4 IMPLEMENTATION PLAN

The final report recommends an implementation strategy that provides a region wide approach to providing risk reduction to the local communities. As described in section 6.3, concurrent construction of all three elements is being recommended to ensure that the regional economy would continue to operate after a storm event and the stress and hardship associated with hurricane storms would be lessened. The pre-construction and construction sequence, and time schedule of the recommended plan is dependent on the timeliness of this report's approval and allocation of funds by Congress, the foregoing construction procedures, and the ability of local interests to implement the items of local cooperation. These items of local cooperation are principally the furnishing of the required real estate easements by the three local construction sponsors. The construction schedule is based on a dedicated funding stream with the total duration of construction being 120 months (120 months for Orange 3, 72 months for both the Port Arthur and the Freeport portions of the recommendation).

In the areas of the Port Arthur and the Freeport recommendation, in order to effectively implement the plan, the construction sequence should focus on levees, floodwalls or structures which have the highest risk for failures under storm events before focusing on overall general system

elevations. Additional work would occur during the design phase of the project but it would include the identification of construction reaches and prioritizing them for construction. In the areas of the Orange 3 CSRM Plan, in order to effectively implement the plan, the construction sequence should focus on implementing the initial levee lifts, while also closing off the two main conveyance channels for storm surge, Adams and Cow Bayou. These initial construction sequences could obtain some initial levels of risk reduction when combined with interim flood fighting measures.

8.5 COST-SHARING APPORTIONMENT

The Texas General Land Office (GLO), was the non-Federal sponsor for the feasibility study. The cost-share during the feasibility phase was 50% Federal and 50% non-Federal. Following the feasibility phase, the local construction sponsors, identified in the previous section will be the non-Federal Sponsor for the planning, design, construction, operation, maintenance, repair, replacement and rehabilitation of the project. The cost share for the planning, design and construction of the project will be 65% Federal and 35% non-Federal. The local construction sponsors must provide all project LERRD required for the project. OMRR&R of the project would be a 100% local construction sponsor's responsibility. A full description of the non-Federal and Federal responsibilities after the feasibility phase of the project is contained in Section 8.1 of this report. The total estimated annual OMRR&R cost is $5,468,000. Table 8-2 presents the cost apportionment of the Recommended Plan.

Table 8-2: Cost Apportionment of Recommended Plan

	Total	Federal	Non-Federal
Preconstruction Engineering and Design (PED)	$336,759,000	$218,893,350	$117,865,650
Construction	$2,723,934,000	$1,885,558,021	$838,375,979
Pipeline Relocations	$128,320,000	$0	$128,320,000
Lands, Easements, & ROW	$59,595,084	$7,143,884	$52,451,200
Total First Costs	$3,248,608,084	$2,111,595,255	$1,137,012,829
Cost Apportionment of by Elements of the Recommended Plan			
Orange	Total	Federal	Non-Federal
PED	$202,423,000	$131,574,950	$70,848,050
Construction	$1,622,510,000	$1,114,765,499	$507,744,501
Pipeline Relocations	$62,387,000		$62,387,000
Lands, Easements, & ROW	$38,905,004	$5,705,804	$33,199,200
Total First Costs	$1,926,225,004	$1,252,046,253	$674,178,751
Port Arthur	Total	Federal	Non-Federal

PED	$74,084,000	$48,154,600	$25,929,400
Construction	$607,128,000	$424,803,222	$182,324,778
Pipeline Relocations	$38,544,000		$38,544,000
Lands, Easements, & ROW	$9,313,080	$937,080	$8,376,000
Total First Costs	$729,069,080	$473,894,902	$255,174,178
Freeport	Total	Federal	Non-Federal
PED	$60,252,000	$39,163,800	$21,088,200
Construction	$494,296,000	$345,989,300	$148,306,700
Pipeline Relocations	$27,389,000		$27,389,000
Lands, Easements, & ROW	$11,377,000	$501,000	$10,876,000
	$593,314,000	$385,654,100	$207,659,900
Note: Total Cost Apportionment values maybe slightly different due to rounding			

8.6 RECOMMENDED PLAN AND RECENT USACE INITIATIVES

8.6.1 USACE Campaign Plan

The Recommended Plan addresses the Chief of Engineers Campaign Plan Goal 2: Deliver enduring and essential water resource solutions using effective transformation strategies.

Objective 2a: Modernize the Civil Works project planning program and process. This FIFR-EIS contributes to the objective defined within Goal 2. This report recommends specific solutions to water resource problems and opportunities based on risk-informed decisions. It was developed in close collaboration with stakeholders and partners. The SMART planning principles and risk-informed decision-making were applied in this study and the study complies with the 3x3x3 Rule, which establishes the timeframe and costs required to complete the study.

Objective 2c: Deliver quality solutions and services. This objective is measured by successfully meeting or exceeding established commitments for schedule, cost, and quality to ensure consistent, high-quality performance. A Cost and Schedule Risk Analysis and a Risk Management Plan was performed/developed to ensure the authorized cost limits are set and cost risks are managed with the Recommended Plan.

8.6.2 Environmental Operating Principles

Environmental consequences of construction and operation of the Recommended Plan have been considered in avoiding and minimizing impacts; remaining unavoidable impacts would be fully mitigated. Sustainability was an integral consideration in the development of flood risk reduction

recommendations. A risk management and systems approach was developed with input from the USACE Risk Management Center and the Flood Risk Management Planning Center of Expertise; operation of the projects will also employ a risk management approach. Coordination with stakeholders and the general public began with four public scoping meetings, continued with stakeholder updates, and extensive resource agency input during impact modeling. Resource agency knowledge and evaluation methods developed for similar projects were applied in the impact analysis. A thorough NEPA and engineering analysis has ensured that we will meet our corporate responsibility and accountability for actions that may impact human and natural environments in the Sabine and Brazoria regions. This analysis will be transparent and communicated to all individuals and groups interested in USACE activities.

9 PUBLIC INVOLVEMENT

9.1 PUBLIC INVOLVEMENT ACTIVITIES

Extensive public scoping, stakeholder communication, and resource agency coordination were maintained throughout development of the Recommended Plan. Four scoping meetings were held in early 2012, which resulted in the identification of over 250 ideas addressing CSRM problems and ER opportunities in the six-county study area. The February 6, 2012, invitation to participate in meetings held in Beaumont, Seabrook, Galveston and Freeport, Texas, was published on the USACE-Galveston District website and sent to an extensive mail list.

Two stakeholder briefings were held in the spring of 2014 that focused primarily on communicating the goals and progress of the study with local governments and agencies. Continuous contact has been maintained with outside organizations that have been working to address the same problems as those addressed by this study. In particular, close communication has been maintained with the team at Texas A&M Galveston, which has been working to develop the Ike Dike proposal, the Severe Storm Prediction, Education and Evacuation from Disasters Center (a consortium of several universities headquartered at Rice University in Houston), which has been assessing a number of other CSRM, ER, and recreation initiatives for the Galveston Bay region, and the Gulf Coast Community Protection and Restoration District, which is preparing a report evaluating CSRM opportunities in the six-county study area.

9.2 SUMMARY OF NOTICE OF INTENT COMMENTS

USACE published the Notice of Intent (NOI) to prepare an EIS in the Federal Register on November 24, 2014. Written comments were accepted for a 30-day period following that notice. In total, about 20 written comments were received following the public meetings and NOI. The NOI and comments are presented in Appendix F. Comments made at the public meetings and in the written comments are summarized below.

The majority of the original public and agency comments received pertained to the Galveston Bay Region and to ER opportunities in general. The Audubon Society expressed concerns regarding Colonial Waterbird rookeries and piping plover critical habitat areas. Several rookery and critical habitat areas are within the project area, which provide nesting and feeding habitat, and are currently subject to erosion from storm damage, ship traffic and sand mining activities. The Port of Houston Authority (PHA) advised that solutions will need to reflect industry participation or sponsorship of projects, considering that public and private interests coexist along the coast. The feasibility of structural solutions on the Houston Ship Channel (HSC) need to be considered prior

to implementation, as most of the current transportation systems that serve the HSC cannot appropriately accommodate proposed flood control structures without causing a disruption in the transportation of commerce. The City of Galveston and the general public also expressed interest in public and private partnerships, which can reduce the financial burden on taxpayers. The City of Galveston recommended that a sediment management plan be considered that encourages beneficial use of dredge materials for public and private projects such as beach preservation, beach nourishment, and establishment of a natural sand dune defense system. Local citizens and municipalities would also like to see conservation and enhancement of wetlands, in combination with responsible development, to prevent and mitigate impacts from severe weather and flood damage, specifically on Bolivar Peninsula and west end of Galveston Island. Multiple comments referenced flood control projects, greenspace, and conservation areas as practicable and effective examples.

In the Sabine region, Orange County expressed strong support for an evaluation of surge risk reduction for that county, including risk reduction for Chemical Row and the Entergy Power Plant. USACE was urged to evaluate levee and surge gate alternatives, and to utilize the Orange County Study, which evaluated several potential alternatives. Industrial facilities and the general public emphasized the need to protect petro-chemical facilities in the area, one of which is the largest refinery in the U.S. The general public was also concerned about maintaining or improving evacuation routes during storm emergencies. Jefferson County and Ducks Unlimited supported shoreline erosion control for the GIWW; this would prevent the loss of interior marshes that serve as storm buffers for inland communities. Comments from resource agencies focused on the need for marsh restoration on the lower Neches River and marshes near Sabine Pass, and dune and shoreline restoration of the Jefferson county shoreline, again as a means for buffering surge impacts. GIWW erosion, marsh, dune, and shoreline restoration will be addressed as part of the new USACE Jefferson County ER Feasibility Study being conducted in conjunction with Jefferson County and the Sabine-Neches Navigation District.

In the Brazoria region, the local sponsor of the Freeport Hurricane Flood Protection Project (HFPP) supported evaluation of storm surge impacts on the existing system. This would strengthen existing risk reduction of the dense petrochemical and residential development within the Freeport HFPP. Maintaining or improving evacuation routes were important to local citizens. Local interest groups and the general public expressed concern with maintaining a tidal connection with the Gulf at the San Bernard River, and the effect of altered circulation created by the GIWW intersection with the Brazos River Diversion Channel. Local citizens also expressed concern regarding the effect of the Brazos River Diversion Channel on sediment delivery to the Surfside area. Beach restoration in the Surfside area would protect nearby residences and help attenuate storm surge. Resource agencies recommended restoration of Follets Island, a barrier peninsula, as

a means of buffering storm surge impacts on the Freeport mainland. Tidal circulation, sediment supply, and beach and marsh restoration will be addressed as part of the ongoing USACE Coastal Texas CSRM and ER Feasibility study, in conjunction with the Texas GLO

The Sierra Club provided comprehensive comments, which applied to the six-county study area. In general, they urged restoring natural coastal shoreline system features and urged restraint in the construction of structural systems that would encourage more development. They supported structural measures that are limited in size and focused on vulnerable, developed areas, and recommended targeted buyouts rather than structural alternatives in areas such as Surfside in the Brazoria Region. They urged working with nature and natural processes, as well as protecting shoreline features that provide natural erosion protection.

9.3 COMMENTS ON THE DIFR-EIS

The Notice of Availability and DIFR-EIS were released for public review and comment on September 11, 2015. All comments were due on October 26, 2015. Public meetings on the DIFR-EIS were held on October 6 and 8, 2015, in Beaumont and Freeport, Texas, respectively. Transcripts of these meetings and all comments received during the public comment period are provided in Appendix F. The comments are summarized below. USACE responses to all comments are also presented in Appendix F.

9.3.1 Summary of Public Comments

Comments were received from one city, two local governmental agencies, three companies, the Houston Sierra Club, and seven individuals from Bridge City and Freeport. Several individuals and one company asked for close-up maps, which were added to the Galveston District website during the public comment period. While supportive of the project, individuals and companies expressed concerns over impacts to their properties or operations during construction, or maintaining access through the structures after construction. The City of Port Neches asked that the Orange-Jefferson CSRM Plan be revised to exclude city recreational properties along the Neches River waterfront from the risk reduction plan. Port Freeport identified concerns with how the Freeport and Vicinity CSRM Plan design would impact one of their docks. Badische Anilin- & Sodafabrik (BASF) expressed concerns that the construction and operation of the Dow Barge Canal gate would interrupt their daily operations. The Velasco Drainage District (VDD) and the Sierra Club provided the most extensive comments, which are summarized below.

The VDD suggested that SWG revisit and improve our public notification process. Written notices were sent but not received by some entities; press releases were made but the local press did not respond. The VDD does not concur with USACE's requirement for steady state seepage evaluation

and risk assessment of the levees in their system. They maintain that there is insufficient time during a coastal storm to reach a steady state sufficient to cause breeching. Other comments requested clarification for specific sections of the DIFR-EIS, additional information on specific engineering methodologies, and further explanation of specific plan recommendations.

The Sierra Club objected to our denial of their request for a time extension of the public comment period. The comment period opened on 11 Sep 2015 and their request for the extension was made on 21 Sep 2015. We denied their request at that time, but advised that we would reevaluate the need for an extension as the comment period progressed. No other public requests for an extension were received and the comment period was not formally extended. The Sierra Club also expressed concern that the final Recommended Plan and mitigation were not presented in the DIFR-EIS, and in general, requested that much more information and analyses be presented. Sierra Club comments requested further clarification on numerous topics that were covered in detail in the appendices, such as the comprehensive overview of the six counties, unintended consequence, hydrologic impacts of the new levee system and surge gates, historic property impacts, the economic analysis, and the WVA ecological modeling. The comments requested additional explanation regarding screening of structural and non-structural alternatives, cumulative impacts, O&M, and relative sea-level rise.

9.3.2 Summary of Resource Agency Comments

Comments were received from the following Federal and state resource agencies – the U.S. EPA, USFWS, NMFS Southeast Region Protected Resources Division (PRD) and HCD, NRCS, TPWD, TCEQ Water Quality Division and NEPA coordinator, the Texas GLO, and the Texas SHPO.

Several agencies concurred with our impact and compliance determinations or had few comments. The USFWS had no comments on the DIFR-EIS. SWG coordinated closely with USFWS and the agency has provided a Final Coordination Action Report for the project and a review of the Biological Assessment (BA). The NMFS concluded Endangered Species Act (ESA) consultation responsibilities based on the USACE "no effect." The NRCS reviewed the proposed new levee/floodwall system in Orange and Jefferson Counties and determined that the soils classified as Prime Farmland in the project area need not be given further consideration or protection because the impacts scored beneath the threshold score established by the Farmland Conversion Impact Rating for Corridor Type Projects. The GLO reviewed the DIFR-EIS for consistency with the Texas Coastal Management Program and determined that the proposed project is consistent with the program's goals and policies. The TCEQ NEPA coordinator agreed that the general conformity rules for compliance with national air quality standards do not apply to the TSP components in Orange and Jefferson Counties but they do apply to the Freeport and Vicinity

CSRM Plan in Brazoria County. However, because emissions are expected to be *de minimis*, TCEQ agreed that a general conformity determination is not required. The SHPO concurred with our proposal to execute a Programmatic Agreement to demonstrate compliance with the National Historic Preservation Act.

The NMFS-HCD and TWPD agreed with the impact analysis and confirmed that they wanted to participate in the development and review of the final mitigation plan. The HCD is supportive of the mitigation concept and the potential mitigation sites. They note that EFH impacts are uncertain because the TSP and assumptions underlying some impact assessments may change during final feasibility analysis. HCD provided a list of EFH Conservation Recommendations and SWG has provided an interim response since a determination of the acceptability of these recommendations will not be possible until the final Recommended Plan and mitigation plan are developed. TPWD noted that the TSP identified impacts to TPWD Wildlife Management Areas and that these impacts must be consistent with Chapter 26 of the Parks and Wildlife Code of Texas and Chapter 34 of the Texas Natural Resources Code, as well as TPWD policy. The TCEQ Water Quality Division provided comments requesting clarification of several concerns - the evaluation of practicable alternatives, interior drainage analysis, and impacts to sediment movement and tidal flows. TCEQ confirmed that they wanted to participate in development and review of the final mitigation plan. The EPA rated the Draft EIS as EC-2 (Environmental Concerns and Request Additional Information). EPA provided recommended mitigation measures for air contaminants and greenhouse gas emissions and suggested that they be included in the final Recommended Plan, as applicable and practicable. EPA also recommended further outreach to Native American tribes and environmental justice populations. Clarifications were requested on a number of issues including the scope of the study, the alternatives analysis, impacts to floodplains and wetlands, and the risk of disturbing contaminated soils. The EPA confirmed that they want to participate in development and review of the final mitigation plan.

9.4 DISTRIBUTION LIST*

A list of all Federal and state legislative representatives, agencies, organizations, and persons to whom the notice of availability for FIFR-EIS was sent is presented as Appendix T. Names shown in all caps are owners of properties that are in or adjacent to the Orange-Jefferson CSRM Plan right-of way or adjacent to the existing Port Arthur and Freeport and Vicinities CSRM Plan alignments.

10 RECOMMENDATIONS

10.1 OVERVIEW

A diligent effort was made to coordinate and collaborate with resource agencies, local industry, and environmental interests throughout the study process and public meetings. Environmental resource concerns were addressed early in the study process to assure that adverse impacts were avoided to the maximum extent practicable. The recommendations contained herein reflect the information available at this time. To ensure the Recommended Plan complies with all applicable laws and policies and is acceptable to the public, this FIFR-EIS has undergone public, policy, and technical review. The study team has addressed any outstanding issues raised during the review and confirmed the analysis in this FIFR-EIS.

10.2 RECOMMENDATIONS

The recommendations contained herein reflect the information available at this time and current Departmental policies governing formulation of individual projects. They do not reflect program and budgeting priorities inherent in the formulation of a national Civil Works construction program nor the perspective of higher review levels within the Executive Branch. Consequently, the recommendations may be modified before they are transmitted to the Congress as proposals for authorizations and implementation funding. However, prior to transmittal to the Congress, the non-Federal sponsor, the state, interested Federal agencies, and other parties will be advised of any modifications and will be afforded an opportunity to comment further.

18 MAY 17
Date

Lars N. Zetterstrom, P.E.
Colonel, U.S. Army
Commanding

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12 INDEX*

Adams Bayou, 1-8, 2-6, 2-11, 5-34, 6-5, 6-32, 7-7, 7-14, 7-15, 7-16, 7-18, 7-19, 7-20, 7-21, 7-49, 11-4

Air Quality, xiii, xv, 2-19, 6-37, 7-23, 7-24, 11-3

Aquatic Habitats, 2-17

Brazoria County, 1, 1-4, 1-8, 2-1, 2-6, 2-7, 2-13, 2-14, 2-19, 3-16, 3-18, 4-1, 4-7, 6-37, 7-23, 7-39, 7-44, 11-7

Brazoria NWR, 2-13, 7-2

Brazos River, 1-4, 1-8, 1-9, 2-5, 2-6, 2-7, 2-13, 2-14, 2-17, 2-19, 4-7, 7-8, 7-16, 7-34, 7-52, 7-54, 7-55, 9-2, 11-7

Bridge City, 1-6, 2-11, 2-22, 3-9, 5-37, 6-5, 6-6, 7-13

buyouts, 4, 5-2, 5-20, 5-21, 9-3

coastal marsh, 3, 6-13, 7-1, 7-10, 7-11, 7-12, 7-14, 7-16, 7-18, 7-41

coastal prairie, 2-8, 2-12, 2-13, 7-9, 7-10

Cow Bayou, 2-6, 5-34, 5-36, 5-37, 6-5, 6-32, 7-7, 7-14, 7-15, 7-19, 11-4

Critical habitat, 2-19

critical infrastructure, 4, 7, 8, 1-4, 3-3, 3-16, 3-18, 3-20, 4-5, 5-9, 5-10, 5-21, 5-22, 5-29

cultural resources, 12, 2-21, 4-4, 6-24, 6-44, 7-35, 7-36, 7-37, 7-41

Cumulative Impacts, 7-46

environmental justice, 6-31, 6-46, 7-43

Essential Fish Habitat, 2-17, 5-36, 7-17, 11-4

fish and wildlife impacts, 7-7

floodplain, 2-14, 2-15, 2-16, 3-1, 3-8, 4-4, 4-5, 5-2, 5-34, 6-45, 7-3, 7-4, 7-5, 7-6, 7-8, 7-11, 7-13, 7-39, 7-40, 7-41, 7-42, 7-43, 7-51, 8-1

forested wetland impacts, 7-12

Freeport, 1, 6, 7, 8, 13, *1-2*, 1-3, 1-4, 1-8, 1-9, 2-1, 2-4, 2-6, 2-13, 2-19, 2-20, 2-21, 3-1, 3-3, 3-6, 3-8, 3-10, 3-12, 3-13, 3-15, 3-16, 3-18, 3-19, 3-20, 4-1, 4-2, 4-3, 4-7, 5-8, 5-9, 5-16, 5-18, 5-19, 5-20, 5-21, 5-22, 5-23, 5-25, 5-27, 5-32, 5-39, 5-40, 5-41, 5-42, 6-4, 6-9, 6-12, 6-29, 6-30, 6-31, 6-32, 6-33, 7-2, 7-8, 7-9, 7-11, 7-13, 7-16, 7-18, 7-19, 7-20, 7-22, 7-23, 7-24, 7-29, 7-33, 7-34, 7-35, 7-36, 7-39, 7-41, 7-44, 7-45, 7-47, 7-52, 7-53, 7-54, 7-55, 8-4, 9-1, 9-2, 9-5, 11-2, 11-4, 11-7, 11-10

Galveston, i, 1, 2, 5, 6, 7, 12, xiv, 1-1, *1-2*, 1-3, 1-4, 1-5, 1-6, 1-7, 1-8, 2-1, 2-5, 2-6, 2-7, 2-8, 2-9, 2-11, 2-12, 2-13, 2-14, 2-16, 2-17, 2-19, 2-20, 2-21, 2-22, 4-1, 4-3, 4-4, 4-5, 4-7, 5-2, 5-3, 5-4, 5-5, 5-7, 6-37, 7-33, 7-35, 7-47, 7-52, 9-1, 11-1, 11-3, 11-6, 11-7, 11-9

Galveston Bay, i, 2, 6, 12, *1-2*, 1-3, 1-4, 1-7, 2-1, 2-5, 2-6, 2-7, 2-8, 2-9, 2-12, 2-13, 2-14, 2-16, 2-17, 2-21, 4-1, 4-5, 7-47, 7-52, 9-1, 11-3

Harris County, 2-5, 2-12

historic properties, 12, 2-20, 5-37, 5-38, 5-40, 6-24, 6-31, 6-44, 7-37

HTRW, xiv, 5-37, 5-39, 5-40, 6-36, 7-30, 7-31, 7-32, 7-33

hurricane, 4, 1-5, 2-9, 2-10, 2-21, 4-2, 4-5, 5-3, 5-9, 7-36, 7-40, 7-41, 7-44, 11-3

J.D. Murphree WMA, 2-10, 2-11, 7-2, 7-49

Jefferson County, 2, 13, 1-5, 1-6, 1-7, 2-3, 2-6, 2-11, 2-21, 3-1, 3-10, 3-16, 3-17, 4-2, 5-31, 5-34, 5-38, 5-40, 6-28, 7-2, 7-3, 7-4, 7-13, 7-37, 7-38, 7-44, 7-48, 8-4, 9-2, 11-5, 11-8

Justin Hurst WMA, 2-13, 7-2, 7-55

life safety, 4-1, 4-2

liquefied natural gas (LNG), 7-48

marsh impacts, 5-33

McFaddin NWR, 2-8, 2-10, 3-14

mitigation, 2-11, 4-4, 5-12, 6-14, 6-24, 6-36, 6-44, 6-46, 7-8, 7-11, 7-12, 7-13, 7-17, 7-48, 7-51, 7-56, 8-2

Neches River, 1-9, 2-5, 2-11, 3-9, 3-14, 3-17, 4-4, 5-10, 5-11, 6-32, 7-1, 7-3, 7-8, 7-10, 7-11, 7-12, 7-13, 7-19, 7-47, 7-48, 7-50, 7-51, 9-2

Nelda Stark, 2-11, 7-48, 7-49

noise impacts, 5-37, 5-38, 5-40, 7-29, 7-30

non-structural, 5-7

Old River, 8, 2-11, 3-13, 3-14, 5-9, 5-18, 5-20, 5-22, 5-25, 5-27, 5-39, 5-40, 5-42, 6-15, 7-10, 7-48, 7-49

Orange
City of, 7-47

Orange County, 12, 13, 2-2, 2-11, 3-1, 3-8, 3-9, 3-16, 5-4, 5-20, 5-30, 5-34, 5-40, 6-5, 6-28, 6-33, 7-1, 7-3, 7-4, 7-11, 7-13, 7-20, 7-28, 7-32, 7-36, 7-38, 7-44, 7-45, 7-47, 8-4, 9-2, 11-4, 11-8

Oyster Creek, 8, 1-8, 2-6, 3-13, 5-9, 5-17, 5-20, 5-22, 5-23, 5-25, 5-27, 5-39, 5-42, 7-9, 7-11, 7-13, 7-16, 7-20, 7-29, 7-33, 7-37, 7-39, 7-52

park(s), 7-54, 7-55

pipelines, 2-21, 4-2, 7-31, 7-33, 7-34, 7-48, 7-49, 7-53

population, 6-46

Port Arthur, 2, 6, 7, 13, xiii, 1-3, 1-4, 1-6, 1-7, 1-9, 2-20, 2-21, 3-1, 3-2, 3-3, 3-4, 3-5, 3-8, 3-10, 3-11, 3-15, 3-16, 3-17, 3-19, 4-1, 4-2, 4-3, 5-8, 5-9, 5-13, 5-15, 5-20, 5-21, 5-23, 5-25, 5-27, 5-32, 5-38, 5-41, 6-7, 6-8, 6-12, 6-29, 6-30, 6-31, 6-33, 6-45, 7-2, 7-8, 7-9, 7-11, 7-12, 7-13, 7-14, 7-17, 7-18, 7-19, 7-20, 7-22, 7-23, 7-24, 7-28, 7-32, 7-33, 7-35, 7-36, 7-38, 7-39, 7-41, 7-44, 7-45, 7-47, 7-48, 7-49, 7-51, 8-4, 9-5, 11-5, 11-10
LNG Terminal, 7-48
prime farmlands, 5-37
programmatic overview, 1-2
Public involvement, 7-44
Relative Sea Level Change, 2-6, 3-18, 5-23, 6-32
Sabine River, 6, 1-7, 2-7, 2-11, 2-14, 3-4, 5-10, 6-5, 7-3, 7-6, 7-10, 7-13, 7-20, 7-31, 7-47, 7-49
San Bernard NWR, 2-14, 7-55
Sediment Quality, 2-19, 7-19
storm surge, 2, 3, 4, 12, 1-5, 1-6, 1-7, 2-8, 2-9, 2-10, 2-15, 2-20, 2-21, 3-1, 3-4, 3-7, 3-14, 3-16, 4-2, 4-5, 4-7, 5-9, 5-10, 5-22, 5-29, 6-5, 6-6, 6-33, 7-6, 7-7, 7-13, 7-32, 7-33, 7-34, 7-36, 7-44, 7-45, 7-57, 9-2, 11-2
Texas
Point Wildlife Management Area (WMA), 6-46
Texas Point NWR, 2-1, 2-8, 2-11
Threatened and Endangered Species, 2-18, 7-18
Tony Houseman WMA, 2-11, 7-1
Velasco Drainage District, 13, xvi, 1-3, 1-8, 3-3, 8-4
water quality, 1-1, 2-13, 2-16, 2-17, 5-39, 7-18, 7-19, 7-20, 7-22, 7-51, 7-55

Sabine Pass to Galveston Bay, Texas
Coastal Storm Risk Management and Ecosystem Restoration
Final Integrated Feasibility Report and Environmental Impact Study

APPENDIX A

MEASURE INFORMATION SHEETS

May 2017

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURE 1
INFORMATION SHEET

DESCRIPTION OF MEASURE 1: The Ike Dike, Chambers, Galveston and Harris Counties

Texas A&M University at Galveston (TAMUG) and the City of Galveston are sponsoring a study of the Ike Dike proposal for storm surge protection of Galveston Island and Galveston Bay. The Ike Dike is a surge barrier system located along the Gulf of Mexico coastline that would protect the entire Galveston Bay system. The plan consists of approximately 62 miles of dike and an existing seawall, and two new gated structures. This measure was developed with general information provided by TAMUG. The Ike Dike measure would adhere to the following four principles:

- shorten the perimeter of the flood defense system as much as possible,
- keep the surge out of internal waters,
- use gated barriers to allow shipping, and,
- conserve and/or improve the ecology of the bay.

LOCATION OF MEASURE: (See attached drawing Measure 1-Ike Dike)

DESIGN ASSUMPTIONS

Dike: The proposed crest height of the dike would be NAVD 88 17 feet, the same height as the Galveston Seawall. The Ike Dike would protect all of the property surrounding Galveston Bay, including the cities of Houston and Galveston, communities around the east and west shorelines of Galveston Bay, as well as portions of Bolivar Peninsula and West Galveston Island. The total length of the new dike, not including the existing Galveston Sewall, would be about 52 miles. The dike would be constructed as a raised highway, following the right-of-way of existing highways on Bolivar Peninsula and West Galveston Island. The measure, as presented here, does not include necessary extensions at the eastern and western ends to reach corresponding inland elevations in Chambers and Brazoria counties, and similarly, it does not provide for gates where these extensions would cross the GIWW.

Surge Gates: The two surge gates would be located in the Houston-Galveston Ship Channel Entrance at Bolivar Roads and in San Luis Pass.

The Houston-Galveston Ship Channel Entrance would feature a 590 feet-wide floating sector gate barrier. Two vertical lifting gate barriers would provide access for barges. Smaller vertical lifting gates would allow circulation of water but close the inlet in case of storm surge.

The approximately 2,625 feet-wide San Luis Pass, is located at the west end of Galveston Island. The San Luis Pass Bridge limits the maximum size of the vessels to a width of about 33 feet. A vertical lift barrier would ensure passage of the small recreational vessels that currently utilize the pass. San Luis Pass is not an authorized navigation channel and it is not proposed that the barrier would be designed to accommodate commercial navigation. A set of smaller vertical lift gate barriers would allow tidal exchange.

HYDRAULICS & HYDROLOGY

The design storm used for the H&H analysis is the 100-year storm surge derived by FEMA using the recent results from the FEMA 2011 Texas coastal study. The ADCIRC results were converted into a Without-Project 100-year flood depth grid that corresponds to the existing Without-Project condition.

Although the without-project 100-year flood depth grids show the Texas City Hurricane Flood Protection (HFP) system as functioning for a 100-year surge, this study assumes that it would fail since it has designs similar to those found in the New Orleans HFP project and do not include current USACE standards for resiliency and redundancy features that are critical for life-safety structures.. The data derived for damages associated with the Texas City HFP system were provided from a recent levee safety risk assessment completed by USACE Galveston District and data from the National Levee Database. The Without-Project flood depth grid is used to estimate the With-Project benefits as the Without-Project flood grid represents the reconstructed system performing fully at a 100-year surge level.

Assumptions included the following:
The Ike Dike includes the seawall and the seawall is up to design standards.
No surge will come through the Ike Dike into Galveston Bay for a 100-year design storm. It is also assumed no overtopping will occur. (100% Effective)

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

Measure 1 - The Ike Dike, Chambers, Galveston and Harris Counties

Total Estimated Real Estate Cost: $142,500,000 ®

ENVIRONMENTAL

The Ike Dike would be a combination of an open and a closed system, as complete closure would have major implications on the ecology of the Galveston Bay system. During normal (non-flood) conditions, the surge gates should allow free water flow while assuring safe navigation. However, a barrier in Bolivar Roads would reduce the Bolivar Roads flow area by 40 to 60%, leading to a decrease of the tidal prism between 21 and 41% (Ruijs, 2011). Because of the smaller tidal prism, an increase in residence time, and a decrease in salinity could be expected. The reduction of the tidal prism, tidal range and current speeds could cause a redistribution of the sediment from marshes and flats to the channels within the bay. The blocking of sediment from the Gulf of Mexico by the barrier could further enhance this effect. Changes to the hydrodynamics, water quality and morphology in the bay could potentially result in loss of habitat and disturb the ecology. Further research would be required to evaluate these effects.

The surge protection would, however, have some beneficial effects on forested and emergent marsh wetlands in the Galveston Bay system. The Ike Dike system would not protect the natural environment from damages caused by hurricane-force winds, but it would reduce surge damages due to scouring and marsh loss due to elevated salinities following the storm. Environmental benefits are presented in wetland acres that would be protected by this measure. The wetland acres were calculated with a GIS analysis of National Wetland Inventory wetland maps (USFWS, 2012) It is estimated that approximately 121,000 acres of wetlands (emergent marsh, bottomland hardwood forest, swamp and scrub-shrub) in the Galveston Bay area would be protected from adverse surge effects. These sensitive wetland areas include the USACE Wallisville Lake Project and the Anahuac National Wildlife Refuge.

BENEFITS

With and without project damages to structures, contents, and vehicles were calculated using HEC-FIA (Flood Impact Analysis) software package which analyzes consequences for a given flood event, in this case, a 1% annual exceedence probability (100-year). Without-project damages are those that would occur under the current existing condition. Residual damages are those that would occur with a given measure in place. Benefits are the difference between the two. These numbers are listed in the tables below.

This economic analysis does not take into account loss of human life or impacts to the economy of the region that would result from economic and industrial disruptions caused by storm surge.

The U.S. Department of Commerce, Economic Development Administration partnered with the Texas Engineering Extension Service (TEEX) in a study examining the economic impact of Hurricane Ike to an eight-county region including the six counties in the Sabine to Galveston study (Brazoria, Chambers, Galveston, Harris, Jefferson, Orange) and two additional inland counties (Liberty, Tyler). The study's Disaster Impact Model calculated the total economic impact of Hurricane Ike for the 12 months immediately following the storm to be an estimated $142 billion (TEEX, no date).

Storm Surge Regions

Region	Counties
6	Brazoria, Galveston, Harris
7	Chambers, Galveston, Harris, Jefferson
8	Chambers, Jefferson, Orange

Benefits for Measure 1 – The Ike Dike, Chambers, Galveston and Harris Counties

	Region 6		
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$378,371,000	$5,252,524,000
Contents	$5,854,589,000	$351,748,000	$5,502,841,000
Vehicles	$1,337,005,000	$109,829,000	$1,227,176,000
Total	**$12,822,489,000**	**$839,948,000**	**$11,982,541,000**

	Region 7		
	Without Project Damages	Residual Damages	Benefits
Structure	$1,016,448,000	$16,916,000	$999,532,000
Contents	$833,516,000	$20,703,000	$812,813,000
Vehicles	$252,516,000	$4,978,000	$247,538,000
Total	**$2,102,480,000**	**$42,597,000**	**$2,059,883,000**

Total Combined Region 6 and Region 7 Benefits **$14,042,424,000**

COSTS

The Total Project Cost without RE cost is estimated to be $6,090,000,000. This cost is derived from the TAMU IKE Dike report (see reference below). A detailed breakdown of this cost was not available and therefore no review of reasonableness was possible.

REFERENCE DOCUMENTS

The design and cost developed in the following report were used: Applying best practices from the Delta Works and New Orleans to Galveston Bay, Prepared by: Kasper Stoeten, Master Student Hydraulic Engineering, Delft University of Technology, November 2012. A copy of this report with eight appendices can be found on SharePoint:
https://extranet.dse.usace.army.mil/sites/Divisions/SWD/SWG/S2G/default.aspx

Discussion of environmental effects of the Ike Dike barrier were based, in part, on a report entitled The effects of the "Ike Dike" barriers on Galveston Bay, prepared by M. Ruijs (2011). A copy of this report can be found on SharePoint:
https://extranet.dse.usace.army.mil/sites/Divisions/SWD/SWG/S2G/default.aspx

Texas Engineering Extension Service (TEEX). No Date. Hurricane Ike Impact Report, Accessed on the internet at http://www.thestormresource.com/index.aspx

U.S. Fish and Wildlife Service (USFWS). 2012. National Wetland Inventory. Accessed on the internet at http://www.fws.gov/wetlands/Data/Mapper.html

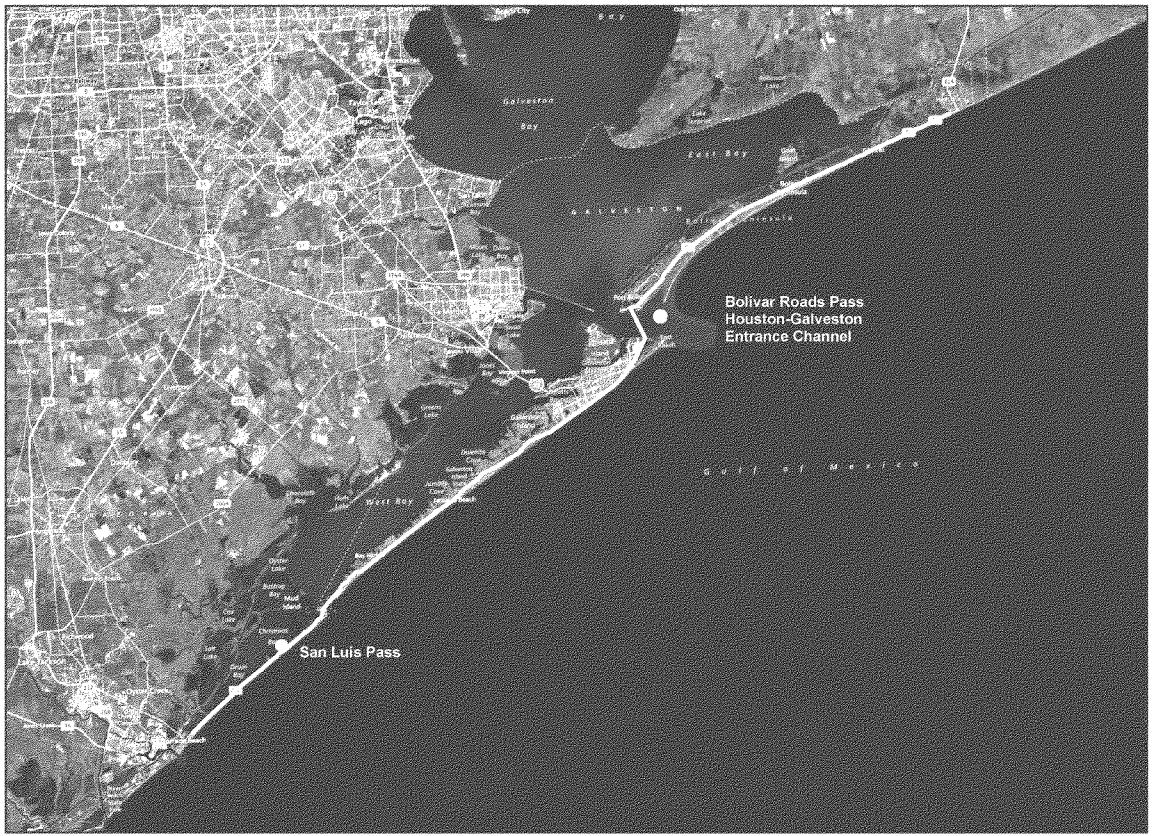
RISKS:

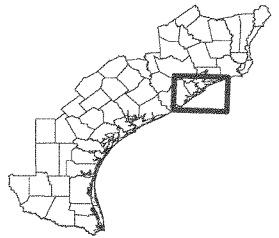
- Geotechnical feasibility of the proposed storm protection system was not studied. Complex geology and hydrology of San Luis Pass will present design challenges.
- No review of available public information or data from in-house files relative to the general geology and soil conditions along the proposed alignments was conducted.
- No preliminary assessment of possible levee or flood-wall cross-sections, or considerations for additional study for the preliminary and final design was considered.
- System configuration and gated structures were not assessed.
- It was assumed that every 15 years the vertical lift surge gates at Bolivar Roads and San Luis Pass would need to be removed and rehabbed.
- Relocation of utilities and acquisition of ROW for measures has not been accounted for.
- Extensive H&H modeling and environmental impact evaluation would be needed to evaluate ecological effects of decreased tidal flows into Galveston Bay.
- This environmental analysis does not take into account environmental impacts that would occur without the surge protection system as a result of contaminant spills from the high number of petro-chemical plants and other industrial facilities on the Houston Ship Channel and in the Barbour's Cut and Bayport areas.

- Existing surge runs are available for the with-project condition performed by others but were not utilized for this stage of analysis. These would have to be examined during future phases of the study if this measure goes forward.
- It will be very important if this measure is pursued to accurately understand the impacts at the ends of the Dike. There could be an increase in surge where the Ike Dike ends and fully understanding this consequence should involve ADCIRC modeling.
- Modeling is needed to evaluate the effect of overtopping of the system in case a larger storm than the 100-year event occurs. If water gets trapped behind the Ike Dike and it takes longer to drain than it would without the Ike Dike in place, there could be significant consequences.
- The assumption that the system is 100% effective (no surge into Galveston Bay) was used for initial assessment. Current design is based on TAMUG Ike Dike which would allow some level of overtopping.

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 1 - The Ike Dike, Chambers, Galveston and Harris Counties





Legend

Measure_Number

Levee System

Surge Gates

0 10,500 21,000 42,000 63,000 84,000 Feet

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURE 2
INFORMATION SHEET

DESCRIPTION OF MEASURE 2 Surge Gate and Barrier at Hartman Bridge, Harris County.

The proposed surge barrier at the Fred Hartman Bridge in Harris County would consist of a principal navigation gated structure, smaller gated structures and a levee barrier system designed to protect the industrial areas adjacent to the Houston Ship Channel (HSC) north of the Fred Hartman Bridge as well as communities and businesses located within the area. The proposal for the HSC surge system has been developed by the Severe Storm Prediction, Education and Evacuation from Disasters (SSPEED) Center, which was established in 2007 as a university-based research and education organization. Led by Rice University, the SSPEED Center organizes leading universities, researchers, emergency managers, and private and public entities to better address severe storm prediction and its impact on the Gulf Coast area. This measure was developed, in part, using general information provided by the SSPEED Center. The measure includes five miles of levee barrier tying into high ground on either side of the HSC, one principle surge gate across the HSC and one smaller gate at Goose Creek. Additionally, the proposed design could also include two tidal exchange structures, one located at the entrance to Black Duck Bay and one at the entrance to Lower San Jacinto Bay (just west of Spilman Island Placement Area). The gates would remain open to provide access for vessel traffic and allow for circulation of riverine and bay waters, only closing in anticipation of storm surge events.

LOCATION OF MEASURE

See attached drawing Surge Gates and Barrier at Hartman Bridge.

DESIGN ASSUMPTIONS

The proposed crest height for the levees and gates of the surge barrier at Fred Hartman Bridge would be NAVD 88 25 ft. The plan consists of approximately 5 miles of levees to tie into high ground on either side of the barrier system and between the surge gates. The primary gate would be located in the HSC on the southern side of the Fred Hartman Bridge. A second and smaller surge gate is located at Goose Creek.

- The proposed crest height for the surge barrier would be NAVD 88 25 ft.

- A combination of levees and gates would protect the areas north of the Fred Hartman Bridge.
- The plan would consist of approximately 5 mi of levees, one navigation structure and two gated passages.

HYDRAULICS & HYDROLOGY

The design storm used for the H&H analysis is the 100 year storm surge derived by FEMA using the recent results from the FEMA 2011 Texas coastal study. The ADCIRC results were converted into a Without-Project 100-year flood depth grid that corresponds to the existing Without Project conditions. The proposed crest height for the system (25 ft) is based upon the predicted surge height of a modified Hurricane Ike. If a 100-year storm had come ashore further south, near San Luis Pass, the surge up the Ship Channel would have reached almost about 25 feet after taking into account the funneling effects of Galveston Bay.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

Measure 2: Surge Gate and Barrier at Hartman Bridge, Harris County
Total Estimated Real Estate Cost: $3,400,000 ®

ENVIRONMENTAL

The Surge Gate and Barrier at Hartman Bridge would be a combination of an open and a closed system. During normal (non-flood) conditions, the surge gates should allow free water flow while assuring safe navigation. However, a barrier in the HSC would reduce the flow area in the tidal areas of the lower San Jacinto River and Buffalo Bayou by an unknown amount. Because of the smaller tidal prism and an increase in residence time, a decrease in tidal flushing could be expected. Changes to the hydrodynamics, water quality and morphology in the lower San Jacinto River/Buffalo Bayou systems could potentially result in loss of habitat and disturb the ecology. Further research would be required to evaluate these effects.

The surge protection would however have some beneficial effects on forested and emergent marsh wetlands in the lower San Jacinto River/Buffalo Bayou systems. The Ike Dike system would not protect the natural environment from damages caused by hurricane-force winds, but it would reduce surge damages due to scouring and marsh loss due to elevated salinities following the storm. Environmental benefits are presented in wetland acres that would be protected by this

measure. The wetland acres were calculated with a GIS analysis of National Wetland Inventory wetland maps (USFWS, 2012). It is estimated that approximately 3,200 acres of wetlands (emergent marsh, bottomland hardwood forest, swamp and scrub-shrub) in the affected area would be protected from adverse surge effects.

BENEFITS

With and without project damages to structures, contents, and vehicles were calculated using HEC-FIA (Flood Impact Analysis) software package which analyzes consequences for a given flood event, in this case, a 1% annual exceedance probability (100-year). Without project damages are those that would occur under the current existing condition. Residual damages are those that would occur with a given measure in place. Benefits are the difference between the two. These numbers are listed in the tables below.

This economic analysis does not take into account losses of human life or impacts to the economy of the region that would result from economic and industrial disruptions caused by storm surge. It could take weeks to get critical petro-chemical facilities back on-line, and months to clean-up and fully repair flooded facilities. The lives of thousands of people would be disrupted until homes could be rebuilt, and temporary dislocations would adversely affect employers who would lose employees as they relocate to other areas.

Storm Surge Regions

Region	Counties
6	Brazoria, Galveston, Harris
7	Chambers, Galveston, Harris, Jefferson
8	Chambers, Jefferson, Orange

Benefits for Measures 2 (Region 6)

	Region 6		
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$4,510,957,000	$1,119,938,000
Contents	$5,854,589,000	$4,483,304,000	$1,371,285,000
Vehicles	$1,337,005,000	$1,079,836,000	$257,169,000
Total	**$12,822,489,000**	**$10,074,097,000**	**$2,748,392,000**

Benefits for Measures 2 (Region 7)

	Region 7		
	Without Project Damages	Residual Damages	Benefits
Structure	$1,016,448,000	$863,739,000	$152,709,000
Contents	$833,516,000	$709,642,000	$123,874,000
Vehicles	$252,516,000	$223,310,000	$29,206,000
Total	**$2,102,480,000**	**$1,796,691,000**	**$305,789,000**

Total Region 6 and Region 7 $3,054,181,000

COSTS

This cost does not include real estate. The Total Project Cost is $ 798,442,000.00.

It was assumed that every 15 years the gates would need to be removed and rehabbed. This cost was estimated based, in part, on preliminary costs developed for the TAMUG IKE Dike project (Stoeten, 2012). A detailed breakdown of this cost was not available and therefore no review of reasonableness was possible.

REFERENCE DOCUMENTS

The cost, gates and levee designs developed in the report: Applying best practices from the Delta Works and New Orleans to Galveston Bay, Prepared by: Kasper Stoeten, Master Student Hydraulic Engineering, Delft University of Technology, November 2012 were used. A copy of this report with eight appendices can be found on SharePoint:
https://extranet.dse.usace.army.mil/sites/Divisions/SWD/SWG/S2G/default.aspx

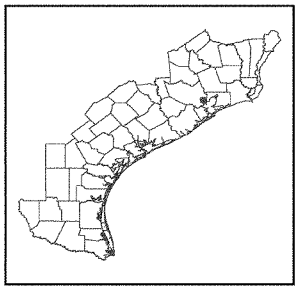
The drawings showing the alignment were taken from a PowerPoint presentation by Tom Colbert at the Gulf Coast Hurricanes: Mitigation and Response Conference (April 10-11, 2012), sponsored by the Severe Storm Prediction, Education and Evacuation from Disasters Center (SSPEED), Rice University.

U.S. Fish and Wildlife Service (USFWS). 2012. National Wetland Inventory. Accessed on the internet at http://www.fws.gov/wetlands/Data/Mapper.html

RISKS:

- Geotechnical feasibility of the proposed storm protection system was not studied.
- No review of available public information or data from in-house files relative to the general geology and soil conditions along the proposed alignments was conducted.
- No preliminary assessment of possible levee cross-sections was considered.
- System configuration and gated structures were not assessed.
- The unit cost developed in the report: Applying best practices from the Delta Works and New Orleans to Galveston Bay, Prepared by: Kasper Stoeten, Master Student Hydraulic Engineering, Delft University of Technology, November 2012 were used to develop this measure.
- It was assumed that every 15 years the gates would need to be removed and rehabbed. This needs to be investigated and validated.
- Relocation of utilities and acquisition of ROW for measures has not been accounted for.
- Extensive H&H modeling and environmental impact evaluation would be needed to evaluate ecological effects of decreased tidal flows into the lower San Jacinto River/Houston Ship Channel system.
- This environmental analysis does not take into account environmental impacts that would occur without the surge protection system as a result of contaminant spills from the high number of petro-chemical plants and other industrial facilities on the Houston Ship Channel and in the Barbour's Cut and Bayport areas.
- Existing surge runs are available for the with-project condition performed by others but were not utilized for this stage of analysis. These would have to be examined during future phases of the study if this measure goes forward.
- There could be an increase in surge where the HSC system ends which would require ADCIRC modeling to fully investigate.
- Modeling is needed to evaluate the effect of overtopping of the system in case a larger storm than the 100-year occurs. If water gets trapped behind the surge system and it takes longer to drain. there could be significant consequences.

Measure 2: Surge Gate and Barrier at Hartman Bridge, Harris County



Legend

Name

Surge Gate

Name

Levee Walls

0 355 710 1,420 2,130 2,840

Feet

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Date Created: 4/12/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 3-1, 3-2, and 3-3
INFORMATION SHEET

DESCRIPTION OF MEASURES:
3-1 Port Arthur and Vicinity, Texas Hurricane Flood Protection;
3-2 Texas City, Texas Hurricane Flood Protection;
3-3 Freeport and Vicinity, Texas Hurricane Flood Protection

Measures 3-1, 3-2, and 3-3 involve reevaluating and adding resiliency features to existing Hurricane Flood Protection (HFP) systems at Port Arthur, Texas City, and Freeport. These measures would reconstruct various parts of the existing systems to reduce their risk of failure and thereby raise their level of protection. The resiliency features correct items with similar designs as those found in the New Orleans HFP that did not perform well during Hurricane Katrina. Some of the deficiencies identified in New Orleans include lack of overtopping protection, high stick-up heights of floodwall elements, vulnerabilities to erosion at transitions between different components of the system, use of erodible materials for construction of earthen levees, improper design heights for hurricane protection components, and general lack of resiliency and/or redundancy for critical life safety structures (Wooten, 2009). The HFP systems at Port Arthur, Texas city and Freeport would experience overtopping at the design storm from waves and splash-over. The increased level of protection provided by the newly constructed resiliency features would decrease the flood risk to the protected communities.

Measure 3-1 Port Arthur and Vicinity, Texas Hurricane Flood Protection, Jefferson County, Texas. This measure would evaluate the existing hurricane protection system at Port Arthur. Construction of the existing hurricane protection system was completed in April, 1982. The HFP system includes 27.8 miles of earthen embankment and 6.6 miles of floodwall protecting a population of 89,705. The system was designed and constructed for a 100-year storm event. The proposed Port Arthur System reevaluation would consist of adding resiliency features to reduce flood risk, and thereby increasing the level of protection. These features consist of embankment overtopping erosion protection, floodwall tie-in protection, and floodwall overtopping erosion protection.

Measure 3-2 Texas City, Texas Hurricane Flood Protection, Galveston County, Texas. This measure would evaluate the existing HFP system at Texas City (including the existing guillotine gate). Construction of the existing hurricane protection system at Port Arthur, Texas was completed in 1987. The HFP system includes 20.5 miles of earthen embankment and 1.3 miles of floodwall protecting a population of 42,144. The system was designed and constructed for a

100-year event. The Texas City System reevaluation would consist of adding resiliency features to reduce flood risk, thereby increasing the level of protection. These features consist of embankment overtopping erosion protection, floodwall tie-in protection, and floodwall overtopping erosion protection.

Measure 3-3 Freeport and Vicinity Hurricane Flood Protection, Brazoria County, Texas. This measure would evaluate the existing HFP system at Freeport (including existing guillotine gate). Construction of the existing hurricane protection system at Freeport was completed in January, 1981. The HFP system includes 40.7 miles of earthen embankment and 2.6 miles of floodwall protecting a population of 45,903. The system was designed and constructed for a 100-year event. The Freeport system reevaluation would consist of adding resiliency features and correcting changed conditions that have reduced the factors of safety on key components of the system. These features consist of embankment overtopping erosion protection, floodwall tie-in protection, and floodwall overtopping erosion protection, along with features that would address general stability issues. These measures would reconstruct various parts of the existing systems to reduce their risk of failure and thereby raise their level of protection.

LOCATION OF MEASURES

- Measure 3-1 Port Arthur and Vicinity, Texas Hurricane Flood Protection, Jefferson County, Texas (See attached drawing)
- Measure 3-2 Texas City, Texas Hurricane Flood Protection, Galveston County, Texas (See attached drawing)
- Measure 3-3 Freeport and Vicinity Hurricane Flood Protection, Brazoria County, Texas (See attached drawing)

DESIGN ASSUMPTIONS

Measure 3-1: Would provide items listed with assumed specifications.

1. Turf Reinforcement: The overtopping protection and erosion control for levee embankments would consist of turf reinforcement on the protected side.
   - Overtopping protection and erosion control along earth embankments. Assume 2/3 of levees.
   - Quantity: 18.5 miles x 100 ft.
   - 2. Grouted Riprap Reinforcement: The floodwall tie-in to levee consists of 20 inch riprap grouted in place for each tie-in at 38 locations.
   - All material to be trucked to site.

2. Floodwall Scour Protection: The floodwall scour protection would consist of fill on the protected side of the floodwall and concrete scour protection on top of the fill.

Measure 3-2: Would provide items listed with assumed specifications.
1. Turf Reinforcement: The overtopping protection and erosion control for levee embankments would consist of turf reinforcement on the protected side.

- Assume 2/3 of levees covered.
- Quantity: 13.3 miles x 100 ft.).

2. Grouted Riprap Reinforcement: The floodwall tie-in to levee consists of 20 inch riprap grouted in place for each tie-in at 18 locations.

- All material to be trucked to site.

3. Floodwall Scour Protection: The floodwall scour protection consists of fill on the protected side of the floodwall and concrete scour protection on top of the fill.

- Provide scour protection along floodwalls.
- Assume 2/3rd of levees covered
- Quantity: 1.32 miles x 25 ft x 8 inch

Measure 3-3: Would provide items listed with assumed specifications. Design and costs were provided by the Velasco Drainage District.

The overtopping protection and erosion control for levee embankments would consist of turf reinforcement on the protected side. The floodwall tie-in to the levee consists of 20 inch riprap grouted in place for each tie-in. The floodwall scour protection would consist of fill on the protected side of the floodwall and concrete scour protection on top of the fill. In addition to the resiliency features, items identified by the USACE (2011) and the local sponsor (Baker & Lawson, 2011) that require action to ensure an adequate level of protection would be included, such as increasing levee stability at Dow Plant A, removing abandoned infrastructure, strengthening I-walls to current design requirements, addressing seepage and erosion issues due to sand and utilities, and addressing height deficiencies.

HYDRAULICS & HYDROLOGY ASSUMPTIONS

The design storm used for the H&H analysis is the 100 year storm surge derived by FEMA using the recent results from the FEMA 2011 Texas coastal study. The ADCIRC results were converted into a Without-Project 100-year flood depth grid that corresponds to the existing Without Project condition.

Although the Without-Project 100 Year flood depth grids show the Port Arthur, Freeport, and Texas City as functioning for a 100 year surge, this study this study assumes that they would fail since they have designs similar to those found in the New Orleans HFP project and do not include current USACE standards for resiliency and redundancy features that are critical for life-safety structures. The data derived for damages associated with the areas behind the three existing surge protection systems was provided from a recent levee safety risk assessment completed by USACE Galveston District and data from the National Levee Database. For each of these measures the Without-Project flood depth grid is used to estimate the With-Project benefits as the Without-Project flood grid represents the reconstructed system performing fully at a 100-year surge level.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'. Costs identified as $0 are generally associated with Federal and/or State lands.

Measure 3-1: Port Arthur and Vicinity, Texas Hurricane Flood Protection
Total Estimated Real Estate Cost: $239,000 ®

Measure 3-2: Texas City, Texas Hurricane Flood Protection
Total Estimated Real Estate Cost: $49,000 ®

Measure 3-3: Freeport and Vicinity, Texas Hurricane Flood Protection
Total Estimated Real Cost: $0

ENVIRONMENTAL

All three of these measures protect dense residential and industrial developments. For this initial evaluation, it was assumed that there would be no wetland benefits. Further evaluation would need to take into account potential benefits to Moses Lake and Dollar Bay which are protected by the Texas City HFP system. The total wetland acres environmental benefit for each measure was assumed to be "0."

BENEFITS

Economic benefits were estimated based upon direct damages from failure of the HFP systems contained in the National Levee Database.

Measure 3-1 Port Arthur and Vicinity, Texas Hurricane Flood Protection: $4,446,703,670
Measure 3-2 Texas City, Texas Hurricane Flood Protection: $2,139,338,620

Measure 3-3 Freeport and Vicinity, Texas Hurricane Flood Protection: $2,195,837,080

COSTS

None of the estimated cost include real estate costs.

Measure 3-1: The total estimated cost for this measure is $63,909,000.
Measure 3-2: The estimated cost for this measure is $36,936,000.
Measure 3-3: The estimated cost for this measure is $123,784,337. The cost for this measure was provided by Velasco Drainage District.

REFERENCE DOCUMENTS

Applying Best Practices from the Delta Works and New Orleans to Galveston Bay,
Prepared by: Kasper Stoeten, Master Student Hydraulic Engineering, Delft University of Technology, November 2012.

Reconnaissance of the New Orleans Hurricane and Storm Damage Risk Reduction System after Hurricane Gustav. Principal Author: R. Lee Wooten, P.E., prepared for Geoengineering Extreme Events Reconnaissance Association, sponsored by the National Science Foundation. February 2009

Levee Deficiency Report: Freeport and Vicinity Hurricane Protection System. Prepared by Baker & Lawson, Inc for Velasco Drainage District. July 2011

Freeport and Vicinity Hurricane Flood Protection Project 2011 Inspection, US Army Corps of Engineers Galveston District, October 2011.

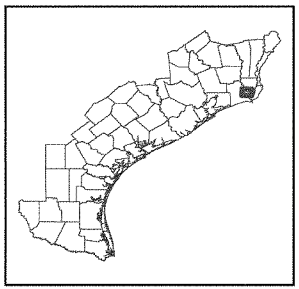
RISKS

- Geotechnical and Structural feasibility of the proposed features was not studied.
- No review of available public information or data from in-house files relative to the general geology and soil conditions along the proposed alignments was conducted.
- The unit cost developed in the report: Applying best practices from the Delta Works and New Orleans to Galveston Bay, Prepared by: Kasper Stoeten, Master Student Hydraulic Engineering, Delft University of Technology, November 2012, were used to develop this measure.
- Hydraulics and Hydrology is using information from the levee risk safety assessment to evaluate damages behind each of the levees for a 100 year return period. Rerunning the

ADCIRC storm surge model for the Without Project condition including levee failures would be more accurate.

- Orange County has run ADCIRC assuming failure of the Port Arthur levee and that data should be captured at further stages of analysis. It is worthwhile to check and see if any ADCIRC modeling with failure of the Freeport and Texas City levees has been done.
- Relocation of utilities and acquisition of ROW for measures has not been accounted for.
- This environmental analysis does not take into account environmental impacts that would occur without the surge protection system as a result of contaminant spills from the high number of petro-chemical plants and other industrial facilities in the protected area.
- Costs from the National Levee Database likely understate the value of the industrial complexes in the leveed areas and do not include the true economic exposure associated with the systems

Measure 3-1: Port Arthur and Vicinity, Texas Hurricane Flood Protection



Legend

Port Arthur HFP

0 1,900 3,800 7,600 11,400 15,200

Feet

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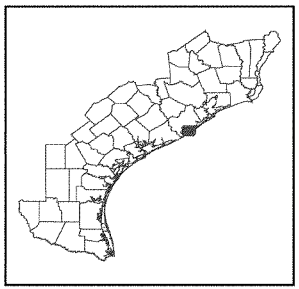
Date Created: 4/24/2013

Measure 3-2: Texas City, Texas Hurricane Flood Protection

Measure 3-3: Freeport and Vicinity, Texas Hurricane Flood Protection



Legend

Name

Freeport HFP

0 1,750 3,500 7,000 10,500 14,000

Feet

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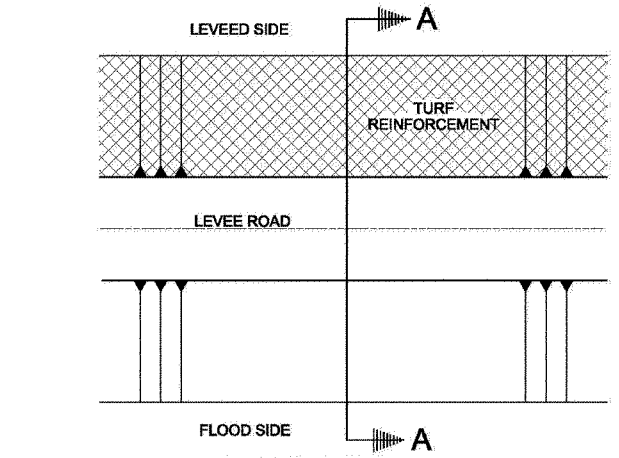
Date Created: 4/24/2013

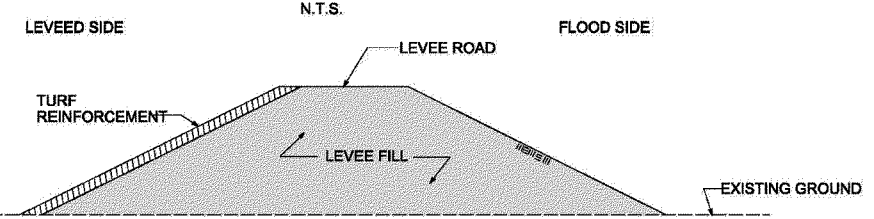
Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-01: Turf Reinforcement



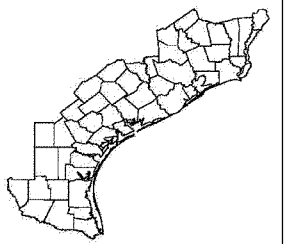
PLAN VIEW

N.T.S.



A S-01 | S-01 SECTION

N.T.S.



Typical Section S-01

Measures:
3-1
3-2
3-3

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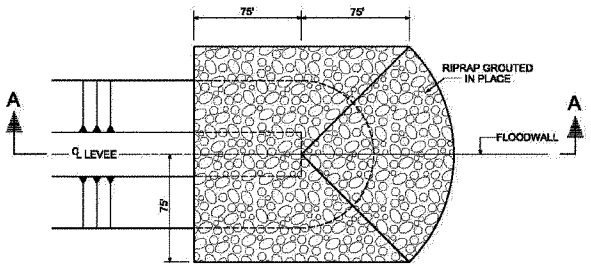
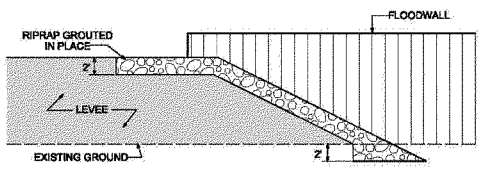
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

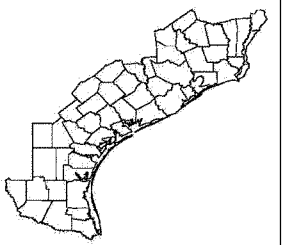
Typical Section S-02: Floodwall Tie-in



PLAN VIEW
N.T.S.



A
S-01 S-01
SECTION
N.T.S.



Typical Section S-02

Measures:
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3-2
3-3

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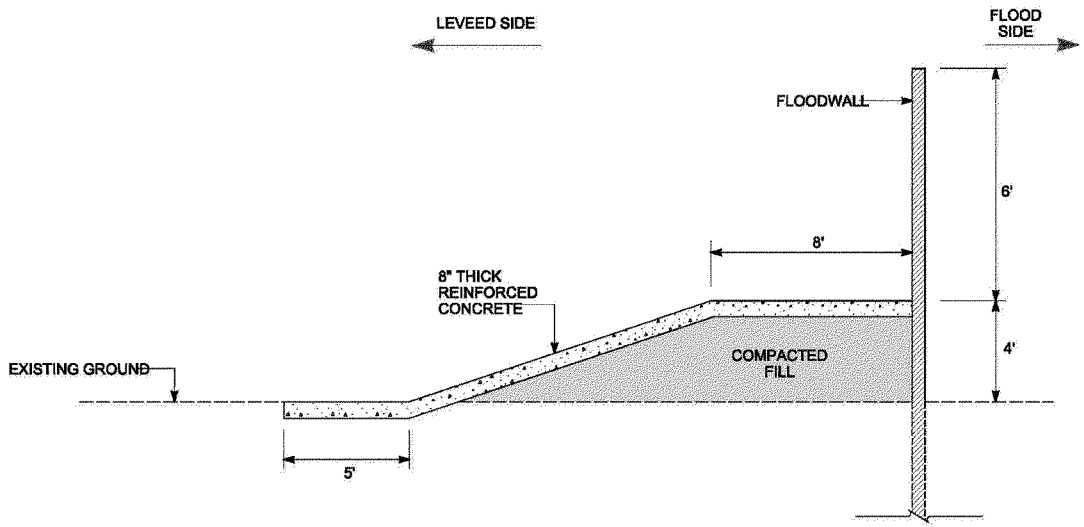
Date Created: 4/24/2013

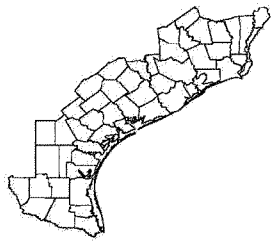
Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-03: Scour Protection



SCOUR PROTECTION

N.T.S.



Typical Section S-03

Measures:
3-1
3-2
3-3

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 3-4, 3-5, 3-6, 3-7, and 3-8
INFORMATION SHEET

DESCRIPTION OF MEASURES

The Orange County Economic Development Corporation and the Texas Water Development Board have sponsored a feasibility study of alternatives to address storm surge flooding in Orange County, Texas (see References). The study was initiated in response to severe storm surge damage from Hurricane Ike. These measures address various scales of surge protection, with some limited to Orange County and others encompassing adjacent parts of Jefferson County and Calcasieu Parish, Louisiana.

Measure 3-4 County-Wide Protection System on Sabine River and East Bank of Neches River, Orange County. This measure is an earthen levee/flood wall protection system that would provide full protection to Orange County but would not offer the protection to the cities of Beaumont and Nederland on the west bank of the Neches River. The levee/wall system would start on the east bank of the Sabine River north of Interstate Highway (IH) 10, follow the Sabine River southward to the vicinity of Adams Bayou where it would turn westward, follow the high terrace banks at the confluence of the Sabine-Neches rivers to the Bridge City area, and turn northward following the high terrace of the east bank of the Neches River, terminating at a point north of the IH 10.

Measure 3-5 County-Wide Protection System on the East and West Bank of the Neches River, Orange County and Part of Jefferson County. This measure is an earthen levee/flood wall protection system that would provide full protection to both Orange County and the cities of Beaumont and Nederland, without using a closure structure on the Neches River. This system would connect to the Sabine River-East Bank of Neches River Measure 3-4 near IH 10, follow the west bank of the Neches River to the southeast, and terminate with a connection to the existing Port Arthur levee system.

Measure 3-6 County-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In, Orange County and Part of Jefferson County. This measure is an earthen levee/flood wall protection system that would provide full protection to both Orange County and the cities of Beaumont and Nederland. It connects the Sabine River levee/floodwall section of Measure 3-4 near Bridge City to a closure structure crossing the mouth of the Neches River and then connects to the existing Port Arthur protection system on the west bank of the Neches River.

Measure 3-7 Sabine River Crossing, Orange County and Calcasieu Parish.
This measure is a closure structure on the Sabine River and a connecting earthen levee protection system that would protect fresh water supplies managed by the Sabine River Authority of Texas. The Sabine River closure structure would tie-in to a segment of Measure 3-4, the east bank Sabine River earthen levee/floodwall system, just south of I10 and a levee would extend eastward to higher ground on the outskirts of Toomey, Louisiana.

Measure 3-8 Orange County Industrial Complex Protection System, Orange County.
This measure is an earthen levee/floodwall system that would protect a concentration of petro-chemical industries near West Orange, Texas. This is ring system which would provide an initial level of protection to critical economic infrastructure in Orange County as a possible "first phase" of a county-wide protection system.

LOCATION OF MEASURES (See attached drawings)

Orange County Drawing 3-4.pdf
Measure 3-4: Orange County - County-Wide Protection - East Bank of Neches River.pdf

Orange County Drawing 3-5.pdf
Measure 3-5: Orange County - Protection System on the East and West Bank of the Neches River.pdf

Orange County Drawing 3-6.pdf
Measure 3-6: Orange County - County-Wide Protection with Neches River Crossing.pdf

Orange County Drawing 3-7.pdf
Measure 3-7: Orange County - County-Wide Protection with Neches and Sabine River Crossings.pdf

Orange County Drawing 3-8.pdf
Measure 3-8: Orange County - Industrial Complex Protection System.pdf

DESIGN ASSUMPTIONS

All Measures: Earthen levees would be the main protection system used in each alternative alignment, but flood walls would be used where necessary to limit impacts to adjacent facilities or existing development. Two typical L-wall sections were used to represent the flood wall geometry throughout the proposed alignments, with only the stem height varying to

accommodate variations in natural ground elevations. Footing width, stem thickness, and pile arrangements for the floodwall typical section were based on a stem height of 14' for the larger typical section and 8' for the smaller typical section. All measures would require the installation of pump stations to facilitate removal of water inside the proposed levee systems while the gate structures are closed. Numerous storm water pump stations would need to be constructed with pumping capacity ranging in size from 100,000 gallons per minute to 2,500,000 gallons per minute. The pumps stations would be concrete structures that would provide protection of the equipment during major storm events.

Measures 3-4, 3-5 and 3-6 would require closure of Cow and Adams Bayou. A sector gate with a navigable opening of 56' was selected to represent the navigable structure at Cow Bayou [check for typical plan]. This structure is large enough to accommodate single barges and other moderate draft vessels that are likely to use the waterway. The navigable closure structure at Cow Bayou was modeled after the sector gate recently completed at the Caernarvon Canal as part of the New Orleans Hurricane Protection Project Work. Due to the width of the floodway at the proposed crossing, an additional series of non-navigable flood gates are proposed to mitigate impacts to channel flow during regular upland rainfall events. Two 160 feet wide vertical lift flood gates would flank the sector gate and an additional vertical lift flood gate would be provided in an adjacent oxbow to the south to maximize the flow area available for the passage of flood flows during times of high runoff not associated with a concurrent storm surge. Adams Bayou would be closed with same type of structure as Cow Bayou. A pair of smaller non-navigable vertical lift flood gates would also flank the navigable sector gate.

Measure 3-6 would include a navigable closure structure at the mouth of the Neches River that would allow the river to be closed prior to hurricane landfall but open for navigation and normal flow at all other times. For the purposes of considering feasibility, the Maeslant Barrier in Hoek van Holland, The Netherlands was considered as the model for this closure structure. The Neches River Closure Structure is required to provide protection for surge elevations to a minimum elevation 20.0 feet and a sill elevation of approximately -50.00 feet to accommodate the proposed deepening of the Neches River. Measure 3-6 would also include a non-navigable closure structure to protect operational requirements of the Entergy Intake Canal. A typical flood gate structure is proposed to affect closure of the canal. Six 84" diameter bypass pipes with redundant valves on each would allow flow through the levee system to be controlled as head increased on the outside of the structure during a storm surge. For the purpose of this study, it is assumed that an additional pump station would be included in this measure.

HYDRAULICS & HYDROLOGY

All of the proposed measures provide a higher level of protection than the minimum 100-year recurrence interval required by the Federal Emergency Management Agency (FEMA). Updated and calibrated Advanced Circulation (ADCIRC) modeling of the "worst case" event (for the purposes of the Orange Co EDC study) indicated resulting surge and wave heights considerably higher than the FEMA 100 year elevations. The chosen protection level would more than satisfy FEMA requirements while protecting Orange County from a direct hit from an "Ike level" event. The summary of top elevations utilized for preliminary design and cost estimating purposes is as follows:

- Elevation 19 from tie in to Port Arthur system to Cow Bayou
- Elevation 18 from Cow Bayou to Adams Bayou
- Elevation 16 from Adams Bayou to IH 10
- Elevation 12.5 from IH 10 to approximately 8 miles north of IH 10

The design rainfall event utilized for analysis of the interior drainage systems is the FEMA benchmark 100-year rainfall (1% probability of occurrence). Peak flows were developed for point locations where the interior drainage channels would drain through the proposed structural systems. At these locations, proposed closure structures and pump stations would concurrently provide protection against storm surges and pumping capacity adequate to convey the 100-year runoff that may be associated with a tropical storm or hurricane event.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

- Measure 3-4: County-Wide Protection System on Sabine River and East Bank of Neches River, Orange County

  Total Estimated Real Estate Cost of Measure 3-4: $15,800,000 ®

- Measure 3-5: County-Wide Protection System on the East and West Bank of Neches River, Orange County and Part of Jefferson County

  Total Estimated Real Estate Cost of Measure 3-5: $5,500,000 ®

- Measure 3-6: County-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In, Orange County and Part of Jefferson County

  Total Estimated Real Estate Cost of Measure 3-6: $463,000 ®

- Measure 3-7: Sabine River Crossing, Orange County and Calcasieu Parish
  Total Estimated Real Estate Cost of Measure 3-7: $580,000 ®

- Measure 3-8: Orange County Industrial Complex Protection System, Orange County
  Total Estimated Real Estate Cost of Measure 3-8: $970,000 ®

ENVIRONMENTAL

These measures would protect dense residential and/or industrial areas in Orange and Jefferson Counties, as well as valuable marsh, swamp and bottomland hardwood wetland systems. The levee/floodwall systems would protect these areas from the adverse effects of surge scouring and salinity insults. Very large marsh systems on the Neches River would be protected by Measures 3-4 and 3-5, including the Lower Neches Wildlife Management Area (WMA) (Nelda Stark, Old River Cove, and Adam Bayou units). Extensive fresh swamp and bottomland hardwood systems would be protected by Measures 3-6 and 3-7, including the Blue Elbow and Sabine Island WMAs. Environmental benefits are presented in wetland acres that would be protected by these measures. The wetland acres were calculated with a GIS analysis of National Wetland Inventory wetland maps (USFWS, 2012). The benefits for each measure are presented in the table below:

Measure Number and Location	Forested or Emergent Marsh Wetlands (acres)
Measure 3-4 (County-Wide Protection System on Sabine River and East Bank of Neches River)	7,000
Measure 3-5 (County-Wide Protection System on the East and West Banks of the Neches River)	7,400
Measure 3-6 (County-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In)	31,500
Measure 3-7 (Sabine River Crossing)	37,000
Measure 3-8 (Orange County Industrial Complex Protection System)	650

BENEFITS

With and without project damages to structures, contents, and vehicles were calculated using HEC-FIA (Flood Impact Analysis) software package which analyzes consequences for a given flood event, in this case, a 1% annual exceedance probability (100-year). Without project damages are those that would occur under the current existing condition. Residual damages are those that would occur with a given measure in place. Benefits are the difference between the two. These numbers are listed in the tables below.

This economic analysis does not take into account losses of human life or impacts to the economy of the region that would result from economic and industrial disruptions caused by storm surge. It could take weeks to get critical petro-chemical facilities back on-line, and months to clean-up and fully repair flooded facilities. The lives of thousands of people would be disrupted until homes could be rebuilt, and temporary dislocations would adversely affect employers who would lose employees as they relocate to other areas.

Storm Surge Regions

Region	Counties
6	Brazoria, Galveston, Harris
7	Chambers, Galveston, Harris, Jefferson
8	Chambers, Jefferson, Orange

Benefits for Measures 3-4 to 3-8

Measure 3-4: County-Wide Protection System on Sabine River and East Bank of Neches River, Orange County			**Region 8**
	Without Project Damages	Residual Damages	Benefits
Structure	$1,041,712,000	$429,098,000	$612,614,000
Contents	$1,078,037,000	$419,311,000	$658,726,000
Vehicles	$362,768,000	$141,784,000	$220,984,000
Total	**$2,482,517,000**	**$990,193,000**	**$1,492,324,000**

Measure 3-5: County-Wide Protection System on the East and West Bank of the Neches River, Orange County and Part of Jefferson County			**Region 8**
	Without Project Damages	Residual Damages	Benefits
Structure	$1,041,712,000	$408,787,000	$632,925,000
Contents	$1,078,037,000	$402,144,000	$675,893,000
Vehicles	$362,768,000	$136,033,000	$226,735,000
Total	**$2,482,517,000**	**$946,964,000**	**$1,535,553,000**

Measure 3-6: County-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In, Orange County and Part of Jefferson County			**Region 8**
	Without Project Damages	Residual Damages	Benefits
Structure	$1,041,712,000	$279,588,000	$762,124,000
Contents	$1,078,037,000	$262,179,000	$815,858,000
Vehicles	$362,768,000	$91,196,000	$271,572,000
Total	**$2,482,517,000**	**$632,963,000**	**$1,849,554,000**

Measure 3-7: Sabine River Crossing, Orange County and Calcasieu Parish			**Region 8**
	Without Project Damages	Residual Damages	Benefits
Structure	$1,041,712,000	$266,386,000	$775,326,000
Contents	$1,078,037,000	$258,190,000	$819,847,000
Vehicles	$362,768,000	$88,151,000	$274,617,000
Total	**$2,482,517,000**	**$612,727,000**	**$1,869,790,000**

Measure 3-8: Orange County Industrial Complex Protection System, Orange County			**Region 8**
	Without Project Damages	Residual Damages	Benefits
Structure	$1,041,712,000	$994,875,000	$46,837,000
Contents	$1,078,037,000	$1,024,728,000	$53,309,000
Vehicles	$362,768,000	$347,910,000	$14,858,000
Total	**$2,482,517,000**	**$2,367,513,000**	**$115,004,000**

COSTS

Cost for these measures were derived from the Orange County Report (see reference below).

Measure 3-4: The estimated cost for this measure is $ 1,472,000,000.
Measure 3-5: The estimated cost for this measure is $1,738,000,000.
Measure 3-6: The estimated cost for this measure is $ 1,549,000,000.
Measure 3-7: The estimated cost for this measure is $ 1,842,000,000.
Measure 3-8: The estimated cost for this measure is $ 212,000,000.

REFERENCE DOCUMENTS

The cost, drawings, gates, I walls and levee designs developed in the report "Flood Protection Planning Study Hurricane Flood Protection System Orange County, Texas," Final Report dated August 2012, were used for this measure. The report was prepared for the Orange County Economic Development Corporation and Texas Water Development Board by Carroll and Blackman, Inc, Costello, Inc., and LJA Engineers, Inc. A copy of the Orange County Report with appendices can be found on SharePoint: https://extranet.dse.usace.army.mil/sites/Divisions/SWD/SWG/S2G/default.aspx.

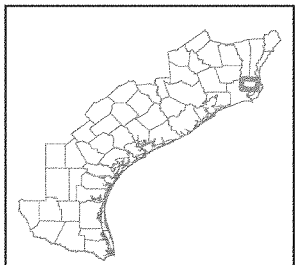
U.S. Fish and Wildlife Service (USFWS). 2012. National Wetland Inventory. Accessed on the internet at http://www.fws.gov/wetlands/Data/Mapper.html .

RISKS:

- Geotechnical and Structural feasibility of the proposal was not reviewed by the COE.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.
- System configuration and the proposed structures were not assessed by the COE.
- Project design would need to include the development and calibration of a hydrologic and hydraulic model of the Neches River which would allow development of various hydrographs at the location of the proposed Neches River gate structure.
- This environmental analysis does not take into account environmental impacts that would occur without the surge protection system as a result of contaminant spills from the high number of petro-chemical plants and other industrial facilities in these areas.
- Existing surge runs are available for the with-project condition performed by others but were not utilized for this stage of analysis. These would have to be examined during future phases of the study if this measure goes forward.
- There could be an increase in surge where the levee/floodwall system end and fully understanding this consequence should involve ADCIRC modeling.
- Modeling is needed to evaluate the effect of overtopping of the system in case a larger storm than the 100-year occurs. If water gets trapped behind the surge protection systems, there could be significant consequences.

Measure 3-4: County-Wide Protection on Sabine River and East Bank of Neches River, Orange County

Measure 3-5: County-Wide Protection System on East and West Bank of the Neches River, Orange County and Part of Jefferson County



Legend

- Neches River Levee (West)
- Neches River Levee (East)
- Sabine River Levee

0 3,100 6,200 12,400 18,600 24,800 Feet

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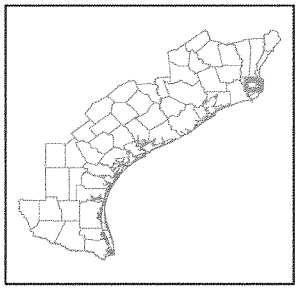
Date Created: 4/24/2013

Measure 3-6: County-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In, Orange County and Part of Jefferson County



Legend

Neches River Crossing

Sabine River Levee

0 2,900 5,800 11,600 17,400 23,200

Feet

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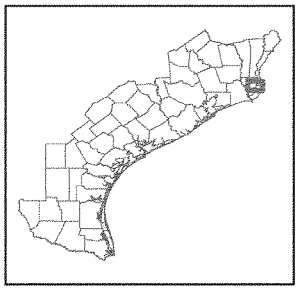
Date Created: 4/24/2013

Measure 3-7: Sabine River Crossing, Orange County and Calcasieu Parish



Legend

- Neches River Crossing
- Sabine River Crossing
- Sabine River Levee

0 2,850 5,700 11,400 17,100 22,800 Feet

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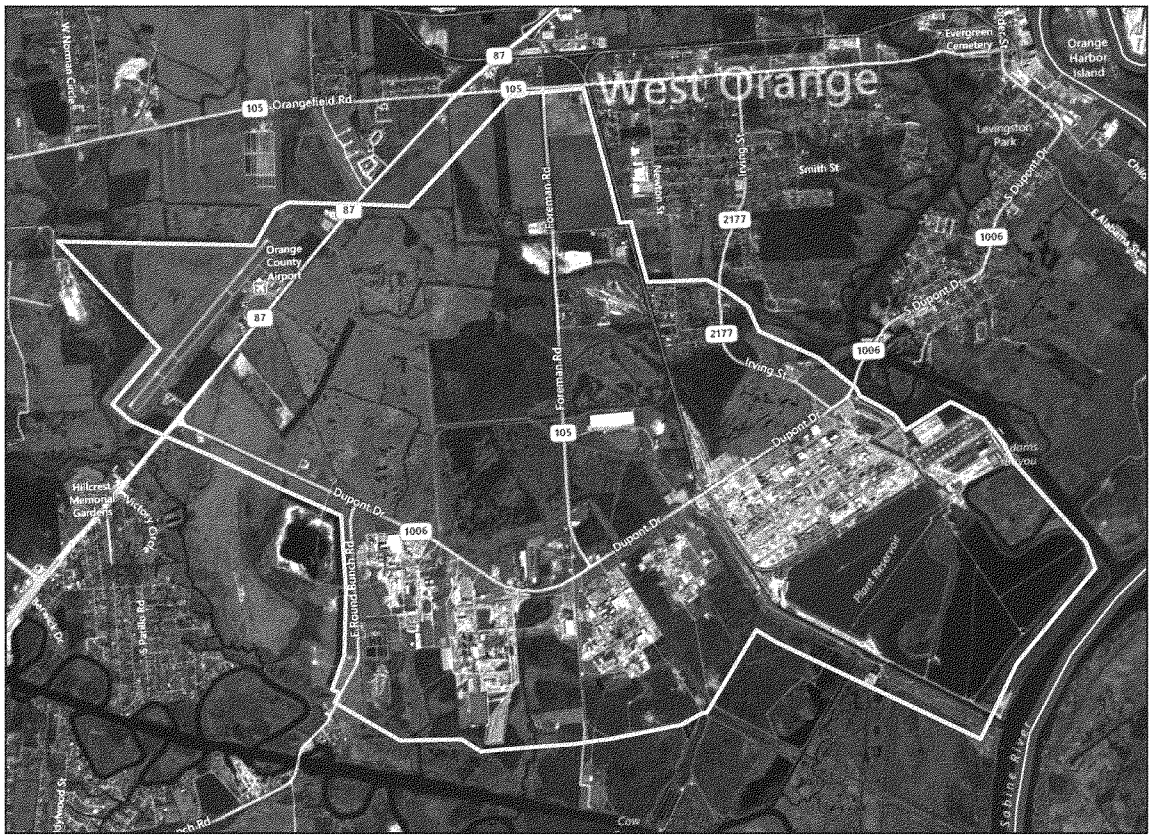
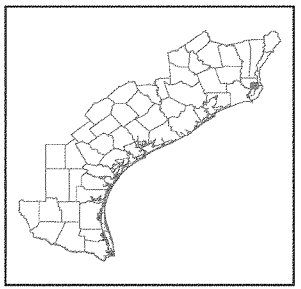
Date Created: 4/24/2013

Measure 3-8: Orange County Industrial Complex Protection System, Orange County





Legend

Industry Levee

0 700 1,400 2,800 4,200 5,600

Feet

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 3-9, 3-10.1, 3-10.2, 3-10.3, 3-10.4, 3-10.5 and 3-10.6
INFORMATION SHEET

DESCRIPTION OF MEASURES

This group of measures would provide storm surge protection to localized areas with dense concentrations of population, petro-chemical industries or nationally significant public facilities.

Measure 3-9 Galveston Ring Levee, Galveston County: This measure would consist of the construction of a new ring levee and floodwall system around the bay side of east Galveston Island, tying into each end of the Seawall. This system would provide protection for the city of Galveston behind the Seawall when hurricane-force winds are blowing from the north. The levee alignment would extend from the east end terminus of the Seawall around the San Jacinto Placement Area to Harborside Drive, and along the Island's north side (or bay side) until Offatts Bayou. From Offatts Bayou a levee would extend parallel to 103rd street until it meets the west end of the Seawall. Approximately 7.8 miles of earthen embankment and 4.9 miles of floodwall would be required for this measure, with two navigation structures, one at Laguna de Oro and a second, larger structure with circulation gates at Offatts Bayou.

Measures 3-10 Various Local Surge Protection Measures: These measures would provide localized surge protection to industrial areas on the Houston Ship Channel (HSC), or at job centers like NASA and UTMB.

Measure 3-10.1 Local Surge Protection, Houston Ship Channel North, Harris County. This measure would provide protection to the portion of Harris County north of the Buffalo Bayou reach of the HSC through the construction of a surge protection system of levees and floodwalls.

Measure 3-10.2 Local Surge Protection, Houston Ship Channel South, Harris County. This measure would provide protection to the portion of Harris County south of the Buffalo Bayou reach of the HSC through the construction of a surge protection system of levees and floodwalls.

Measure 3-10.3 Local Surge Protection, Baytown, Harris County. This measure would provide protection to a concentration of petro-chemical plants in the city of Baytown, east of the HSC and just north of the Fred Harman Bridge, through the construction of a surge protection system of levees and floodwalls.

3-10.4 Local Surge Protection, NASA, Harris County. This measure would provide protection to NASA's Johnson Space Center on the north shore of Clear Lake through the construction of a surge protection system of levees and floodwalls.

Measure 3-10.5 Local Surge Protection, UTMB, Galveston County. This measure would provide protection to the complex of hospitals and research facilities around the University of Texas Medical Branch on Galveston Island through the construction of a surge protection system of levees and floodwalls.

Measure 3-10.6 Local Surge Protection, Chocolate Bayou, Brazoria County. This measure would provide protection to a concentration of petro-chemical plants located on Chocolate Bayou through the construction of a surge protection system of levees and floodwalls.

LOCATION OF MEASURES (see referenced maps)
Measure 3-9: Local Surge Protection, Galveston Ring Levee
Measure 3-10.1: Local Surge Protection, Houston Ship Channel North, Harris County.
Measure 3-10.2: Local Surge Protection, Houston Ship Channel South, Harris County.
Measure 3-10.3: Local Surge Protection, Baytown, Harris County.
Measure 3-10.4: Local Surge Protection, NASA, Harris County.
Measure 3-10.5: Local Surge Protection, UTMB, Galveston County.
Measure 3-10.6: Local Surge Protection, Chocolate Bayou, Brazoria County.

DESIGN ASSUMPTIONS

Measure 3-9:

- Levee and floodwall locations and lengths estimated using heads-up digitizing on ArcGIS.
- Approximately 7.8 miles of levees estimated.
- Approximately 4.9 miles of floodwall estimated.
- Two 300 ft lift gate type navigation structures will be required. See Applying best practices (Ike Dike) report for details (pg. 21 Barge Lift Gate est. $30 mil).

Measure 3-10 (all)

- Levee and floodwall heights assumed to be 20 feet.

- Levee and floodwall locations and lengths estimated using heads-up digitizing on ArcGIS.
- Alignment was selected to encompass critical infrastructure/industry

MEASURE	LEVEE (MILES)	FLOODWALL (MILE)
3-10.1	8.2	16.1
3-10.2	10.4	16.0
3-10.3	0.6	6.9
3-10.4	5.6	0.0
3-10.5	0.0	1.9
3-10.6	13.4	0.0

HYDRAULICS & HYDROLOGY

The design storm used for the H&H analysis is the 100-year storm surge derived by FEMA using results from the FEMA 2011 Texas Coastal Counties Study. The ADCIRC results from the FEMA study were converted into a without-project 100 year flood depth grid that corresponds to existing conditions. Chosen protection would satisfy FEMA requirements while protecting the evaluated areas from the 100-year surge levels. A summary of top elevations utilized for preliminary design and cost estimating purposes is listed below.

- Measure 3-9: Elevation 19 tying into the west side of the seawall, Elevation 17 tying into the right side of the seawall, providing protection to the Bay Side of Galveston Island
- Measures 3-10.1 and 3-10.2: Elevation 18 for measures providing protection to portions of Harris County North and Harris County South of the Buffalo Bayou Reach of the HSC
- Measure 3-10-3: Elevation 19 for measure providing protection to protecting petro-chemical plants and Baytown
- Measure 3-10.4: Elevation 20 for measure providing protection to NASA's space center on the northern shore of Clear Lake.
- Measure 3-10.5: Elevation 12 for measure protecting UTMB with levee and floodwall systems
- Measure 3-10.6: Elevation 15 for measure protecting concentration of petro-chemical plants located on Chocolate Bayou.

The design rainfall event utilized for analysis of the interior drainage systems is the FEMA benchmark 100-year rainfall (1% probability of occurrence). Peak flows were developed for point locations where the interior drainage channels would drain through the proposed structural

systems. At these locations, proposed closure structures and pump stations would concurrently provide protection against storm surges and pumping capacity adequate to convey the 100-year runoff that may be associated with a tropical storm or hurricane event.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'. Costs identified as $0 are generally associated with Federal and/or State lands.

- Measure 3-9: Galveston Ring Levee, Galveston County
  Total Estimated Real Estate Cost: $95,700,000 ®

- Measure 3-10.1: Local Surge Protection, Houston Ship Channel North, Harris County
  Total Estimated Real Estate Cost: $297,700,000 ®

- Measure 3-10.2: Local Surge Protection, Houston Ship Channel South, Harris County
  Total Estimated Real Estate Cost: $343,700,000 ®

- Measure 3-10.3: Local Surge Protection, Baytown, Harris County
  Total Estimated Real Estate Cost: $37,400,000 ®

- Measure 3-10.4: Local Surge Protection, NASA, Harris County
  Total Estimated Real Estate Cost: $0

- Measure 3-10.5: Local Surge Protection, UTMB, Galveston County
  Total Estimated Real Estate Cost: $8,800,000 ®

- Measure 3-10.6: Local Surge Protection, Chocolate Bayou, Brazoria County
  Total Estimated Real Estate Cost: $19,800,000 ®

ENVIRONMENTAL

These measures would protect dense residential and/or industrial areas in Harris, Galveston and Brazoria Counties; some of which contain patches of forested or emergent marsh wetlands. The levee/floodwall systems would protect these areas from the adverse effects of surge scouring and salinity insults. Environmental benefits are presented in wetland acres that would be protected by these measures. The wetland acres were calculated with a GIS analysis of National Wetland

Inventory wetland maps (USFWS, 2012).The benefits for each measure are presented in the table below:

Measure Number and Location	Forested or Emergent Marsh Wetlands (acres)
Measure 3-9 (Galveston Ring Levee)	300
Measure 3-10.1(Houston Ship Channel North)	2,000
Measure 3-10.2 (Houston Ship Channel South)	400
Measure 3-10.3 (Baytown)	6
Measure 3-10.4 (NASA)	20
Measure 3-10.5 (UTMB)	0
Measure 3-10.6 (Chocolate Bayou)	125

BENEFITS

With and without project damages to structures, contents, and vehicles were calculated using HEC-FIA (Flood Impact Analysis) software package which analyzes consequences for a given flood event, in this case, a 1% annual exceedance probability (100-year). Without project damages are those that would occur under the current existing condition. Residual damages are those that would occur with a given measure in place. Benefits are the difference between the two. These numbers are listed in the tables below.

This economic analysis does not take into account losses of human life or impacts to the economy of the region that would result from economic and industrial disruptions caused by storm surge. It could take weeks to get critical petro-chemical facilities back on-line, and months to clean-up and fully repair flooded facilities. Peoples lives would be disrupted until homes could be rebuilt, and temporary dislocations would adversely effect employers who would loose employees as they relocate to other areas.

Storm Surge Regions

Region	**Counties**
6	Brazoria, Galveston, Harris
7	Chambers, Galveston, Harris, Jefferson
8	Chambers, Jefferson, Orange

Benefits for Measures 3-9 and 3-10 (all)

Measure 3-9: Galveston Ring Levee, Galveston County			**Region 6**
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$4,324,479,000	$1,306,416,000
Contents	$5,854,589,000	$4,258,977,000	$1,595,612,000
Vehicles	$1,337,005,000	$942,738,000	$394,267,000
Total	**$12,822,489,000**	**$9,526,194,000**	**$3,296,295,000**

Measure 3-10.1: Local Surge Protection, Houston Ship Channel North, Harris County			**Region 6**
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$5,347,035,000	$283,860,000
Contents	$5,854,589,000	$5,569,207,000	$285,382,000
Vehicles	$1,337,005,000	$1,281,425,000	$55,580,000
Total	**$12,822,489,000**	**$12,197,667,000**	**$624,822,000**

Measure 3-10.2: Local Surge Protection, Houston Ship Channel South, Harris County			**Region 6**
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$5,158,924,000	$471,971,000
Contents	$5,854,589,000	$5,349,514,000	$505,075,000
Vehicles	$1,337,005,000	$1,224,727,000	$112,278,000
Total	**$12,822,489,000**	**$11,733,165,000**	**$1,089,324,000**

Measure 3-10.3: Local Surge Protection, Baytown, Harris County			**Region 7**
	Without Project Damages	Residual Damages	Benefits
Structure	$1,016,448,000	$1,015,759,000	$689,000
Contents	$833,516,000	$832,015,000	$1,501,000
Vehicles	$252,516,000	$252,338,000	$178,000
Total	**$2,102,480,000**	**$2,100,112,000**	**$2,368,000**

Measure 3-10.4: Local Surge Protection, NASA, Harris County			**Region 6**
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$5,627,126,000	$3,769,000
Contents	$5,854,589,000	$5,843,933,000	$10,656,000
Vehicles	$1,337,005,000	$1,336,154,000	$851,000
Total	**$12,822,489,000**	**$12,807,213,000**	**$15,276,000**

Measure 3-10.5: Local Surge Protection, UTMB, Galveston County			**Region 6**
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$5,622,522,000	$8,373,000
Contents	$5,854,589,000	$5,829,737,000	$24,852,000
Vehicles	$1,337,005,000	$1,335,398,000	$1,607,000
Total	**$12,822,489,000**	**$12,787,657,000**	**$34,832,000**

Measure 3-10.6: Local Surge Protection, Chocolate Bayou, Brazoria County			**Region 6**
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$5,628,258,000	$2,637,000
Contents	$5,854,589,000	$5,852,936,000	$1,653,000
Vehicles	$1,337,005,000	$1,336,186,000	$819,000
Total	**$12,822,489,000**	**$12,817,380,000**	**$5,109,000**

COSTS

Costs do not include Real Estate.
Measure 3-9: The estimated cost for this measure is $460,416,000.
Measure 3-10.1: The estimated cost for this measure is $863,607,000
Measure 3-10.2: The estimated cost for this measure is $924,206,000
Measure 3-10.3: The estimated cost for this measure is $290,145,000
Measure 3-10.4: The estimated cost for this measure is $154,571,000
Measure 3-10.5: The estimated cost for this measure is $76,861,000
Measure 3-10.6: The estimated cost for this measure is $373,197,000

Cost for gates and embankment levee were estimated using costs from the Orange County Study (see reference below). Cost for the floodwall were obtained from New Orleans District for a similar design.

REFERENCE DOCUMENTS

1979 USACE report;
USACE Texas Coast Hurricane Study Feasibility Report.
"Flood Protection Planning Study Hurricane Flood Protection System Orange County, Texas," Final Report dated August 2012, A copy of the Orange County Report with eight appendices can be found on SharePoint:
https://extranet.dse.usace.army.mil/sites/Divisions/SWD/SWG/S2G/default.aspx

Applying best practices from the Delta Works and New Orleans to Galveston Bay, Prepared by: Kasper Stoeten, Master Student Hydraulic Engineering, Delft University of Technology, November 2012 where used. A copy of this report with eight appendices can be found on SharePoint:
https://extranet.dse.usace.army.mil/sites/Divisions/SWD/SWG/S2G/default.aspx

U.S. Fish and Wildlife Service. 2012. National Wetland Inventory. Accessed on the internet at http://www.fws.gov/wetlands/Data/Mapper.html

RISKS

Measure 3-9

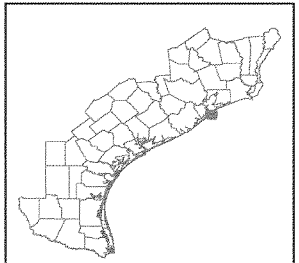
- Geotechnical and Structural feasibility of the proposed was not studied.
- No review of available public information or data from in-house files relative to the general geology and soil conditions along the proposed alignments was conducted.
- Estimated alignment was obtained from USACE Texas Coast Hurricane Study Feasibility Report.
- Cross sections and cost associated with embankment and gates taken from Orange County Flood Protection Planning Study (December 2012).
- Floodwall cost were obtained from MVN for similar design.
- Modeling is needed to evaluate the effect of overtopping of the system in case a larger storm than the 100-year occurs. If water gets trapped behind the surge protection system, there could be significant consequences.

Measure 3-10 (all)

- Alignment was selected to encompass critical infrastructure/industry.
- Geotechnical and Structural feasibility of the proposed was not studied.
- No review of available public information or data from in-house files relative to the general geology and soil conditions along the proposed alignments was conducted.
- Cross sections and cost associated with embankment and gates taken from Orange County Flood Protection Planning Study (December 2012).
- Floodwall cost were obtained from MVN for similar design.
- This environmental analysis does not take into account environmental impacts that would occur without the surge protection system as a result of contaminant spills from the high number of petro-chemical plants and other industrial facilities on the Houston Ship Channel and in the Barbour's Cut and Bayport areas.

- Modeling is needed to evaluate the effect of overtopping of the system in case a larger storm than the 100-year occurs. If water gets trapped behind the surge protection system, there could be significant consequences.

Measure 3-9: Galveston Ring Levee, Galveston County



Legend

- Levee Embankment
- Floodwall
- Navigation Gate

0 1,375 2,750 5,500 8,250 11,000 Feet

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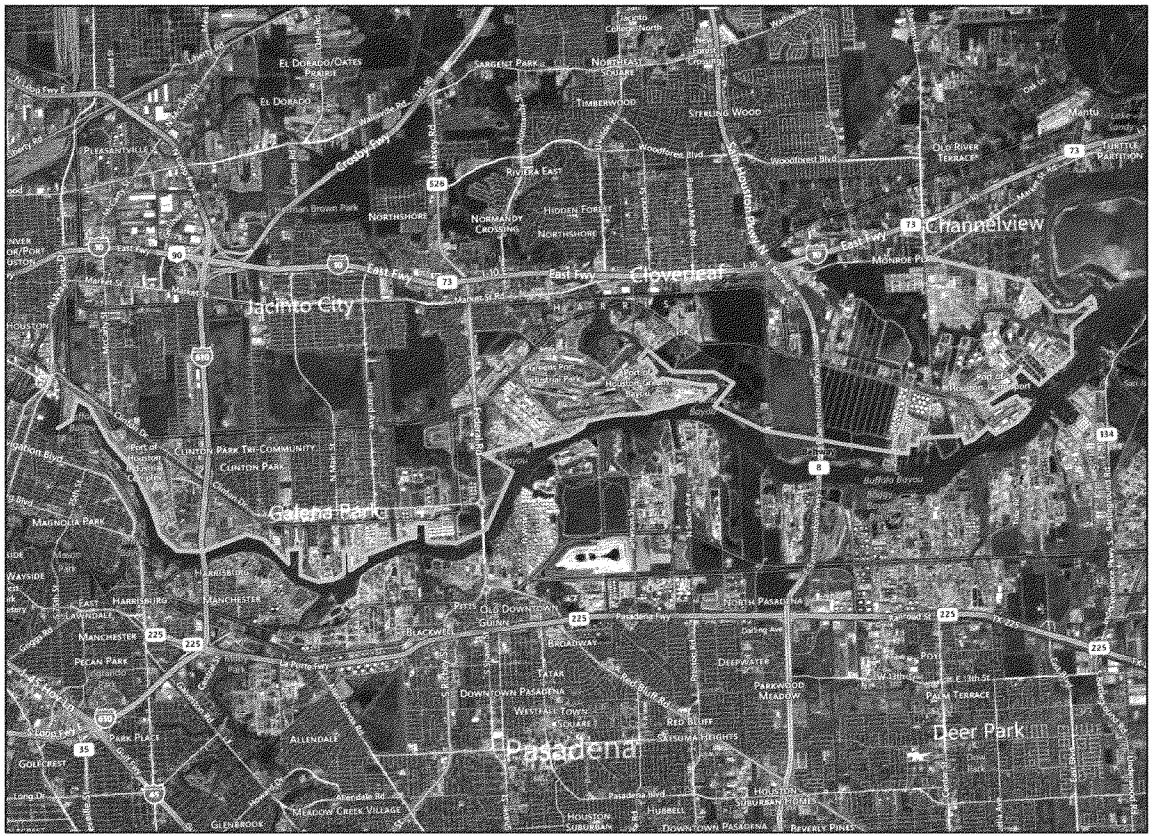
Date Created: 4/24/2013

Measure 3-10.1: Local Surge Protection, Houston Ship Channel North, Harris County


Jacinto City
Galena Park
Pasadena
Deer Park
Channelview
Cloverleaf
Baytown
Manchester
Harrisburg
Pleasantville
Northshore
Normandy Crossing
Hidden Forest
Riviera East
Timberwood
Sterling Wood
Old River Terrace
Turtle Partition
Monroe Plaza
Clinton Park
Clinton Park Tw-Community
Magnolia Park
Pecan Park
Allendale
Golfcrest
Glenbrook
Meadow Creek Village
Old Downtown Galena
Old Downtown Pasadena
Westside Town Square
Red Bluff
Satsuma Heights
Parkwood Meadow
Deep Gate
Palm Terrace
Houston Suburban Home
Downtown Pasadena
Beverly Pines
Houston Suburban
Hubbell
Sargent Park
Northeast Square
El Dorado/Oates Prairie
El Dorado
Greens Bayou
Buffalo Bayou
Fairmont Park
Woodforest Blvd
Fairmont Pkwy
Spencer Hwy
Red Bluff Rd
Pasadena Blvd
Broadway
Blackhawk
Manchester
Harrisburg
Wayside
Port of Houston Bayport Container Terminal
Port of Houston Barbours Cut Container Terminal
Port of Houston Bayport Industrial District
Port of Houston Turning Basin
Port of Houston Bayport Channel
Port of Houston Bayport Ship Channel
Port of Houston Barbours Cut Ship Channel
Port of Houston Turning Basin Ship Channel
Port of Houston Bayport Turning Basin
Port of Houston Barbours Cut Turning Basin
Port of Houston Bayport Container Terminal Ship Channel
Port of Houston Barbours Cut Container Terminal Ship Channel
Port of Houston Bayport Industrial District Ship Channel
Port of Houston Turning Basin Ship Channel
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Port of Houston Barbours Cut Turning Basin Ship Channel
Port of Houston Bayport Container Terminal Turning Basin
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Port of Houston Bayport Industrial District Turning Basin
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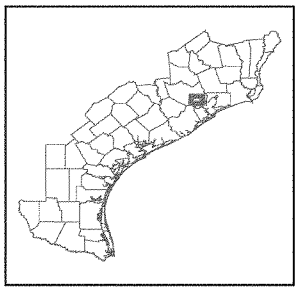
Port of Houston Bayport Industrial District Ship Channel Turning Basin

Measure 3-10.2: Local Surge Protection, Houston Ship Channel South, Harris County



Legend

Floodwall

Levee

0 2,200 4,400 8,800 13,200 17,600

Feet

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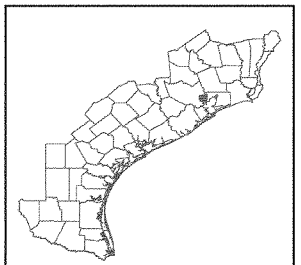
Measure 3-10.3: Local Surge Protection, Baytown, Harris County



Legend

Floodwall

Levee

0 650 1,300 2,600 3,900 5,200

Feet

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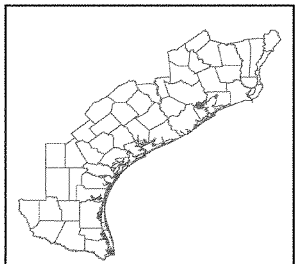
Measure 3-10.4: Local Surge Protection, NASA, Harris County



Legend

Ring Levee

0 650 1,300 2,600 3,900 5,200

Feet

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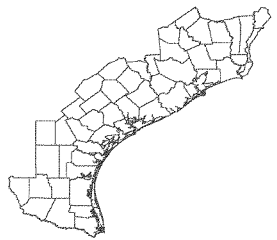
Measure 3-10.5: Local Surge Protection, UTMB, Galveston County



Legend

Ring Levee

0 105 210 420 630 840

Feet

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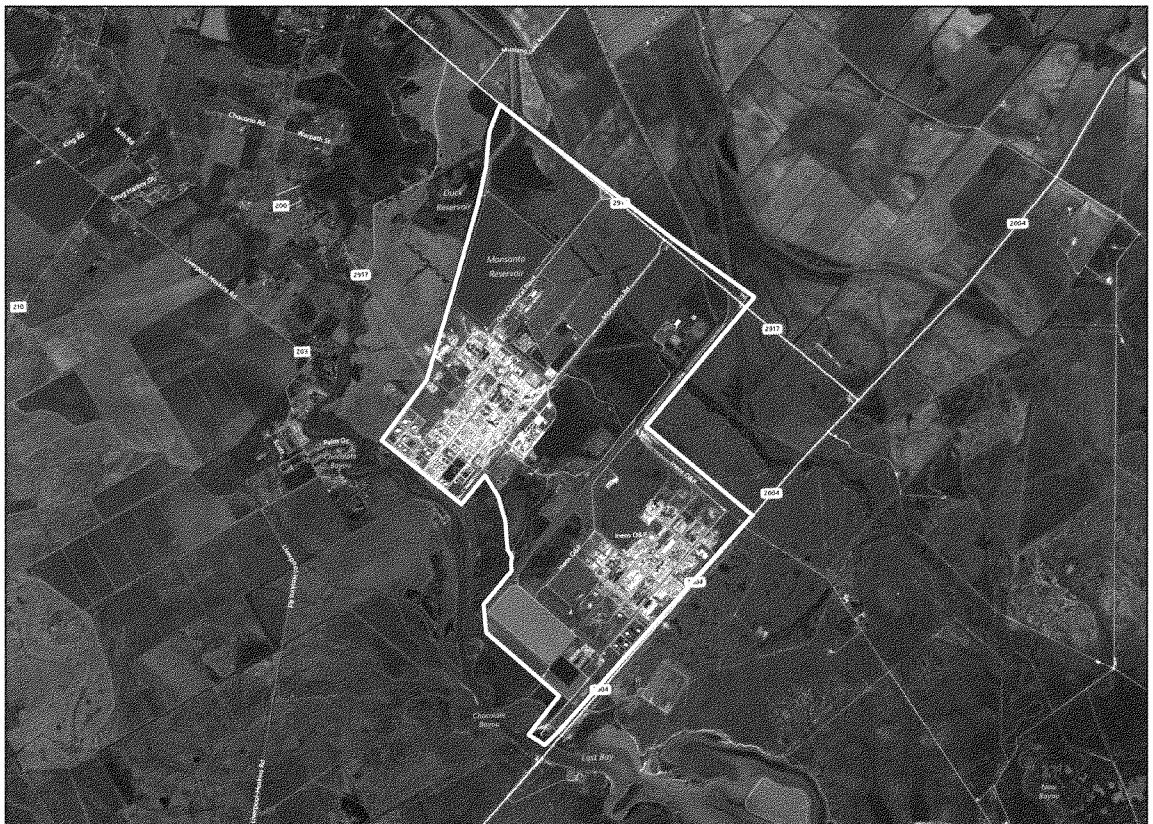
Measure 3-10.6: Local Surge Protection, Chocolate Bayou, Brazoria County



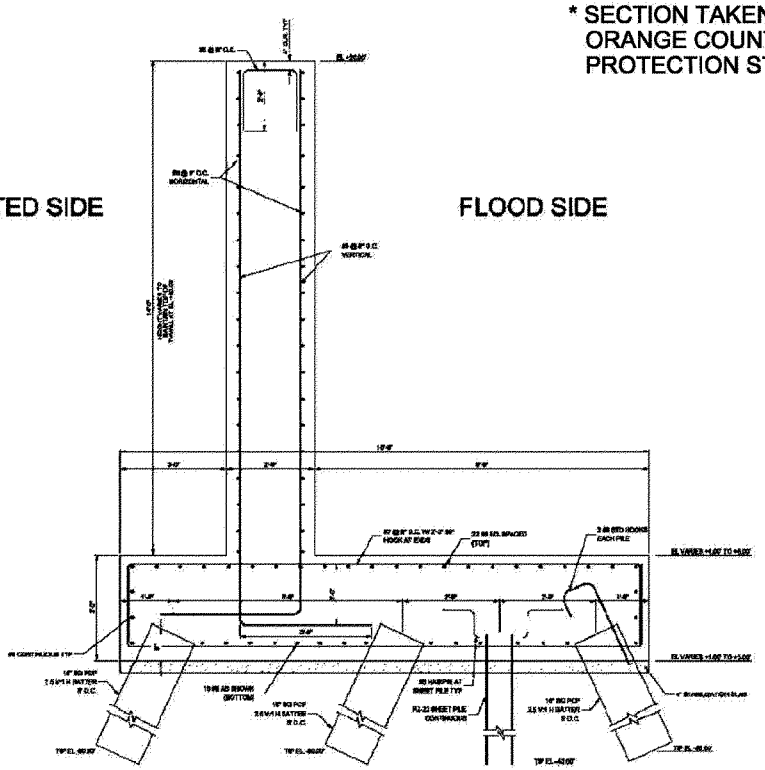
Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

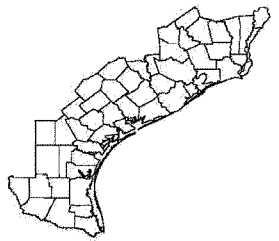
Typical Section S-04: Orange County Floodwall

* SECTION TAKEN FROM ORANGE COUNTY FLOOD PROTECTION STUDY

PROTECTED SIDE

FLOOD SIDE





Typical Section S-04

Measures:
3-4
3-5
3-6
3-7
3-8
3-9
3-10

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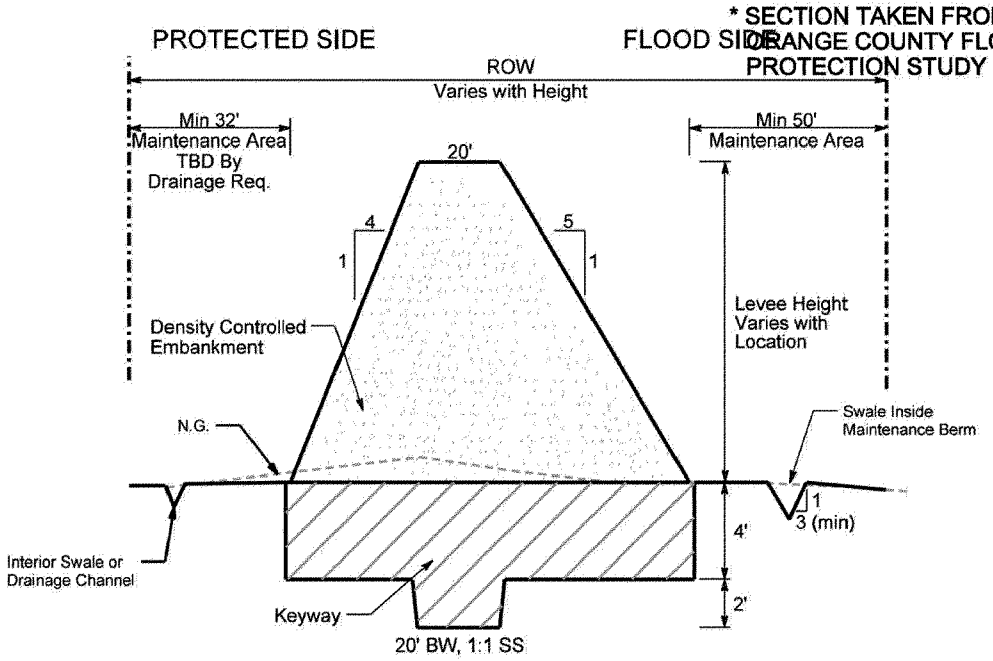
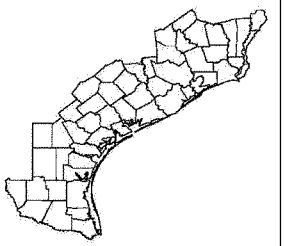
Typical Section S-05: Orange County Levee





Typical Section S-05

Measures:
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3-5
3-6
3-7
3-8
3-9
3-10

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 4-1, 4-2.1, 4-2.2 and 4-2.3
INFORMATION SHEET

DESCRIPTION OF MEASURES

The measures described below all involve road raisings, but they are divided into two separate types of projects. Measure 4-1 involves the raising a highway along the west coast of Galveston Bay to a sufficient height that would protect human lives and infrastructure from impacts during a 100-year storm event. Measure 4-2 is comprised of 3 measures which raise highways on barrier islands and headlands to a lower elevation intended to protect environmentally sensitive areas from the effects of smaller but more frequent storms such as 10, 20 and 30-year events. It is assumed that the lower level of protection could provide significant ecosystem benefits while avoiding the large impacts and costs of a barrier designed to protect human lives and infrastructure.

Measure 4-1: Raise State Highway 146, Galveston and Harris Counties. Rebuild and raise approximately 17 miles of Highway 146 from the existing Texas City Hurricane Protection Project levee to the vicinity of the Hartman Bridge on the Houston Ship Channel. Tie-in to a closure structure on the Houston Ship Channel is assumed. At an elevation of NAVD 25 feet, the new barrier would provide surge protection from a modified Ike-type event to numerous residential communities along the west shore of Galveston Bay in Galveston and Harris counties, in addition to industrial facilities at La Porte, Barber's Cut and Bayport, and important National infrastructure at NASA.

Measure 4-2.1 Raise State Highway 87 from Sabine Pass to High Island, Jefferson and Chambers Counties. Rebuild and raise approximately 32.5 miles (171,806 linear feet) of former State Highway 87 from High Island to Sabine Pass to protect environmentally sensitive areas in the Texas Point and McFaddin National Wildlife Refuges (NWR) and Sea Rim State Park. Located in Jefferson and Chambers counties, the highway has been closed for many years and most of the roadbed has eroded into the Gulf. In addition, the NWR's are undergoing significant wetland loss.

Measure 4-2.2 Raise State Highway 87 from High Island to Port Bolivar, Galveston County. Rebuild and raise approximately 27 miles (143,900 linear feet) of State Highway 87 from High Island to Port Bolivar to protect emergent marshes along the GIWW and on the bay side of Bolivar Peninsula in Galveston County. The highway was repaired after Hurricane Ike and serves as an important hurricane evacuation route..

Measure 4-2.3 Raise County Road 257, Brazoria County. Rebuild and raise approximately 14 miles (72,000 linear feet) of County Road 257 (also known as the Blue Water Highway) from San Luis Pass to Surfside to protect emergent marshes on the bay side of Follets Island in Brazoria County. The highway serves as an important hurricane evacuation route.

LOCATION OF MEASURES (See attached drawings)

Measure 4-1:
Typical Section S-06: Elevate SH-146
Raise State Highway 146, Galveston and Harris Counties

Measures 4-1, 4-2, 4-3:
Typical Section S-07: Elevate and Armor Coastal HWY-87 & CR-257

Measure 4-2.1: Raise State Highway 87 from Sabine Pass to High Island, Jefferson and Chambers Counties

Measure 4-2.2: Raise State Highway 87 from High Island to Port Bolivar, Galveston County

Measure 4-2.3: Raise County Road 257, Brazoria County

DESIGN ASSUMPTIONS

Measure 4-1:

- Existing ground elevation along stretch of SH 146 from Texas City HFP to Bayport is 12 ft MSL. From Bayport to the Hartman Bridge the roadway is at the proposed elevation of NAVD 88 25 ft.
- Roadway will consist of five 12' wide lanes, and two 10' wide shoulders.
- Roadway will be raised a total of 13 ft consisting of 11.5 ft of fill, 1.0 ft of road base, and 0.5 ft of paving. Side slopes will be at 1:3 ft.
- Utility and bridge relocation is not accounted for.
- Additional roadway right-of-way is not accounted for.

Measures 4-2.1, 4-2.2, and 4-2.3:

- All three Ecosystem Protection Design measures are at NAVD 88 levels lower than measure 4-1. Used GLO Brazoria CR 257 design.
- Roadway will be raised a total of 6' consisting of 4.5 ft of fill, 1.0 ft of road base, and

0.5 ft of paving. Side slopes will be at 1:3 ft. See plan sheet cross section S2 for details.

- Roadway has two 12 ft wide lanes and two shoulders at 8 ft wide each.
- The 3:1 side slopes would be armored with riprap. See plan sheet cross section S2 for details.
- Utility and bridge relocation is not accounted for.
- Additional roadway right-of-way is not accounted for.

HYDRAULICS & HYDROLOGY

The design storm used for the H&H analysis is the 100 year storm surge derived by FEMA using the recent results from the FEMA 2011 Texas coastal study. The ADCIRC results were converted into a without-project 100 year flood depth grid that corresponds to existing without-project conditions.

Raising State Highway 146, Measure 4-1 would have the most impact on the without-project condition of these measures. Everyone to the eastern side of the raised highway, along the west bay shoreline, would be inundated more than they previously have been and buyouts would have to be considered. Additionally, the drainage behind a raised Highway 146 would be of concern and design would need to be modeled extensively.

Measures 4-2.1, 4-2.2 and 4-3 would have some impact with regard to surge protection, but primarily for events lesser than the 100-year storm surge. In order to fully understand the effects of these measures, smaller storms should be examined and cross shore transport modeling with SBEACH (Storm Induced Beach Change Model) and possibly some longshore sediment transport with GENESIS (Generalized Model for Causing Shoreline Change) should be conducted.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

- Measure 4-1: Raise State Highway 146, Galveston and Harris Counties
  Total Estimated Real Estate Cost: $73,200,000 ®

- Measure 4-2.1 Raise State Highway 87 from Sabine Pass to High Island, Jefferson and Chambers Counties
  Total Estimated Real Estate Cost: $39,400,000 ®

- Measure 4-2.2 Raise State Highway 87 from High Island to Port Bolivar, Galveston County
  Total Estimated Real Estate Cost of Measure 4-2.2: $42,400,000 ®

- Measure 4-2.3 Raise County Road 257, Brazoria County
  Total Estimated Cost: $15,700,000 ®

ENVIRONMENTAL

Measure 4-1 would reduce surge damages due to scouring and marsh loss caused by elevated salinities following the storm. The protected area would be equivalent to the area H&H modeling determined would be protected by construction of the measure.

Measures 4-2.1, 4-2.2 and 4-2.3 would have little beneficial environmental effects for a 100-year storm, but they could have a significant effect as a first line of defense for storms of lower magnitude such as 10-, 20, 30-year events. The higher roadbeds would be effective at blocking the storm surge of smaller storms, thus prevent scouring and salinity insults to fresher wetland environments over a large area inland from the roadway. No H&H modeling was conducted to determine areas that would be protected by measures for the smaller but more frequent storm events. The wetland acre benefits presented below assume that the benefits would extend inland up to the vicinity of the Gulf Intracoastal Waterway.

Environmental benefits are presented in wetland acres that would be protected by this measure. The wetland acres were calculated with a GIS analysis of National Wetland Inventory wetland maps (USFWS, 2012).

BENEFITS

With and without project damages to structures, contents, and vehicles were calculated using HEC-FIA (Flood Impact Analysis) software package which analyzes consequences for a given flood event, in this case, a 1% annual exceedance probability (100-year). Without project damages are those that would occur under the current existing condition. Residual damages are those that would occur with a given measure in place. Benefits are the difference between the two. These numbers are listed in the tables below.

This economic analysis does not take into account losses of human life or impacts to the economy of the region that would result from economic and industrial disruptions caused by storm surge. It could take weeks to get critical petro-chemical facilities back on-line, and

months to clean-up and fully repair flooded facilities. The lives of thousands of people would be disrupted until homes could be rebuilt, and temporary dislocations would adversely effect employers who would loose employees as they relocate to other areas.

Storm Surge Regions

Region	Counties
6	Brazoria, Galveston, Harris
7	Chambers, Galveston, Harris, Jefferson
8	Chambers, Jefferson, Orange

Benefits for Measures 4-1 to 4-2.3

Measure 4-1: Raise State Highway 146, Galveston and Harris Counties			**Region 6**
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$4,115,223,000	$1,515,672,000
Contents	$5,854,589,000	$4,585,865,000	$1,268,724,000
Vehicles	$1,337,005,000	$1,048,105,000	$288,900,000
Total	**$12,822,489,000**	**$9,749,193,000**	**$3,073,296,000**

Measure 4-2.1: Raise State Highway 87 from Sabine Pass to High Island, Jefferson and Chambers Counties			**Region 8**
	Without Project Damages	Residual Damages	Benefits
Structure	$1,041,712,000	$1,006,288,000	$35,424,000
Contents	$1,078,037,000	$1,042,874,000	$35,163,000
Vehicles	$362,768,000	$349,603,000	$13,165,000
Total	**$2,482,517,000**	**$2,398,765,000**	**$83,752,000**

Measure 4-2.2: Raise State Highway 87 from High Island to Port Bolivar, Galveston County			**Region 7**
	Without Project Damages	Residual Damages	Benefits
Structure	$1,016,448,000	$1,008,479,000	$7,969,000
Contents	$833,516,000	$826,053,000	$7,463,000
Vehicles	$252,516,000	$252,516,000	$0
Total	**$2,102,480,000**	**$2,087,048,000**	**$15,432,000**

Measure 4-2.3: Raise County Road 257, Brazoria County			**Region 6**
	Without Project Damages	Residual Damages	Benefits
Structure	$5,630,895,000	$5,609,442,000	$21,453,000
Contents	$5,854,589,000	$5,840,373,000	$14,216,000

Vehicles	$1,337,005,000	$1,336,965,000	$40,000
Total	**$12,822,489,000**	**$12,786,780,000**	**$35,709,000**

COSTS

These costs do not include Real Estate costs.

Measure 4-1: Raise State Highway 146, Galveston and Harris Counties
The estimated cost for this measure is $489,890,000.
The basis for the cost of the flood control structures required at Dickinson Bayou, Channel to Clear Lake, and Taylor Bayou were derived from the TAMU Ike Dike report.

The basis for the unit prices used was derived from the General Land Office work on Brazoria Co. Road 257 and the Ike Dike report.

Measure 4-2.1: Raise State Highway 87 from Sabine Pass to High Island, Jefferson and Chambers Counties.
The estimated cost for this measure is $387,654,000.
The basis for the unit prices used was derived from the General Land Office work on Brazoria Co. Road 257.

Measure 4-2.2: Raise State Highway 87 from High Island to Port Bolivar, Galveston County.
The estimated cost for this measure is $324,547,000.
The basis for the unit prices used was derived from the General Land Office work on Brazoria Co. Road 257.

Measure 4-2.3: Raise County Road 257, Brazoria County.
The estimated cost for this measure is $162,274,000.
The basis for the unit prices used was derived from the General Land Office work on Brazoria Co. Road 257.

Additional Cost Assumption:

- A standard 25% contingency, E&D of 8%, and CM of 6% were added to the cost.

REFERENCE DOCUMENTS

Hwy 146 alignment and raising - SSPEED Center Phase I Report: Learning the Lessons of Hurricane Ike: Preparing for the Next Big One, November 2011.

For Hwy 87 and CR 257 – Brazoria County Plans of Proposed County Road Repair and Protection CR 257 (Blue Water Highway).

Applying best practices from the Delta Works and New Orleans to Galveston Bay, Prepared by: Kasper Stoeten, Master Student Hydraulic Engineering, Delft University of Technology, November 2012.

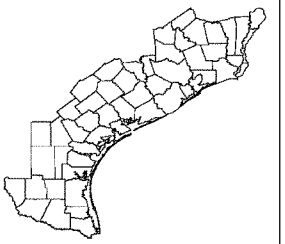
U.S. Fish and Wildlife Service. 2012. National Wetland Inventory. Accessed on the internet at http://www.fws.gov/wetlands/Data/Mapper.html

RISKS

- The alignment for measure 4-1 was taken from the SSPEED center proposals.
- Geotechnical and structural feasibility of the proposal was not reviewed by the COE.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.
- System configuration and the proposed structures were not assessed by the COE.
- The area of environmental benefits for measures 4-2.1, 4-2.2, and 4-3 was estimated based on best professional judgment. H&H modeling would be needed to determined the actual area of protection.

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 4: Raise State Highways 146 And 87, And County Road 257



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Measure 4

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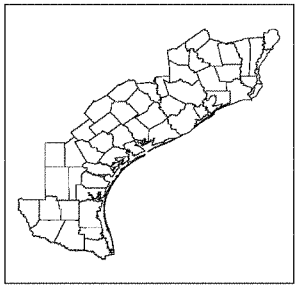
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 4-1: Raise State Highway 146



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Measure 4-1

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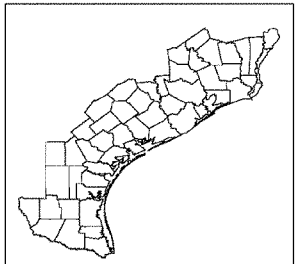
Date Created: 4/11/2013

Measure 4-2.1: Raise State Highway 87 From Sabine Pass To High Island



Legend

Measure 4-2.1

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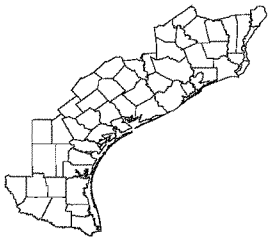
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 4-2.2: Raise State Highway 87 From High Island To Port Bolivar



Legend

Measure 4-2.2

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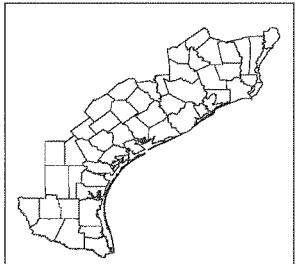
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 4-3: Raise County Road 257



Legend

Measure 4-3

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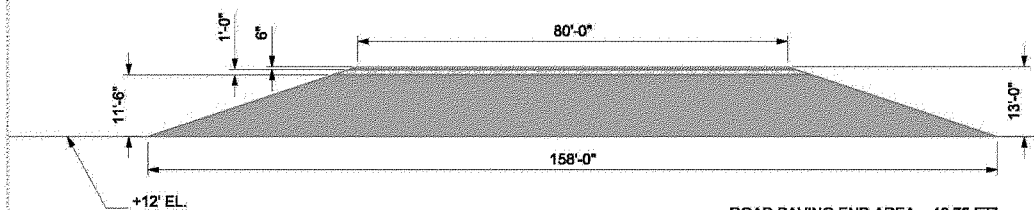
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-06: Elevate SH-146



ROAD PAVING END AREA = 40.75 FT²
ROAD BASE END AREA = 86.0 FT²
ROAD FILL END AREA = 1420.25 FT²

ASSUMPTIONS:
1. FILL IS COMPACTED 95% STANDARD
2. FILL IS TRUCKED IN HAUL DISTANCE IS 5 MILES
3. VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH
4. ROAD PAVING IS ASPHALT

Typical Section S-06

Measure:
4-1

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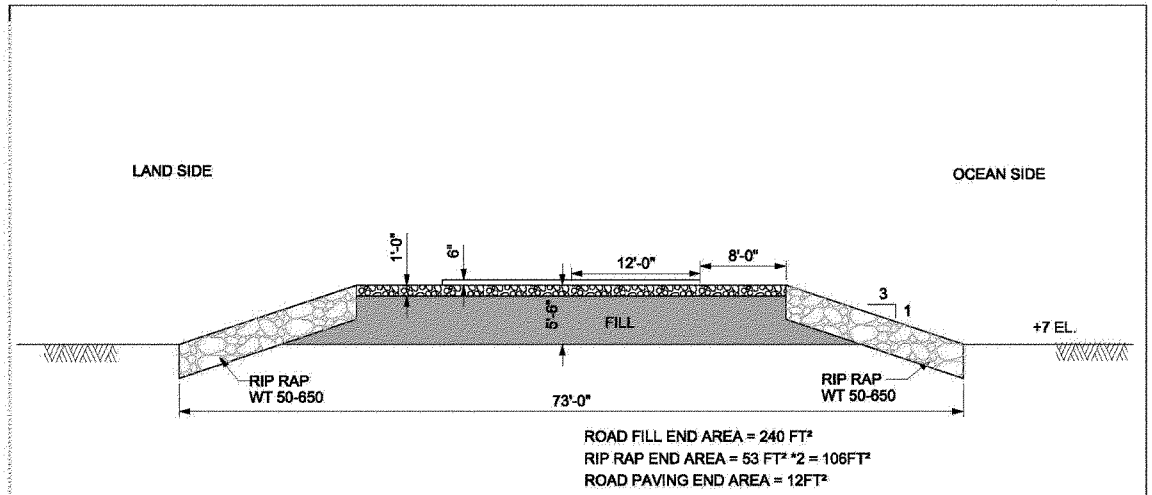
Date Created: 4/15/2013

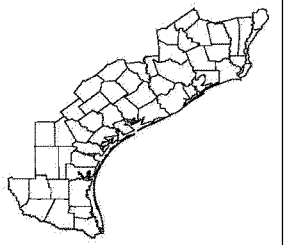
Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-07: Elevate And Armor Coastal HWY-87 & CR-257



ROAD FILL END AREA = 240 FT²
RIP RAP END AREA = 53 FT² *2 = 106FT²
ROAD PAVING END AREA = 12FT²

ASSUMPTIONS:
1: FILL IS COMPACTED 95% STANDARD
2: FILL IS TRUCKED IN HAUL DISTANCE IS 5 MILES
3: ROAD TEMPLATE IS FOUNDED ON THE 7 FT CONTOUR
4: RIP RAP IS A UNIFORM 2FT THICKNESS
5: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH
6: ROAD PAVING IS ASPHALT
7: STRIPING IS 6IN



Typical Section S-07

Measures:
4-2.1
4-2.2
4-3

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Date Created: 4/15/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURE 5-1
INFORMATION SHEET

DESCRIPTION OF MEASURE 5-1 Chenier Ridge Restoration, Jefferson County

This measure would restore three Chenier ridges in the Texas Point National Wildlife Refuge that once protected the marsh from storm surge impacts. Chenier Ridge 1 would be 13,000 ft long by 600 ft wide by 10-15 ft high. Chenier Ridge 2 would be 9,500 ft long by 600 feet wide by 10-15 ft high. Chenier Ridge 3 would be 25,500 ft long by 2,100 ft wide and 15 ft hi

DESIGN ASSUMPTIONS

- The reconstruction of the three ridges would require approximately 27,530,000 CY of fill.
- The ridges would be constructed by hydraulic fill from an offshore source at Sabine Bank using a hopper dredge with a maximum 3 mile pump out distance.
- The topsoil would be trucked in using a 12 mile haul distance.
- The topsoil area would be hydro-mulched with coastal Bermuda grass over entire area of ridge.
- Dozer would be used to spread the material.
- Assume placement of 1 foot of top soil worked into to flat tops of ridges and side slopes to promote growth of vegetation.
- Assume planting tree seedlings of oak and hackberries at 30 feet on center.

HYDRAULICS & HYDROLOGY

No H&H analysis was performed for this phase of the study. The location and size of the reconstructed ridges were based on historical maps, and their function as surge attenuators was assumed based on a report prepared by Louisiana's Department of Natural Resources (DNR, 2009) and other historical accounts.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'. Costs identified as $0 are generally associated with Federal and/or State lands.

- Measure 5-1: Chenier Ridge Restoration, Jefferson County
  Total Estimated Real Estate Cost Measure 5-1 $0

ENVIRONMENTAL

The environmental benefits for this measure, as presented here, are limited to approximately 1,200 total acres of Chenier ridge restoration. An H&H study would need to be performed to evaluate the efficacy of Chenier ridges in storm surge protection in this area. Given the height and limited footprint of these ridges, any surge protection would be limited to smaller but more frequent storms such as 10, 20 and 30-year events. The ridge acres were calculated with a GIS analysis of National Wetland Inventory wetland maps (USFWS, 2012).

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

This cost does not include Real Estate cost.
The estimated cost for this measure is $ $328,136,102.

REFERENCE DOCUMENTS

Louisiana Department of Natural Resources (DNR). 2009. Cheniers and Natural Ridges Study. Prepared for Louisiana DNR by Providence Engineering and Environmental Group, LLC, Baton Rouge.

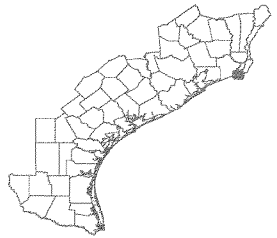
U.S. Fish and Wildlife Service. 2012. National Wetland Inventory. Accessed on the internet at http://www.fws.gov/wetlands/Data/Mapper.html

RISKS

- The alignment was estimated.
- Geotechnical and structural feasibility of the proposal was not reviewed.
- Ground elevations were estimated.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.

- Engineering analyses need to be conducted to determine strongest possible engineered structure.
- Fill material and source would need to be verified.
- H&H modeling of storm surge attenuation effects would need to be conducted.
- Extent of Chenier ridges is limited to historical footprint, which may limit the ridges surge attenuation effectiveness in this area.

Measure 5-1: Chenier Beach Ridge Restoration, Jefferson County



Legend

- Chenier Ridge 1
- Chenier Ridge 2
- Chenier Ridge 3

N

0 1,300 2,600 5,200 7,800 10,400

Feet

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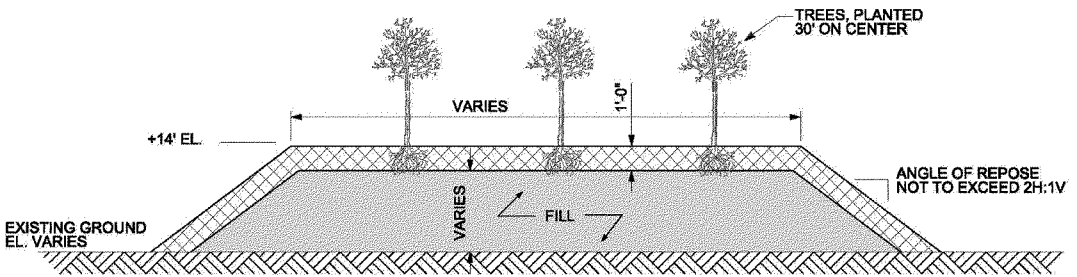
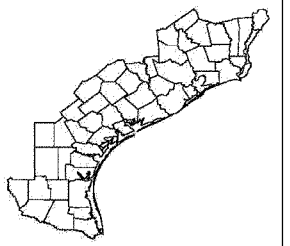
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-08: Chenier Ridge Restoration



ASSUMPTIONS:
1: HYDRAULIC PLACEMENT OF FILL SAND FROM OFFSHORE BORROW SOURCE
2: 1 FOOT LAYER OF TOPSOIL SEEDED WITH COASTAL BERMUDA GRASS
3: LIVE OAK AND HACKBERRY SEEDLINGS PLANTED 30 FEET ON CENTER



Typical Section S-08

Measure:
5-1

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURE 5-2
INFORMATION SHEET

DESCRIPTION OF MEASURE 5-2 Beneficial Use (BU) of Dredged Material for Shoreline Nourishment at Texas Point, Jefferson County

This measure involves the beneficial use of dredged material from the Sabine-Neches Waterway (SNWW) project for shoreline nourishment at Texas Point near Sabine Pass. The maintenance material would be hydraulically pumped from the adjacent Sabine Pass Channel onto three miles of shoreline on the west side of Sabine Pass. An estimated 977,900 cubic yards would be deposited every six years for fifty years according to the SNWW Channel Improvement Feasibility Study.

LOCATION OF MEASURES (See attached drawings)

Measure 5-2: Jefferson County – BU of Dredged Material from SNWW for Beach Nourishment.pdf

Typical Section S-09: Beach Dune And Beach Renourishment

DESIGN ASSUMPTIONS

- Construction method based on assumptions developed for the SNWW study (USACE, 2011).
- Dredge material would be pumped on the shoreline in a swath 100 ft wide.
- Historic dredging records indicate that the maintenance material from Sabine Pass will average 51 percent silt, 31 percent clay, and 18 percent fine sand (USACE dredging data base).
- Maintenance material from every maintenance cycle of the Sabine Pass Channel (approximately 3-year long cycle) would be hydraulically pumped onto the first beach ridge at Texas Point for a length of approximately 3 miles. The unconfined release of material would be expected to flow into the existing marsh and the Gulf of Mexico surfzone.
- This measure would provide a regular source of predominantly fine-grained sediment that would contribute to mudflat accretion and periodically move onshore to become shore-attached while also providing sediment to raise and nourish eroding marsh at Texas Point.

- The fine-grained sediments are expected to initially be highly mobile and some portion of the material will be rapidly lost from the vicinity of the shoreline. Because of the prevailing wave climate, the mobile material within the surf zone should generally migrate to the west and move toward the eroding shoreline at Texas Point. There, the additional fine-grained sediments could lower erosion rates through mudflat accretion and wave attenuation processes. A small quantity of material may migrate to the east and contribute to the Sabine fillet at the west jetty.

HYDRAULICS & HYDROLOGY

No H&H analysis was performed for this phase of the study. The location and size of the shoreline to be restored is based on shoreline erosion data from the Bureau of Economic Geology (2012) and on the USACE SNWW Feasibility Study (2011).

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

- Measure 5-2 BU of Dredge Material for Shoreline Nourishment at Texas Point, Jefferson County.
  Total Estimated Real Estate Cost: $17,100,000 ®

ENVIRONMENTAL

This measure is located entirely within the Texas Point National Wildlife Refuge (NWR) which is undergoing severe shoreline erosion, with net long-term shoreline retreat ranging between 8.2 and 16.4 ft per year. This is one of the highest rates of shoreline loss on the upper Texas coast and a state "critical erosion area." The current shoreline is a narrow beach front of silty clay that lies seaward of eroding overwash marsh terraces. Given the unusual characteristics of this sand-starved system, returning the material to the littoral system is likely to have a net beneficial effect, regardless of material type. The longshore transport in this system contains primarily fine-grained sediments, but these sediments have been shown to accumulate in the near shore zone and result in shoreline accretion by, as yet, poorly understood processes. The presence of additional fine-grained sediments in the littoral system should reduce the current erosion rate as the presence of additional muddy sediment in the nearshore environment may attenuate waves and lessen wave-induced erosion. Based on these assumptions, it has been estimated that the periodic nourishment would nourish and restore approximately 250 acres of marsh along the

shoreline over a 50 year period of analysis, while substantially reducing the current erosion rate at the placement site and on down drift shorelines, where even higher rates of erosion occur.

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

This cost does not include Real Estate. The estimated cost for this measure is $239,109,600.

REFERENCE DOCUMENTS

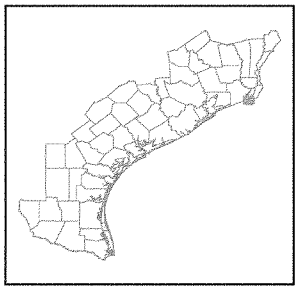
USACE. 2011. Final Feasibility Study and Environmental Impact Statement for the Sabine-Neches Waterway Channel Improvement Project, Southeast Texas and Southwest Louisiana. Galveston District.

Bureau of Economic Geology. 2012. Texas Shoreline Change Atlas – http://igor.beg.utexas.edu/SCA/

RISKS

- Geotechnical and structural feasibility of the proposal was not reviewed.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.
- Maintenance material dredged from SNWW does not contain beach quality sand. The fine-grained sediments are expected to initially be highly mobile and some portion of the material will be rapidly lost from the vicinity of the shoreline.
- Implementation of this measure would require a revised Dredged Material Management Plan (DMMP) for the existing SNWW navigation project. Additional document preparation and coordination through USACE O&M would likely be required.
- The behavior of the BU sediments within this complex littoral system cannot be predicted with certainty over the period of analysis, especially given the potential for strong storms to affect the coastal environment. However, there is sufficient knowledge of general processes and baseline conditions to support evaluation of potential impacts and benefits. Furthermore, the engineering feasibility and potential environmental benefits have been demonstrated by successful recent BU projects at Texas and Louisiana Points.

Measure 5-2: BU of Dredged Material for Shoreline Nourishment at Texas Point, Jefferson County



Legend

Beach Nourishment

0 1,350 2,700 5,400 8,100 10,800

Feet

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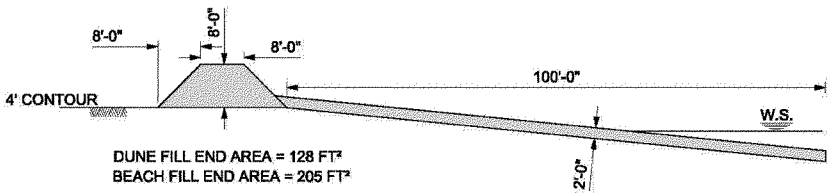
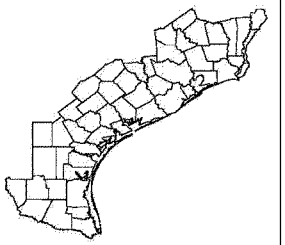
Date Created: 4/24/2013

Typical Section S-09: Beach Dune And Beach Renourishment



ASSUMPTIONS:
1: FILL IS LOOSELY PLACED NON COMPACTED
2: FILL IS TRUCKED IN HAUL DISTANCE IS 5 MILES
3: DUNE TEMPLATE IS FOUNDED ON THE 4FT CONTOUR
4: BEACH FILL IS A UNIFORM 2FT THICKNESS OVER 100FT
5: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH



Typical Section S-09

Measures:
5-2 (No Dune Construction)
5-3
5-6
5-7 (No Dune Construction)
5-8
5-11
5-12
5-13
5-14

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 5-3, 5-6, 5-7, 5-8, 5-11, 5-12, and 5-13
INFORMATION SHEET

DESCRIPTION OF MEASURES

These measures consist of placing fill material along shoreline regions to provide beach nourishment and dune restoration, with periodic renourishment over a 50 year period of analysis. It is assumed that these measures would stabilize the shoreline and prevent erosion during this time period.

Measure 5-3: Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties. This measure would restore approximately 35 miles of shoreline. The area protected by the shoreline includes the community of Sabine Pass, the McFaddin and Texas Point National Wildlife Refuges (NWR), the J.D. Murphree Wildlife Management Area (WMN), and Sea Rim State Park. Just inland of the protected coastal marshlands lies the city of Port Arthur and the largest oil refinery in the United States (Motiva). With the exception of a small sandy beach at Sea Rim State Park, all of this shoreline is an eroding marsh face with little or no sand Gulfward of the marsh. The erosion rate ranges from moderate (average of -4.1 feet/year) to very high (-24.6 feet/year), except near the West Sabine Jetty, where a short section of shoreline is aggrading.

Measure 5-6: Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston County. This measure would restore approximately 25.4 miles of shoreline. The area protected by the shoreline includes the entire Bolivar Peninsula and several beach communities such as Gilchrist, Crystal Beach and Port Bolivar. This area was completely destroyed by Hurricane Ike. Some of the community and residential structures have been rebuilt and meet minimum FEMA flood elevations standards and building codes. Sandy beaches with degrading beach dunes predominate the shoreline in this measure, which has an moderate average erosion rate of -4.1 feet/year. A short section of the shoreline near the Galveston East Jetty is aggrading.

Measure 5-7: Beach Nourishment, East Galveston Island Seawall, Galveston County. This measure would restore approximately 7 miles of beach located in front of the Seawall on Galveston Island. No dune restoration is proposed for this measure. The measure would increase the resiliency of the existing Galveston Seawall by restoring and maintaining a beach at the toe of the seawall. No nourishment is proposed for the easternmost 3 miles of the Seawall, as the beach in this area is aggrading. The area protected by the measure is the City of Galveston.

Beaches are eroding at a moderate average rate of -4.1 feet/year to a high average rate of -12.3 feet/year. Groins, constructed to capture sand, capture sand on their up-current sides but starve beaches located down current.

Measure 5-8: Dune Restoration and Beach Nourishment, West Galveston Island, Galveston County. This measure would restore approximately 18.4 miles of Galveston Island west of the Galveston Seawall. The area protected by the shoreline includes the communities or neighborhoods of Pirate's Beach, Jamaica Beach, the Silverleaf Seaside Resort, Vista Del Mar, Terramar, and Baywater, among others. Beaches in this area are eroding at a moderate rate of -4.1 feet/year.

Measure 5-11: Dune Restoration and Beach Nourishment, San Luis Pass to Surfside, Brazoria County. This measure would restore approximately 10.2 miles of shoreline. The area protected by the shoreline includes the narrow barrier peninsula named Follet's Island and its extensive bayside marsh system, one large community named Treasure Island, and other scattered residential developments. Follet's Island also protects a series of extremely productive bays (Bastrop, Christmas and Drum bays) and the Brazoria National Wildlife Refuge on the mainland behind this bay system. Beaches and dunes in this area are eroding at a moderate average rate of -4.1 feet/year to a high average rate of -12.3 feet/year.

Measure 5-12: Dune Restoration and Beach Nourishment, Surfside to Brazos River, Brazoria County. This measure would restore approximately 1.9 miles of shoreline extending eastward from near the Freeport East Jetty. The area protected by the shoreline is the City of Surfside. The average erosion rate for this section of shoreline is moderate, an average of -4.1 feet/year. But within one mile of the East Jetty, there has been about 1,125 feet of erosion over the last 50 years (CHE 2008). The erosion in the area near the jetty is increasing in large part because of the erosion and collapse of the Brazos River delta. The collapse of the delta is the result, in large part, of the construction of the Brazos River Diversion Channel, a USACE project completed in the 1930's. Erosion of the delta began immediately upon completion of the diversion, and the submerged delta face is now located close to shore, increasing wave energy on the Surfside shoreline.

Measure 5-13: Dune Restoration and Beach Nourishment Brazos River to Brazos River Diversion Channel, Brazoria County. This measure would restore approximately 6.3 miles of shoreline. The area protected by this shoreline includes two popular recreation areas at Quintana and Bryan Beaches, the Justin Hurst WMA and several industrial facilities and placement areas. Beach erosion rates in this area range from moderate to very high, with the majority being in the high average rate of -12.3 feet/year.

LOCATION OF MEASURES (See attached drawings)

- Measures 5-3, 5-6, 5-7, 5-8, 5-11, 5-12, 5-13:
- Typical Section S-09: Beach Dune And Beach Renourishment
- Measure 5-3: Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties
- Measure 5-6: Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston County
- Measure 5-7: Dune Restoration and Beach Nourishment, East Galveston Island Seawall, Galveston Island
- Measure 5-8: Dune Restoration and Beach Nourishment, West Galveston Island, Galveston County
- Measure 5-11: Dune Restoration and Beach Nourishment, San Luis Pass to Surfside, Brazoria County
- Measure 5-12: Dune Restoration and Beach Nourishment, Surfside to Brazos River, Brazoria County
- Measure 5-13: Dune Restoration and Beach Nourishment, Brazos River to Brazos River Diversion channel, Brazoria County

DESIGN ASSUMPTIONS

- Dune and beach fill will be obtained from the same source.
- A 5 mile round trip haul distance from fill source to location.
- Using 12 CY dump trucks.
- Material placed by dozer, with no additional compaction measures needed.
- Area of beach nourishment is approximately 100 ft wide x 2 ft high per plan typical.
- The dune section will be trapezoidal 8 ft high with a 24 ft wide base per plan typical.

Measure	Fill Estimate (CY)
5-3	2,244,667
5-6	1,652,667
5-7	280,926
5-8	1,196,333
5-11	666,000
5-12	246,667
5-13	407,000

HYDRAULICS & HYDROLOGY

No H&H analysis was performed for this phase of the study. The location and size of the shoreline to be restored is based on shoreline erosion data from the Bureau of Economic Geology (2012).

REAL ESTATE REQUIREMENTS

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

- Measure 5-3: Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties.
  Total Estimated Real Estate Cost: $17,900,000 ®

  Measure 5-6: Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston County
  Total Estimated Real Estate Cost: $16,200,000 ®

- Measure 5-7: Beach Nourishment, East Galveston Island Seawall, Galveston County.
  Total Estimated Real Estate Cost: $4,500,000 ®

- Measure 5-8: Dune Restoration and Beach Nourishment, West Galveston Island, Galveston County.
  Total Estimated Real Estate Cost: $11,700,000 ®

- Measure 5-11: Dune Restoration and Beach Nourishment, San Luis Pass to Surfside, Brazoria County.
  Total Estimated Real Estate Cost: $5,400,000 ®

- Measure 5-12: Dune Restoration and Beach Nourishment, Surfside to Brazos River, Brazoria County.
  Total Estimated Real Estate Cost: $1,000,000 ®

- Measure 5-13: Dune Restoration and Beach Nourishment Brazos River to Brazos River Diversion Channel, Brazoria County.
  Total Estimated Real Estate Cost: $3,400,000 ®

ENVIRONMENTAL

Dune restoration and beach nourishment on the Gulf shoreline would initially restore a 125 feet wide dune-beach complex along the shoreline of each measure. Regular beach renourishment (every 5 years) and dune restoration (every 20 years) would ensure that the beach and dune are in place throughout the 50-year period of analysis, as the renourishment rate results in no net loss when compared to the average long-term erosion rate. Therefore, environmental benefits for measures 5-6, 5-7, 5-8, 5-11, and 5-12 are based on the acres of erosion that would be prevented over the 50-year period of analysis. The 50-year estimate of acres lost was estimated using Bureau of Economic Geology (BEG) long-term erosion rates for the Texas coast (BEG, 2012).

Measure 5-3 Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties is different from the other measures in that the dune/beach complex would prevent the Gulf from breaking through and threatening a 50,000 acre coastal wetland that is covered with interconnected lakes and bayous. Erosion of the beach ridge along the McFaddin/Texas Point NWR and Sea Rim State Park property would allow Gulf seawater to wash into interior marshes during high tides and storm surges. This has the potential to cause widespread loss of wetlands in this federally- and state-protected coastal wetland system. The total estimated environmental benefit for this measure (20,200 acres) is the total acres of shoreline erosion that would be prevented over the 50-year period analysis (for the entire measure) plus the wetland acres of the Unit that lie behind the shoreline that would be lost. The entire shoreline of Measure 5-3 protects the McFaddin and Texas Point National Wildlife Refuges, and Sea Rim State Park.

Measure 5-13 Dune Restoration and Beach Nourishment Brazos River to Brazos River Diversion Channel, Brazoria County would protect the Bryan Beach Unit of the Justin Hurst WMA in addition to placement areas, and residential, industrial and recreational development. This Unit is located at the western end of the measure, and accounts for approximately 10 percent of the total shoreline length. The Unit is 440 acres dominated by a 90-acre embayment which is flooded by Gulf waters during high tides and storms. The embayment is separated from the Gulf by a large vegetated coastal dune. Coastal marshes surround the embayment behind the dune. Continued erosion of the embayment shoreline at the long-term rate reported by the Bureau of Economic Geology would result in the complete opening of the embayment and loss of the surrounding coastal marsh. The total estimated environmental benefit for this measure (450 acres) is the total acres of shoreline erosion that would be prevented over the 50-year period analysis (for the entire measure) plus the wetland acres of the Unit that lie behind the shoreline that would be lost.

Measure Description	Length of Shoreline (miles)	Restored Shoreline (acres)	Acres of Erosion Prevented Over 50 Yrs
Measure 5-3 (Sabine Pass to High Island)	35	530	20,200
Measure 5-6 (High Island to Galveston East Jetty)	25.4	385	530
Measure 5-7 (East Galveston Island-Seawall)	7	106	235
Measure 5-8 (West Galveston Island)	18.4	279	420
Measure 5-11 (San Luis Pass to Surfside)	10.2	155	500
Measure 5-12 (Surfside to Brazos River)	1.9	29	45
Measure 5-13 (Brazos River to Brazos River Diversion Channel)	6.3	95	475

BENEFITS:

All benefits are assumed be environmental for this phase of analysis.

COSTS:

These costs do not include Real Estate.

Measure 5-3: Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties The estimated cost for this measure is $462,912,000.
Measure 5-6: Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston County The estimated cost for this measure is $340,829,000.
Measure 5-7: Dune Restoration and Beach Nourishment, East Galveston Island Seawall, Galveston Island. The estimated cost for this measure is $95,112,000.
Measure 5-8: : Dune Restoration and Beach Nourishment, West Galveston Island, Galveston County. The estimated cost for this measure is $246,713,000.
Measure 5-11: Dune Restoration and Beach Nourishment, San Luis Pass to Surfside, Brazoria County. The estimated cost for this measure is $137,349,000.

Measure 5-12: Dune Restoration and Beach Nourishment, Surfside to Brazos River, Brazoria County. The estimated cost for this measure is $50,875,000.
Measure 5-13: Dune Restoration and Beach Nourishment, Brazos River to Brazos River Diversion channel, Brazoria County The estimated cost for this measure is $83,932,000.

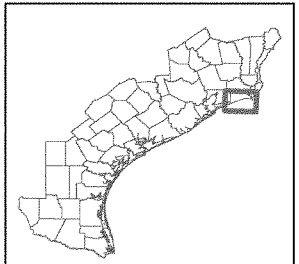
REFERENCE DOCUMENTS:

Bureau of Economic Geology (BEG). 2012. Texas Shoreline Change Atlas – http://igor.beg.utexas.edu/SCA/

RISKS:

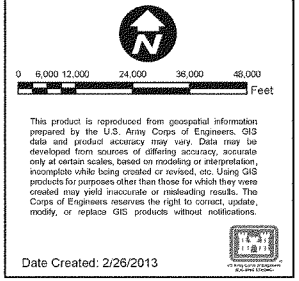
- Geotechnical and Structural feasibility of the proposal was not reviewed.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.
- Shoreline erosion rates are based on the midpoint of long-term erosion rate ranges that have been measured by the Bureau of Economic Geology at the University of Texas at Austin. Actual erosion rates may be lower or higher than the estimate. Additionally, these erosion rates are based on historical data and do not account for any increase in the rate of relative sea level rise that may be occur in conjunction with climate change.

Measure 5-3: Jefferson County - Restore Beach Ridge - Sabine Pass to High Island



Legend

Clay Core Dune



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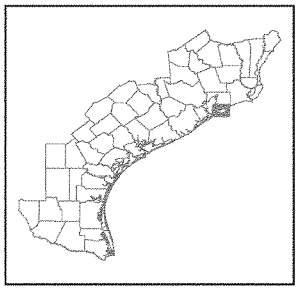
Date Created: 2/26/2013

Measure 5-6: Galveston County - Dune and Beach Nourishment - High Island to Bolivar



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Dune and Beach Renourishment

0 2,500 5,000 10,000 15,000 20,000
Feet

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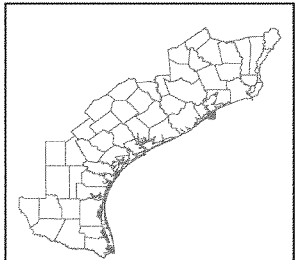
Date Created: 2/26/2013

Measure 5-7: Galveston County - Beach Renourishment - East Galveston in front of Seawall



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Beach Renourishment

0 850 1,700 3,400 5,100 6,800

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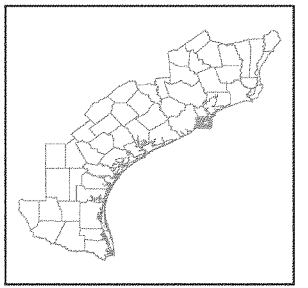
Date Created: 2/26/2013

Measure 5-8: Galveston County - Dune Restoration and Beach Nourishment - Galveston West End



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Dune and Beach Nourishment

0 2,300 4,600 9,200 13,800 18,400 Feet

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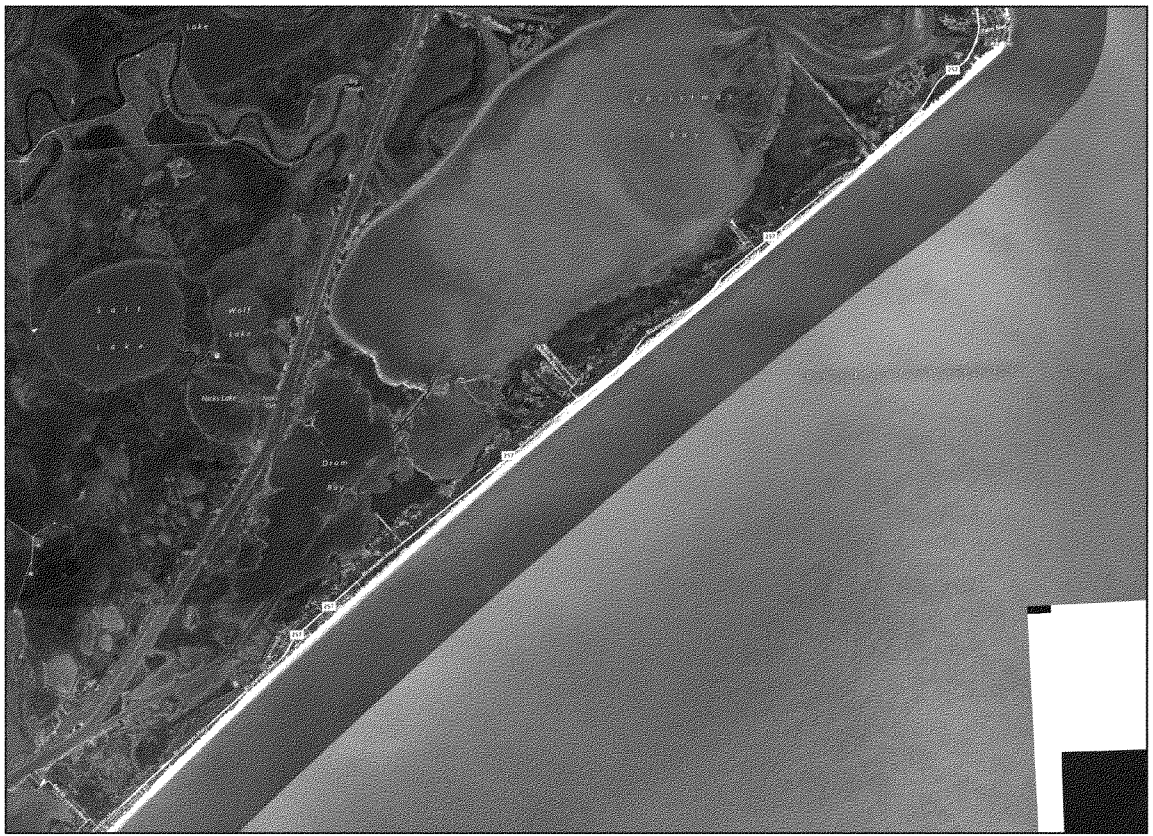
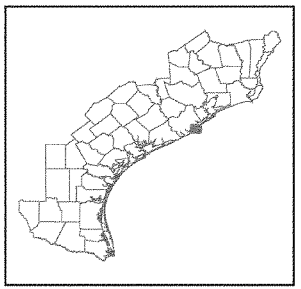
Date Created: 2/26/2013

Measure 5-11: Brazoria County – Dune Restoration and Beach Nourishment - Follets Island





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Dune and Beach Nourishment

0 1,350 2,700 5,400 8,100 10,800

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Date Created: 2/26/2013

Measure 5-12: Dune Restoration and Beach Nourishment, Surfside to Brazos River, Brazoria County

Surfside Beach
Gulf of Mexico
Surfside Jetty
Quintana
Freeport
Jetty
Gulf Intracoastal Waterway
Old Brazos River Channel
Velasco
Surfside Jetty Rd
Cedar Grove Rd
Quintana Rd
Gulf Beach Dr
Bryan Beach Rd
Velasco Dr
Ocean Dr
Surfside Blvd
Texas Ave
Freeport Harbor Channel
Brazos River Channel
Freeport Harbor
Freeport Municipal Airport
Brazos River
Old Brazos River
Brazos River Diversion Channel
Dow Barge Canal
Dow Barge Canal Turning Basin
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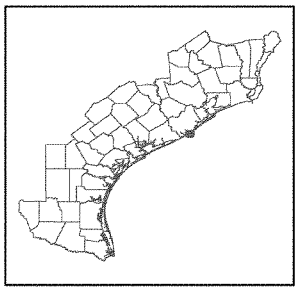
Measure 5-13: Brazoria County - Dune Restoration and Beach Nourishment – Quintana



Legend

Dune and Beach Nourishment

0 800 1,600 3,200 4,800 6,400
Feet

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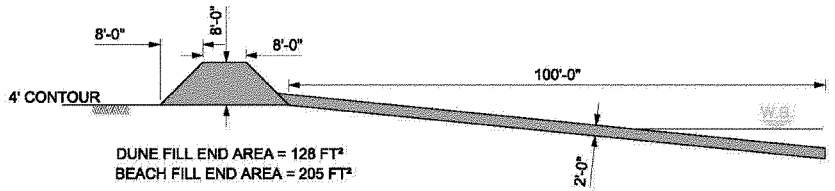
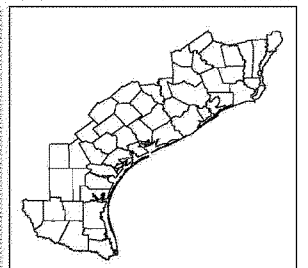
Date Created: 2/26/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-09: Beach Dune And Beach Renourishment



ASSUMPTIONS:
1: FILL IS LOOSELY PLACED NON COMPACTED
2: FILL IS TRUCKED IN HAUL DISTANCE IS 5 MILES
3: DUNE TEMPLATE IS FOUNDED ON THE 4FT CONTOUR
4: BEACH FILL IS A UNIFORM 2FT THICKNESS OVER 100FT
5: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH



Typical Section S-09

Measures:
5-2 (No Dune Construction)
5-3
5-6
5-7 (No Dune Construction)
5-8
5-11
5-12
5-13
5-14

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Date Created: 4/15/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 5-5, 5-9, 5-15
INFORMATION SHEET

DESCRIPTION OF MEASURES

Measure 5-5: Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties

Measure 5-9: Segmented Nearshore Breakwaters, West Galveston Island to San Luis Pass

Measure 5-15: Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria County

All three of these measures involve gulf shoreline protection and restoration using riprap to create segmented nearshore breakwaters and one initial episode of beach nourishment. In conjunction with the beach nourishment, a sand fence would be added on shore along the vegetation line to keep the sand within the beach zone. It is assumed that these measures would stabilize the shoreline and prevent erosion during the 50 year period of analysis.

LOCATION OF MEASURES (See attached drawings)

Measure 5-5: Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties

Measure 5-9: Segmented Nearshore Breakwaters, West Galveston Island to San Luis Pass

Measure 5-15: Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria County.

DESIGN ASSUMPTIONS

- Breakwaters are 150 ft long spaced at 300 ft apart.
- Riprap breakwater is placed in 5ft deep water.
- The breakwater would be trapezoidal 10ft high with a 50 ft wide base per plan typical. See cross section details on plan sheet S4.
- Riprap will be barged in to site. It will also be placed from the barge.
- A 10 ft deep flow channel will need to be excavated for rock barge access.
- Measures 5-5: Length = 182,000 ft; Volume of stone = 674,074 cy.

- Measures 5-9: Length = 137,000 ft; Volume of stone = 507,407 cy.
- Measures 5-15: Length = 110,000 ft; Volume of stone = 407,407 cy.
- Beach fill would be obtained from the same source.
- A 5 mile round trip haul distance from fill source to location.
- Using 12 CY dump trucks.
- Material placed by dozer, with no additional compaction measures needed.
- Area of beach nourishment is approximately 100 ft wide x 2 ft high per plan typical.
- The dune section will be trapezoidal 8 ft high with a 24 ft wide base per plan typical. Sand fence placed along established dune line or 100' from shoreline if dunes are not present.

HYDRAULICS & HYDROLOGY

No H&H analysis was performed for this phase of the study. The location of these measures is based on shoreline erosion data from the Bureau of Economic Geology (2012).

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'. Costs identified as $0 are generally associated with Federal and/or State lands.

- Measure 5-5: Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties
  Total Estimated Real Estate Cost: $6,904,000 ®

- Measure 5-9 Segmented Nearshore Breakwaters, West Galveston Island to San Luis Pass
  Total Estimated Cost of Measure 5-9: $0

- Measure 5-15: Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria County
  Total Estimated Real Estate Cost of Measure 5-15: $5,200,000 ®

ENVIRONMENTAL

Nearshore breakwaters and beach nourishment on the Gulf shoreline would initially restore a 100 feet wide beach along the shoreline of each measure. Regular beach renourishment (every 5 years) would ensure that the beach and dune are in place throughout the 50-year period of analysis, as the renourishment rate results in no net loss when compared to the average long-term erosion rate. Therefore, environmental benefits for measures 5-5, 5-9, and 5-15 are based on the acres of erosion that would be prevented over the 50-year period of analysis. The 50-year

estimate of acres lost was estimated using Bureau of Economic Geology (BEG) long-term erosion rates for the Texas coast (BEG, 2012).

Measure 5-5 Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties is different from the other measures in that the breakwater and beach complex would prevent the Gulf from breaking through and threatening a 50,000 acre coastal wetland that is covered with interconnected lakes and bayous. Erosion of the beach ridge along the McFaddin/Texas Point NWR and Sea Rim State Park property would allow Gulf seawater to wash into interior marshes during high tides and storm surges. This has the potential to cause widespread loss of wetlands in this federally- and state-protected coastal wetland system. The total estimated environmental benefit for this measure (20,200 acres) is the total acres of shoreline erosion that would be prevented over the 50-year period analysis (for the entire measure) plus the wetland acres of the Unit that lie behind the shoreline that would be lost. The entire shoreline of Measure 5-5 protects the McFaddin and Texas Point National Wildlife Refuges, and Sea Rim State Park.

Measure 5-9 Segmented Nearshore Breakwaters, West Galveston Island to San Luis Pass, Galveston County would protect and restore the existing beach on West Galveston Island. The majority of area that would be protected by this measure is developed seaside residential development. The environmental benefits are therefore limited to the acres of erosion that would be prevented over the 50-year period of analysis, or 420 acres.

Measure 5-15 Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria County would protect the shoreline of Folletts Island, seaside residential and industrial developments in the communities of Surfside and Quintana, and the Bryan Beach Unit of the Justin Hurst WMA. The Justin Hurst WMA unit is located at the western end of the measure, and accounts for approximately 10 percent of the total shoreline length. The Unit is 440 acres dominated by a 90-acre embayment which is flooded by Gulf waters during high tides and storms. The embayment is separated from the Gulf by a large vegetated coastal dune. Coastal marshes surround the embayment behind the dune. Continued erosion of the embayment shoreline at the long-term rate reported by the Bureau of Economic Geology would result in the complete opening of the embayment and loss of the surrounding coastal marsh. The total estimated environmental benefit for this measure (475 acres) is the total acres of shoreline erosion that would be prevented over the 50-year period analysis (for the entire measure) plus the wetland acres of the Unit that lie behind the shoreline that would be lost.

Measure Description	Length of Shoreline (miles)	Restored Shoreline (acres)	Acres of Erosion Prevented Over 50 Yrs
Measure 5-5 Segmented Nearshore Breakwaters, Sabine Pass to High Island	35	530	20,200
Measure 5-9 Segmented Nearshore Breakwaters, West Galveston Island to San Luis Pass	18.4	279	420
Measure 5-15 Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel	18.4	279	930

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

These costs do not include Real Estate.

Measure 5-5: Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties. The estimated cost for this measure is $219,772,000.

Measure 5-9: Segmented Nearshore Breakwaters, West Galveston Island to San Luis Pass. The estimated cost for this measure is $165,435,000.

Measure 5-15: Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria County. The estimated cost for this measure is $132,017,000.

REFERENCE DOCUMENTS

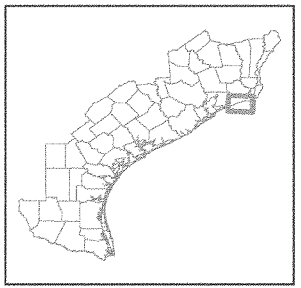
Measures 5-5, 5-9 and 5-15: Holly Beach LADNR / CWPRA project website; Engineering Design Manual; There was a revision report for space between breakwaters.

Bureau of Economic Geology (BEG). 2012. Texas Shoreline Change Atlas – http://igor.beg.utexas.edu/SCA/

RISKS

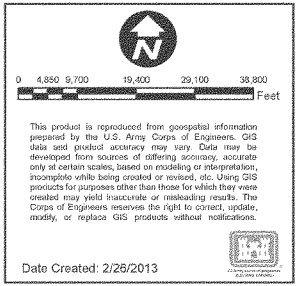
- Geotechnical and Structural feasibility of the proposal was not reviewed.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.
- Area required for sand fence may encroach on private property
- Shoreline erosion rates are based on the midpoint of long-term erosion rate ranges that have been measured by the Bureau of Economic Geology at the University of Texas at Austin. Actual erosion rates may be lower or higher than the estimate. Additionally, these erosion rates are based on historical data and do not account for any increase in the rate of relative sea level rise that may be occur in conjunction with climate change.

Measure 5-5: Jefferson County - Segmented Near-Shore Breakwaters - Sabine Pass to High Island



Legend

Breakwaters



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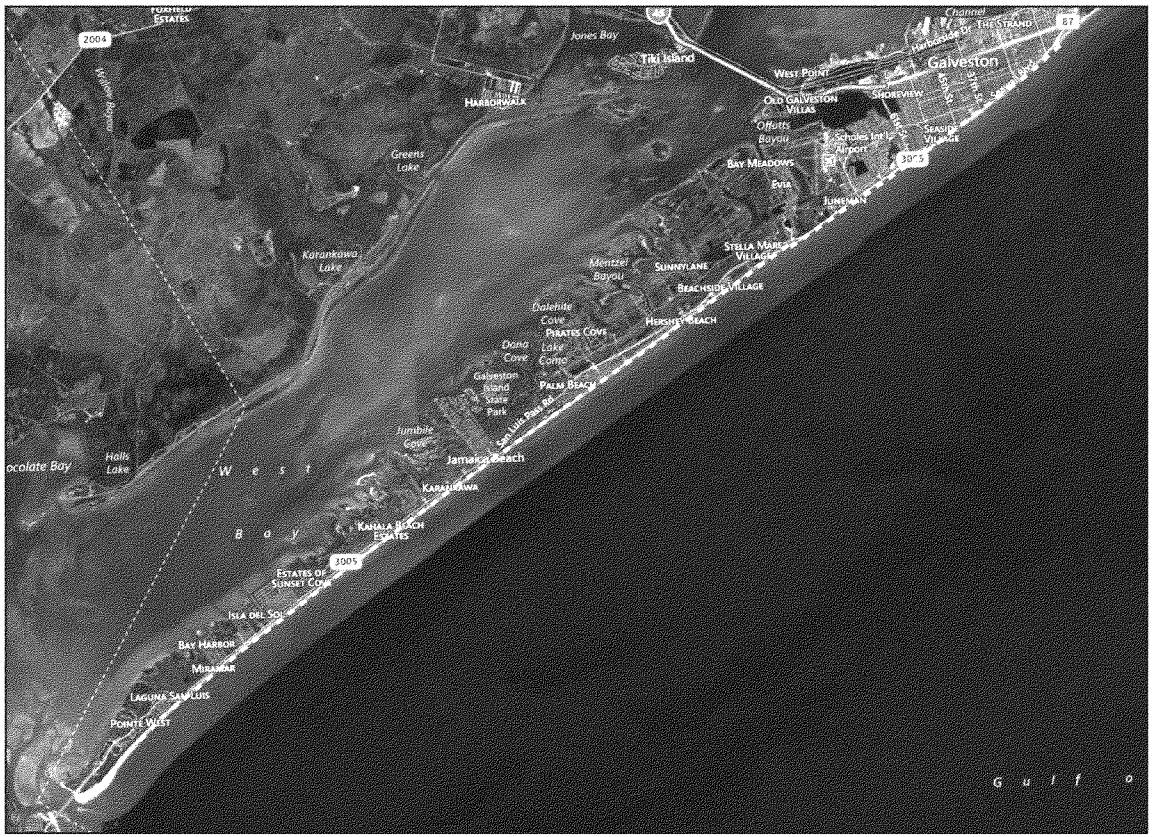
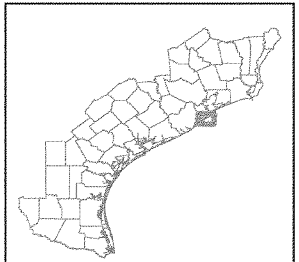
Date Created: 2/26/2013

Measure 5-9: Galveston County - Segmented Near-Shore Breakwaters





Legend

Breakwaters - West End

Breakwaters - East End

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0 3,150 6,300 12,600 18,900 25,200

Feet

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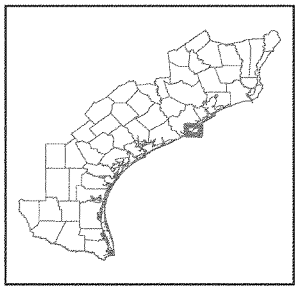
Date Created: 2/26/2013

Measure 5-15: Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria County



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Nearshore Breakwaters

Nearshore Breakwaters

0 2,800 5,600 11,200 16,800 22,400 Feet

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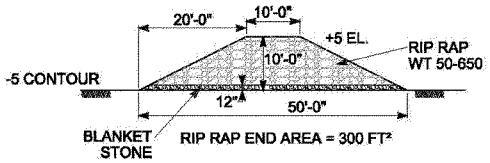
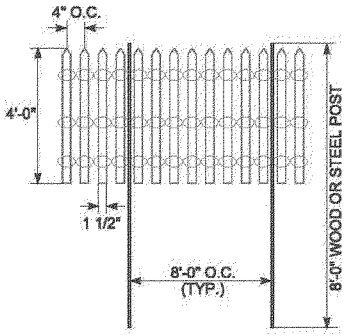
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

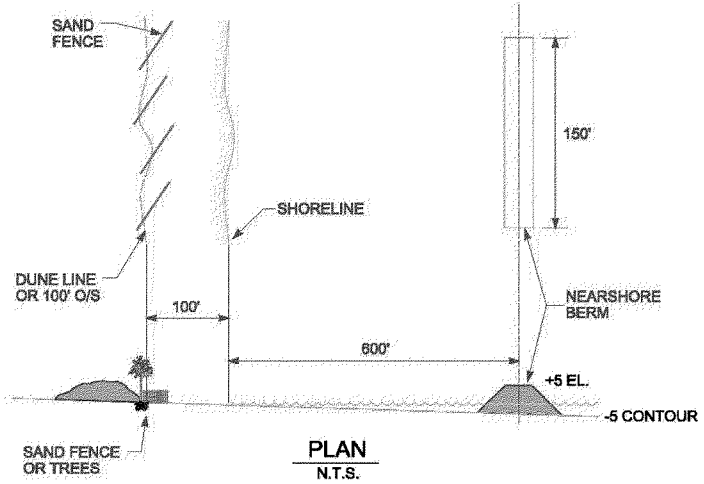
Typical Section S-11 Near Shore Segmented Breakwater



NEARSHORE BERM
N.T.S.

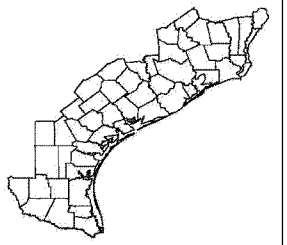


SAND FENCE - TYPICAL
N.T.S.



PLAN
N.T.S.

ASSUMPTIONS:
1: BREAKWATER IS PLACED AT -5' CONTOUR
2: BREAKWATER IS 150 FT LONG
3: BREAKWATERS ARE SPACED 300 FT APART
4: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH
5: TREE PLACED EVERY 15' OR SAND FENCE PLACED ALONG ESTABLISHED DUNE LINE OR 100' FROM EXISTING SHORELINE



Typical Section S-11

Measures:
5-5
5-9
5-15

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Date Created: 4/15/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURE 5-10
INFORMATION SHEET

DESCRIPTION OF MEASURE: 5-10 Closing of Rollover Pass, Galveston County

This measure would close Rollover Pass to prevent Gulf shoreline sediment from entering the pass and GIWW, to reduce USACE maintenance dredging requirements of the GIWW and to reduce accelerated beach erosion caused by the pass. It is proposed to discharge approximately 140,000 cubic yards of sand to fill Rollover Pass to match surrounding grades. The Texas General Land Office (GLO) is actively pursuing this measure and their application for a Section 10 and Section 404 permit has been approved.

LOCATION OF MEASURES (See attached drawing)
Measure 5-10: Close Rollover Pass, Galveston County

DESIGN ASSUMPTIONS

- One of the following sand sources: local Dredged Material Placement Areas (DMPAs), Rollover Bay (SWG-21755 and amendments) or the Gulf Intracoastal Waterway (GIWW) would provide the needed sand.
- DMPA 36 (see sheet 7 of 8) would utilize pumped material, aided by booster pumps placed in the GIWW, to relocate dredged material from the DMPA to Rollover Pass.

HYDRAULICS & HYDROLOGY

No H&H analysis was performed for this phase of the study.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

Measure 5-10 Closing Rollover Pass, Galveston County.
Total Estimated Real Estate Cost of Measure 5-10: $24,000 ®

ENVIRONMENTAL

In 1955, when Rollover Pass was mechanically dredged to create a new opening between the Gulf and Galveston Bay, it was permitted to a width of 80 feet and a depth of eight feet. However, strong tides almost immediately caused the pass to widen to 500 feet and 30 feet deep (currently the pass stands at 200 feet wide). Beach erosion on the Gulf side of the pass began almost immediately. This was illustrated in 1957 when 6,100 cubic feet of sand placed on the west side of the pass disappeared within four months. Much of this sand was sucked into the pass and deposited on its bay side. That erosion continues today, and sand that passes through Rollover Pass accumulates in the adjacent Gulf Intracoastal Waterway. USACE performs maintenance dredging every nine months with a reported cost of $1 million for each effort. Acres of environmental benefit (erosion prevented) would need to be determined by a regional sediment management study, which was not feasible for this phase of analysis.

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

The cost were provided Texas GLO. This cost does not include Real Estate.
The estimated cost for this measure is $6,849,000.

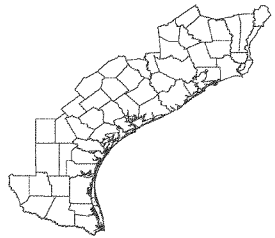
REFERENCE DOCUMENT

Set of preliminary plans dated FEB 2010 by Taylor Engineering Inc. - Texas GLO-Rollover Pass, SWG 2008-00833.

RISKS

- Public interest concerns over loss of recreational fishing could delay the approval process.
- Environmental benefits are not quantified.
- Economic benefits (i.e. reduction in maintenance dredging costs) have not been quantified.

Measure 5-10: Closing of Rollover Pass, Galveston County



Legend

Fill In Rollover Pass

0 165 330 660 990 1,320
Feet

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURE 5-16
INFORMATION SHEET

DESCRIPTION OF MEASURE 5-16 Groin at State Highway 332, Brazoria County

This measure would construct a groin extending into the Gulf at State Highway 332 in conjunction with the beach nourishment to keep the sediment in the system near eroding portions of Surfside beach. The measure would only be implemented in conjunction with Measure 5-12.

LOCATION OF MEASURES (See attached drawing)
Measure 5-16: Groin at State Highway 332, Brazoria County.

DESIGN ASSUMPTIONS

- Groin length is 600 LF

HYDRAULICS & HYDROLOGY:

An H&H analysis of this feature was conducted for Texas General Land Office by Coast and Harbor Engineering (2008).

REAL ESTATE REQUIREMENT

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

Measure 5-16: Groin at State Highway 332, Brazoria County
Total Estimated Real Estate Cost: $27,000 ®

ENVIRONMENTAL

There has been about 1,125 feet of erosion over the last 50 years along the Surfside shoreline within 1 mile from the East Jetty (CHE 2008). The erosion in the area near the jetty is increasing in large part because of the erosion and collapse of the Brazos River delta. The collapse of the delta is the result, in large part, of the construction of the Brazos River Diversion Channel, a USACE project completed in the 1930's. Erosion of the delta began immediately upon completion of the diversion, and the submerged delta face is now located close to shore, increasing wave energy on the Surfside shoreline. A groin structure at SH 332 would provide an

added erosion prevention measure in this area of higher wave attack. The net longshore transport at Surfside is to the northeast; sediments added with the shoreline nourishment would be caught by the groin and prevent the erosion of at least 50 additional acres over 50 years, above the estimated erosion prevented by Measure 5-12. This would prevent losses due to continuing erosion to the Surfside beach community.

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

Cost were provided by Texas GLO for similar work. This cost does not include Real Estate. The estimated cost for this measure is $3,983,000.

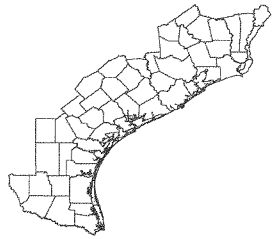
REFERENCE DOCUMENT

Coast and Harbor Engineering. 2008. Surfside Beach Shoreline Stabilization Feasibility Study. Coastal Engineering Analysis and Preliminary Design prepared for the General Land Office.

RISKS

- Little risk is associated with this measure because it is supported by a recent, well-documented feasibility study.

Measure 5-16: Groin at State Highway 332, Brazoria County



Legend

Groin

0 40 80 160 240 320

Feet

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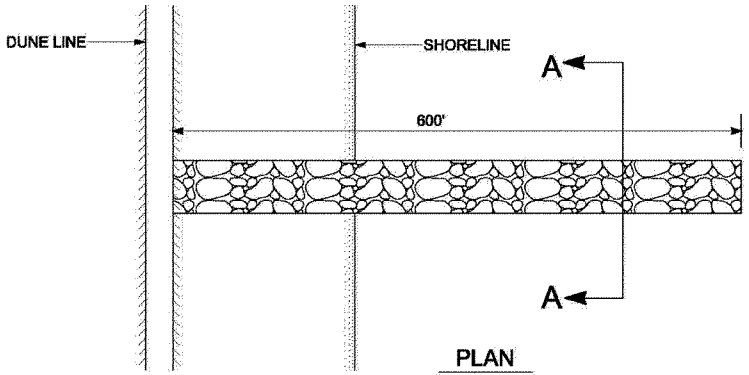
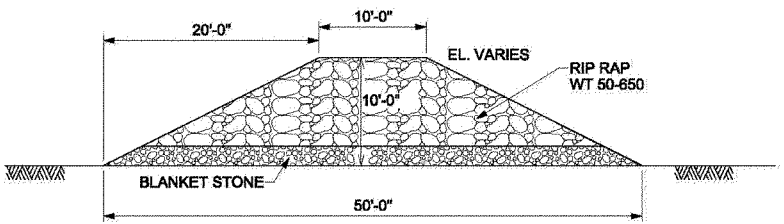
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-12: Groin at SH-332, Brazoria County



PLAN
N.T.S.



RIP RAP END AREA = 300 FT²

A
S-12 S-12

GROIN
N.T.S.

ASSUMPTIONS:
1: GROIN IS 600 FT LONG
2: GROIN SECTION IS CONSTANT
3: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH

Typical Section S-12

Measure:
5-16

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 6-1.1, 6-1.2, 6-2, 6-3, 6-4.1, 6-4.2, 6-5.1, 6-5.2, 6-5.3, 6-6.1, 6-6.2
INFORMATION SHEET

DESCRIPTION OF MEASURES

These measures focus on shoreline protection for the Gulf Intracoastal Waterway (GIWW). Since its construction, the GIWW has eroded to several times its original width. Two types of protection measures are proposed: shoreline breakwaters and barrier island restoration. These measures would prevent further erosion of the coastal marshes that attenuate storm surge.

Measure 6-1.1 GIWW Breakwater at Old River Cove, Orange County.
This measure would provide shoreline protection for the north shore of the GIWW at Lower Neches Wildlife Management Area, Old River Unit. An offset rock breakwater would be constructed following example of Ducks Unlimited breakwater design (SWG-2012-0077-in folder). See drawing S15 for breakwater typical section.

Measure 6-1.2 GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County.
This measure would restore islands that once protected the GIWW at the northern end of Sabine Lake in front of Old River Cove and Hickory Cove. See drawing S13 for breakwater typical section.

Measure 6-2 GIWW Breakwaters, Neches River to High Island, Jefferson County.
This measure would provide shoreline protection for the unprotected GIWW shoreline (north and/or south banks) in Jefferson and Chambers counties. See drawing S15 for breakwater typical section.

Measure 6-3 GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County.
This measure would restore an island that once protected the GIWW at the northern end of Sabine Lake at Pleasure Island. Island remnants exist to a varying degree. See drawing S13 for breakwater typical section.

Measure 6-4.1 GIWW Breakwaters, Bolivar Peninsula, Galveston County.
This measure would provide shoreline protection for the unprotected GIWW shorelines on the Bolivar Peninsula. See drawing S15 for breakwater typical section.

Measure 6-4.2 GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County. This measure would restore an island that once protected the GIWW in the Bolivar Peninsula. See drawing S13 for breakwater typical section.

Measure 6-5.1 GIWW Breakwaters, West Bay, Galveston County.
This measure would provide shoreline protection for the unprotected GIWW north shorelines in West Bay. See drawing S15 for breakwater typical section.

Measure 6-5.2 GIWW Barrier Island Restoration, West Bay 1, Galveston County
This measure would restore an island that once protected the GIWW in West Bay. Island remnants exist to a varying degree. See drawing S13 for breakwater typical section.

Measure 6-5.3 GIWW Barrier Island Restoration, West Bay 2, Galveston County
This measure would restore an island that once protected the GIWW in West Bay. Island remnants exist to a varying degree. See drawing S13 for breakwater typical section.

Measure 6-6.1 GIWW Breakwaters, Brazoria County
This measure would provide shoreline protection for unprotected GIWW shorelines in Brazoria County. See drawing S15 for breakwater typical section.

Measure 6-6.2 GIWW Barrier Island Restoration, West Bay, Brazoria County
This measure would restore an island that once protected the GIWW in West Bay, Brazoria County. Island remnants exist to a varying degree. See drawing S14 for breakwater typical section.

LOCATION OF MEASURES (See attached drawings)

Measures 6-1.2, 6-3, 6-4.2, 6-5.2, 6-5.3, 6-6.2:
Typical Section S-13: GIWW Shore Protection Island Restoration
Measures 6-5.2, 6-5.3, 6-6.2: Typical Section S-14: Levee Armor
Measures 6-1,2, 6-2, 6-4.1, 6-5.1, 6-6.1: Typical Section S-15: GIWW Shore Protection
Measure 6-1.1: GIWW Breakwater at Old River Cove, Orange County
Measure 6-1.2: GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County
Measure 6-2: GIWW Breakwaters, Neches River to High Island, Jefferson County
Measure 6-3: GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County
Measure 6-4.1: GIWW Breakwaters, Bolivar Peninsula, Galveston County
Measure 6-4.2: GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County
Measure 6-5.1: GIWW Breakwaters, West Bay, Galveston County
Measure 6-5.2: GIWW Barrier Island Restoration, West Bay 1, Galveston County

Measure 6-5.3: GIWW Barrier Island Restoration, West Bay 2, Galveston County
Measure 6-6.1: GIWW Breakwaters, Brazoria County
Measure 6-6.2: GIWW Barrier Island Restoration, West Bay, Brazoria County

DESIGN ASSUMPTIONS

Measure 6-1.1

- Construct offset rock breakwater following example of Mad Island Marsh or Ducks Unlimited breakwater design to protect GIWW at Sargent Marsh (SWG-2012-0077-in folder).
- Breakwater would be placed sufficiently far from GIWW centerline for safe navigation.
- Constructed in depths of approx - 1.5 ft MSL with 8-inch graded riprap.
- Should allow fisheries access and circulation sufficient for accumulation of sediment behind breakwater.
- Breakwater length - 17,400 ft. Volume = 65,733 CY.

Measure 6-1.2

- Containment levee is needed to be constructed to hold hydraulic material until it settles.
- Levee length = 17,400 ft; Volume = 65,733 CY.

Measure 6-2

- Design should allow fisheries access and circulation sufficient for accumulation of sediment behind the breakwater.
- These measures could include "living shorelines" concepts (reef block, oyster bags, etc), but for initial screening, assume offset breakwaters like Mad Island or Sargent marshes.
- Total breakwater shoreline coverage is approximately 159,800 ft. Volume = 603,689 CY.

Measure 6-3

- Containment levee would need to be constructed to hold hydraulic material until it settles.
- Levee length – 10,200 ft Volume = 87,644 CY.
- Island area 42 acres. Volume of fill 271,040 CY.

Measure 6-4.1

- Design should allow fisheries access and circulation sufficient for accumulation of sediment behind the breakwater.
- These measures could include "living shorelines" concepts (reef block, oyster bags, etc), but for initial screening, assume offset breakwaters like Mad Island or Sargent marshes.
- Total breakwater shoreline coverage is approximately 124,825 ft. Volume = 471,561 CY.

Measure 6-4.2

- Containment levee is necessary (type of dike, source of fill material, and existing bottom elevation to be determined by Engineering).
- Levee would need to be constructed to hold hydraulic material until it settles.
- Levee length - 20,500 ft. Volume = 176,148 CY.
- Island area = 200 acres. Fill volume = 113,056 CY.

Measure 6-5.1

- Should allow fisheries access and circulation sufficient for accumulation of sediment behind breakwater.
- These measures could include "living shorelines" concepts (reef block, oyster bags, etc), but for initial screening, assume offset breakwaters like Mad Island or Sargent marshes.
- Total breakwater shoreline coverage is approximately 38,215 ft. Volume = 144,368 CY.

Measure 6-5.2

- Containment levee is necessary (type of dike, source of fill material, and existing bottom elevation to be determined by Engineering).
- Armoring needed on bay and GIWW sides.
- Levee would need to be constructed to hold hydraulic material until it settles.
- Levee length - 18,900 ft; Volume = 162,400 CY
- Island area - 58 acres. Volume of fill 374,293 CY.
- Riprap shore protection. Length = 18,900. 28,300 tons.

Measure 6-5.3

- Containment levee is necessary, (Armoring needed on bay and GIWW sides).
- Levee would need to be constructed to hold hydraulic material until it settles.
- Levee length - 7,600 ft; Volume = 65,304 CY.
- Island area = 14 acres. Volume of fill is 90,347 CY
- Fill material obtained from GIWW.

Measure 6-6.1

- Should allow fisheries access and circulation sufficient for accumulation of sediment behind breakwater.

- These measures could include "living shorelines" concepts (reef block, oyster bags, etc), but for initial screening, assume offset breakwaters like Mad Island or Sargent marshes.
- Total breakwater shoreline length is approximately 191,235 ft. Volume = 722,443 CY.

Measure 6-6.2

- Containment levee is necessary, (Armoring needed on bay and GIWW sides).
- Levee would need to be constructed to hold hydraulic material until it settles.
- Levee length - 33,400 ft; Volume = 286,993 CY.
- Island area = 120 acres. Fill volume = 774,400 CY.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'. Costs identified as $0 are generally associated with Federal and/or State lands.

- Measure 6-1.1: GIWW Breakwater at Old River Cove, Orange County
  Total Estimated Real Estate Cost: $0
- Measure 6-1.2: GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County
  Total Estimated Real Estate Cost: $0
- Measure 6-2: GIWW Breakwaters, Neches River to High Island, Jefferson County
  Total Estimated Real Estate Cost: $0
- Measure 6-3: GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County
  Total Estimated Real Estate Cos: $0
- Measure 6-4.1: GIWW Breakwaters, Bolivar Peninsula, Galveston County
  Total Estimated Real Estate Cost: $0
- Measure 6-4.2: GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County
  Total Estimated Real Estate Cost: $0
- Measure 6-5.1: GIWW Breakwaters, West Bay, Galveston Island
  Total Estimated Real Estate Cost: $0
- Measure 6-5.2: GIWW Barrier Island Restoration, West Bay 1, Galveston County
  Total Estimated Real Estate Cost: $0
- Measure 6-5.3: GIWW Barrier Island Restoration, West Bay 2, Galveston County
  Total Estimated Real Estate Cost: $0
- Measure 6-6.1: GIWW Breakwaters, Brazoria County
  Total Estimated Real Estate Cost: $0
- Measure 6-6.2: GIWW Barrier Island Restoration, West Bay, Brazoria County

Total Estimated Real Estate Cost: $0

ENVIRONMENTAL

Offset breakwaters and barrier islands would be constructed along the GIWW to stop shoreline erosion. Environmental benefits for the breakwater measures are based on the acres of erosion that would be prevented over the 50-year period of analysis. The 50-year estimate of acres lost was developed by measuring shoreline loss over specific time periods using Google Earth. The shorelines of the GIWW are largely undeveloped and therefore protected areas are assumed to be wetland marshes. Environmental benefits of the island restoration measures were calculated as the sum of the restored island acres and acres of erosion prevented on the mainland shoreline over the 50 year period of analysis. Some of these measures would protect portions of several National Wildlife Refuges and Wildlife Management Areas.

Measure Description	Acres of Erosion Prevented Over 50 Years
Measure 6-1.1 (GIWW Breakwater at Old River Cove, Orange County)	50
Measure 6-1.2 (GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County)	131
Measure 6-2 (GIWW Breakwaters, Neches River to High Island, Jefferson County)	761
Measure 6-3 (GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County)	64
Measure 6-4.1 (GIWW Breakwaters, Bolivar Peninsula, Galveston County)	867
Measure 6-4.2 (GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County)	246
Measure 6-5.1 (GIWW Breakwaters, West Bay, Galveston County)	222
Measure 6-5.2 (Brazos River to Brazos River Diversion Channel)	112
Measure 6-5.3 (GIWW Barrier Island Restoration, West Bay 2, Galveston County)	35
Measure 6-6.1 (GIWW Breakwaters, Brazoria County)	1,110
Measure 6-6.2 (GIWW Barrier Island Restoration, West Bay, Brazoria County)	215

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

These costs do not include Real Estate.

Measure 6-1.1: The estimated cost for this measure is $20,480,000
Measure 6-1.2: The estimated cost for this measure is $10,215,000
Measure 6-2: The estimated cost for this measure is $181,509,000
Measure 6-3: The estimated cost for this measure is $3,542,000
Measure 6-4.1: The estimated cost for this measure is $141,782,000
Measure 6-4.2: The estimated cost for this measure is $10,017,000
Measure 6-5.1: The estimated cost for this measure is $43,406,000
Measure 6-5.2: The estimated cost for this measure is $9,764,000
Measure 6-5.3: The estimated cost for this measure is $4,037,000
Measure 6-6.1: The estimated cost for this measure is $219,877,000
Measure 6-6.2: The estimated cost for this measure is $18,202,000

Cost assumptions for Breakwater measures: 6-1.1, 6-2, 6-4.1, 6-5.1, and 6-6.1 :

- Riprap will be barged in to site.
- A 9 ft deep flow channel will need to be excavated to bring in the rock barge.
- Riprap will be placed from the barge.
- A standard 25% contingency, E&D of 8%, and CM of 6% were added to the cost.

Cost assumption for Island measures : 6-1.2, 6-4.2, 6-5.2, 6-5.3, and 6-6.2:

- Riprap will be barged in to site.
- A 9 ft deep flow channel will need to be excavated to bring in the rock barge.
- Riprap will be placed from the barge.
- Levee fill is side cast from access channel construction and loosely placed non-compacted shaped to levee template.
- The island interior is filled 4 feet deep with dredge material.
- Island dredge fill will be from maintenance material from GIWW, along side of the island, and 12,000 LF on each side.
- A standard 25% contingency, E&D of 8%, and CM of 6% were added to the cost.

REFERENCE DOCUMENT

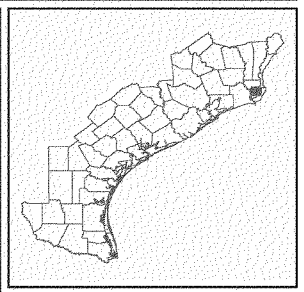
DU permit IR SWG 2012-0077 at GIWW-Sargent Marsh

RISKS

- Geotechnical and structural feasibility of the proposal was not reviewed.

- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.

Measure 6-1.1 and 6-1.2 - Breakwater and Barrier Island Restoration - Orange County



Legend

Breakwater

Barrier Island Restoration

N

0 1,350 2,700 5,400 8,100 10,800

Feet

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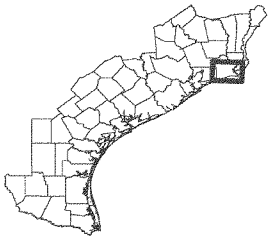
Date Created: 4/11/2013

Measure 6-2 - GIWW Breakwaters, Neches River to High Island, Jefferson County



Legend

GIWW Breakwaters

0 5,500 11,000 22,000 33,000 44,000

Feet

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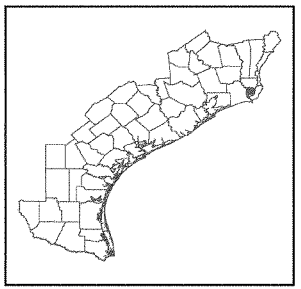
Date Created: 4/11/2013

Measure 6-3 - GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County



Legend

Barrier Island Restoration

0 750 1,500 3,000 4,500 6,000

Feet

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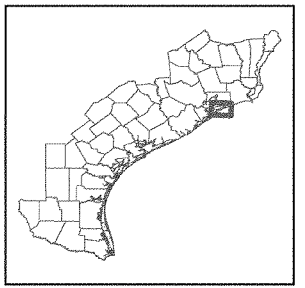
Date Created: 4/11/2013

Measure 6-4.1 - GIWW Breakwaters, Bolivar Peninsula, Galveston County



Legend

GIWW Breakwaters

0 3,850 7,700 15,400 23,100 30,800 Feet

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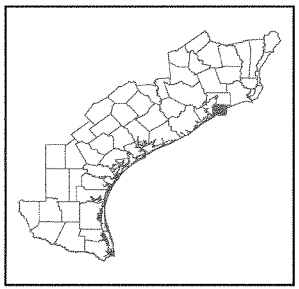
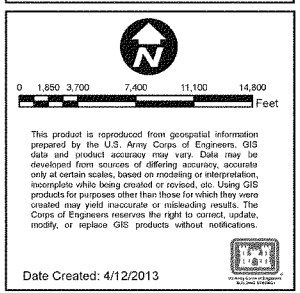
Date Created: 4/12/2013

Measure 6-4.2 - GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County



Legend

Barrier Island Restoration



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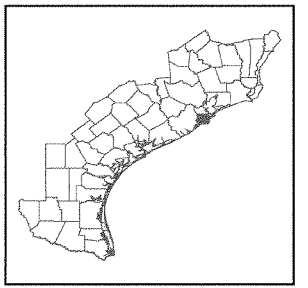
Date Created: 4/12/2013

Measure 6-5.1 - GIWW Breakwaters, West Bay, Galveston County



Legend

GIWW Breakwaters

0 1,625 3,250 6,500 9,750 13,000 Feet

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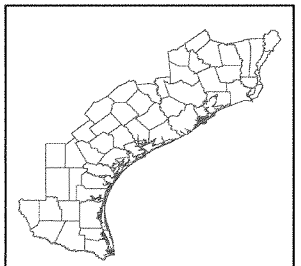
Date Created: 4/12/2013

Measure 6-5.2 - GIWW Barrier Island Restoration, West Bay 1, Galveston County



Legend

Barrier Island Restoration

N

0 900 1,800 3,600 5,400 7,200

Feet

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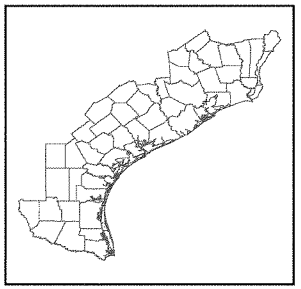
Date Created: 4/12/2013

Measure 6-5.3 - GIWW Barrier Island Restoration, West Bay 2, Galveston County



Legend

Barrier Island Restoration

0 462.5 925 1,850 2,775 3,700
Feet

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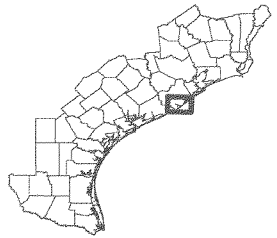
Date Created: 4/12/2013

Measure 6-6.1 - GIWW Breakwaters, Brazoria County



Legend

GIWW Breakwaters

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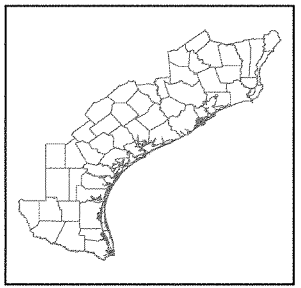
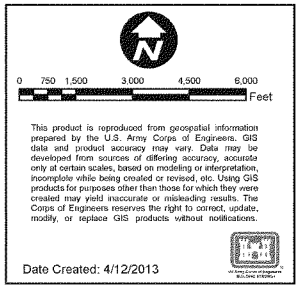
Date Created: 4/12/2013

Measure 6-6.2 - GIWW Barrier Island Restoration, West Bay, Brazoria County



Legend

Barrier Island Restoration



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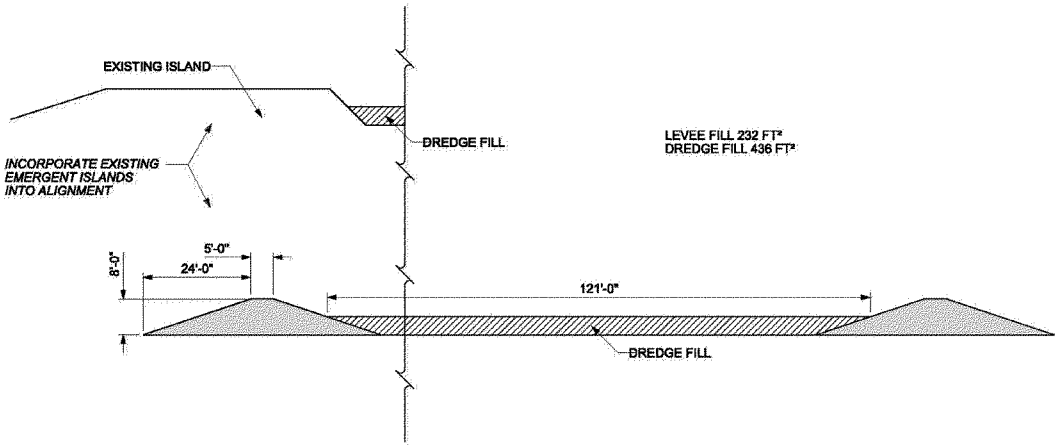
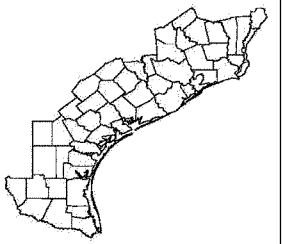
Date Created: 4/12/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-13: GIWW Shore Protection Island Restoration



ASSUMPTIONS:
1: LEVEE FILL IS LOOSELY PLACED NON COMPACTED
2: LEVEE FILL IS SIDE CAST FROM ACCESS CHANNEL CONSTRUCTION
3: LEVEE TEMPLATE IS FOUNDED ON THE -4FT CONTOUR
4: DREDGE FILL IS A UNIFORM 4FT THICKNESS
5: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH
6: INCORPORATE EXISTING EMERGENT ISLANDS INTO ALIGNMENT



Typical Section S-13

Measure:
6-1.2
6-3
6-4.2
6-5.2 (Existing Islands)
6-5.3 (Existing Islands)
6-6.2
7-3 (Existing Islands)

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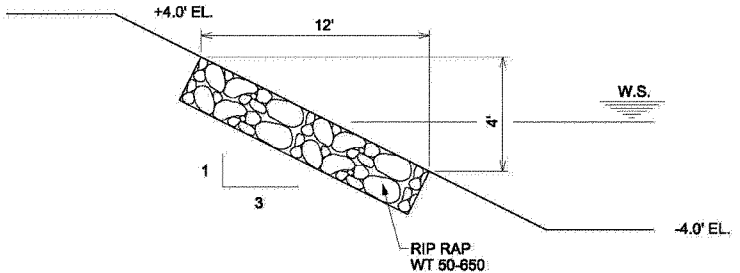
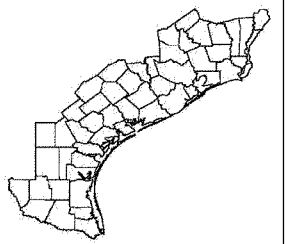
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-14: Levee Armor





Typical Section S-14

Measures:
6-5.2
6-5.3
6-6.2

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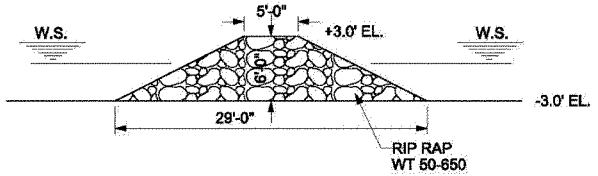
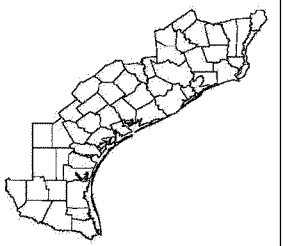
Date Created: 4/24/2013

Typical Section S-15: GIWW Shore Protection



RIP RAP END AREA = 102 FT²

ASSUMPTIONS:
1: BREAKWATER IS PLACED IN 3 FT DEEP WATER
2: BREAKWATER IS CONTINUOUS
3: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH



Typical Section S-15

Measures:
6-1.1
6-2
6-4.1
6-5.1
6-6.1
7-1
7-2
8-4
8-6
8-7

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 7-1, 7-2, 7-3
INFORMATION SHEET

DESCRIPTION OF MEASURES

Measure 7-1 Shoreline Protection, East Bay, Chambers County.
This measure would install shoreline protection along 22 miles of East Bay shoreline, north shore of East Bay. See drawing S-15 for breakwater typical section. The measure would allow fisheries access and circulation sufficient for accumulation of sediment behind breakwater.

Measure 7-2 Shoreline Protection, Bastrop Bay, Brazoria County.
This measure would install shoreline protection along 3.2 miles of Bastrop Bay. See drawing S-15 for breakwater typical section. The measure would allow fisheries access and circulation sufficient for accumulation of sediment behind breakwater.

Measure 7-3 Island Restoration, Vingt-et-un, Chambers County.
This measure would reconstruct islands that formerly protected Smith Point from wave attack. A containment levee would be constructed and filled to reestablish the island. A levee would need to be constructed to hold hydraulic material in place until it settles. See Drawing S-13 for Island Restoration typical section.

LOCATION OF MEASURES (See attached drawings)

Measure 7-1: East Bay Shoreline Protection, Chambers County
Measure 7-2: Bastrop Bay Shoreline Protection, Brazoria County
Measure 7-3: Vingt-et-un Island Restoration, Chamber County
Measures 7-1, 7-2: Typical Section S-15: GIWW Shore Protection
Measure 7-3: Typical Section S-13: GIWW Shore Protection Island Restoration

DESIGN ASSUMPTIONS

Measure 7-1:

- Should allow fisheries access and circulation sufficient for accumulation of sediment behind the breakwater.
- Breakwater is placed in 3 feet deep water.
- Breakwater is continuous for the entire length (not segmented). Length = 116,640 ft (22 mi).
- Volume is based on cross sectional area multiplied by total length. Volume = 440,640 CY.

- Riprap size is W50-650.
- Quantities are neat line, settlement not accounted for.
- Access channel is 9 feet deep and 50 feet wide with 1:1 side slopes, excavated material is side cast and left in place.

Measure 7-2:

- Should allow fisheries access and circulation sufficient for accumulation of sediment behind breakwater.
- Breakwater is placed in 3 feet deep water.
- Breakwater is continuous for entire length (not segmented). Length = 17,370 ft.
- Volume is based on cross sectional area multiplied by total length. Volume = 65,620 CY.
- Riprap size is W50-650.
- Quantities are neat line, settlement not accounted for.
- Access channel is 9 feet deep and 50 feet wide with 1:1 side slopes, excavated material is side cast and left in place.

Measure 7-3:

- Levee fill is side cast from access channel construction and loosely placed non-compacted shaped to levee template.
- Levee template is founded on the -4 foot contour. Length = 33,400 ft.
- Levee volume is based on cross sectional area multiplied by total length. Volume = 286,993 CY.
- Quantities are neat line, settlement not accounted for.
- Access channel is 9 feet deep and 50 feet wide with 1:1 side slopes, excavated material used for levee template.
- Containment levee can tie into existing islands.
- Island area is 27 and interior dredge fill is 4 feet deep. The area fill volume is 332,037 CY.
- Island dredge fill from maintenance material from Channel to Liberty along side of island and 12,000 LF on each side.
- No erosion protection applied to outside of levees.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'. Costs identified as $0 are associated with Federal navigational servitude.

- Measure 7-1: Shoreline Protection, East Bay, Chambers County

Total Estimated Real Estate Cost of Measure 7-1: $0

- Measure 7-2: Shoreline Protection, Bastrop Bay, Brazoria County

Total Estimated Real Estate Cost of Measure 7-2: $0

- Measure 7-3: Island Restoration, Vingt-et-un, Chambers County

Total Estimated Real Estate Cost of Measure 7-3: $5,000 ®

ENVIRONMENTAL

For measures 7-1 and 7-2, environmental benefits are presented in wetland acres that would be protected by this measure. The wetland acres were calculated with a GIS analysis of National Wetland Inventory wetland maps (USFWS, 2012).

Measure 7-1 would protect the north shore of East Bay which has experienced a shoreline erosion rate of up to 4.5 feet per year since 1970. The breakwaters would protect the shoreline of the Moody and Anahuac National Wildlife Refuges (NWR) and the Candy Abshier Wildlife Management Area, preventing the erosion of approximately 600 wetland acres over the 50 year period of analysis.

Measure 7-2 would protect the west shore of Bastrop Bay. Nearshore breakwaters would be constructed along the shorelines of Bastrop Bay which has experienced erosion of up to 2 feet per year since 1943. This erosion is threatening to open the bay to the more saline waters of the GIWW. The breakwaters would protect the shoreline of the Brazoria NWR and prevent the erosion of approximately 40 wetland acres over the 50 year period of analysis, while maintaining the protected shallow bay aquatic environment.

Measure 7-3 would restore the Vingt-et-Un Islands which once protected Smith Point from wave attack erosion. The total acreage of the restored islands would be 27 acres. There was no attempt to calculate erosion that would be prevented based on restoration of the islands.

COSTS:

These cost do not include real estate cost.

Measure 7-1: The estimated cost for this measure is $137,121,000.
Measure 7-2: The estimated cost for this measure is $20,420,000.
Measure 7-3: The estimated cost for this measure is $5,381,000.

Cost assumptions for Measures 7-1 and 7-2:

- Riprap will be barged in to site.
- A 9 ft deep flow channel will need to be excavated to bring in the rock barge.
- Riprap will be placed from the barge.

Cost assumptions for Measure 7-3:

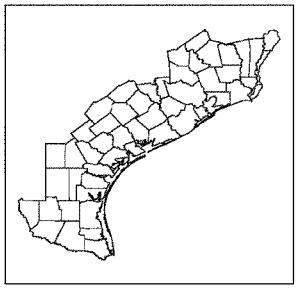
- Riprap will be barged in to site.
- A 9 ft deep flow channel will need to be excavated to bring in the rock barge.
- Riprap will be placed from the barge
- Levee fill is side cast from access channel construction and loosely placed non-compacted shaped to levee template.
- Island interior is filled with dredge material 4 feet deep.
- Island dredge fill will be from maintenance material from GIWW along side of island and 12,000 LF on each side.
- A standard 25% contingency, E&D of 8%, and CM of 6% were added to the cost.

RISKS:

- Geotechnical and structural feasibility of the proposal was not reviewed.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 7: Bay Shoreline Protection and Island Restoration, Chambers and Brazioria Counties



Legend

Measure 7

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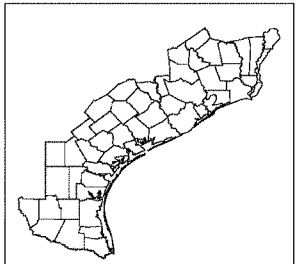
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 7-1: Shoreline Protection, East Bay, Chambers County



Legend

Measure 7-1

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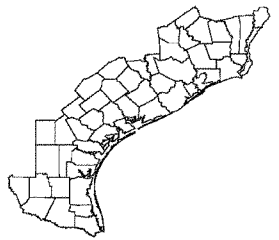
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 7-2: Shoreline Protection, Bastrop Bay, Brazoria County



Legend

Measure 7-2

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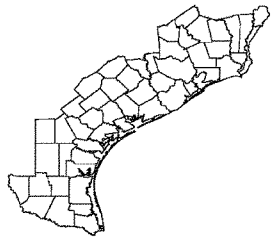
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 7-3: Island Restoration, Vingt-et-un, Chambers County



Legend

Measure 7-3

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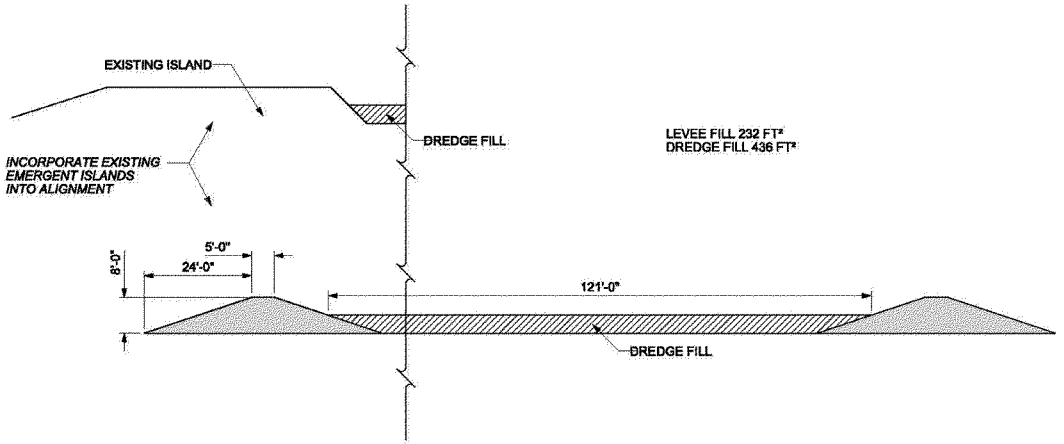
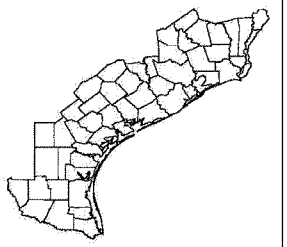
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-13: GIWW Shore Protection Island Restoration



ASSUMPTIONS:
1: LEVEE FILL IS LOOSELY PLACED NON COMPACTED
2: LEVEE FILL IS SIDE CAST FROM ACCESS CHANNEL CONSTRUCTION
3: LEVEE TEMPLATE IS FOUNDED ON THE -4FT CONTOUR
4: DREDGE FILL IS A UNIFORM 4FT THICKNESS
5: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH
6: INCORPORATE EXISTING EMERGENT ISLANDS INTO ALIGNMENT



Typical Section S-13

Measure:
6-1.2
6-3
6-4.2
6-5.2 (Existing Islands)
6-5.3 (Existing Islands)
6-6.2
7-3 (Existing Islands)

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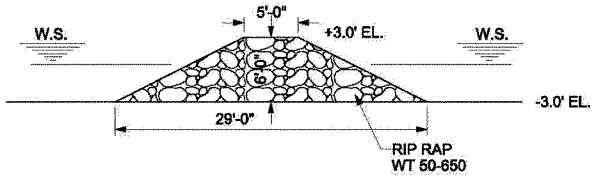
Date Created: 4/24/2013

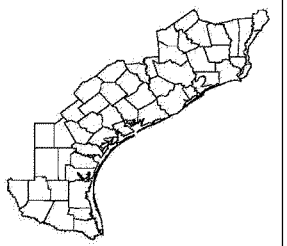
Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-15: GIWW Shore Protection



RIP RAP END AREA = 102 FT²

ASSUMPTIONS:
1: BREAKWATER IS PLACED IN 3 FT DEEP WATER
2: BREAKWATER IS CONTINUOUS
3: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH



Typical Section S-15

Measures:
6-1.1
6-2
6-4.1
6-5.1
6-6.1
7-1
7-2
8-4
8-6
8-7

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURE 8-1, 8-2, 8-3
INFORMATION SHEET

DESCRIPTION OF MEASURES

These measures would restore large, degraded marsh systems on the Neches River. The restored marshes would attenuate storm surge and reduce impacts to communities such as Bridge City and Vidor, which are located on the river terraces north of the marshes.

Measure 8-1 Marsh Restoration, Bessie Heights East , Orange County
This measure would restore 679 acres of brackish and 1,190 acres of intermediate marsh, 660 acres of shallow-water habitat, and nourish 651 acres of existing marsh. The total influence area is 3,180 acres.

Measure 8-2 Marsh Restoration, Old River Cove , Orange County.
This measure would restore 639 acres of brackish marsh, 139 acres of shallow-water habitat, and nourish 432 acres of existing marsh. The total influence area is 1,210 acres.

Measure 8-3 Marsh Restoration, Rose City East, Orange County.
This measure would restore 345 acres of fresh marsh, 72 acres of shallow water, and nourish 151 acres of existing marsh. The total influence area is 568 acres.

LOCATION OF MEASURES 8-1, 8-2, 8-3 (See attached drawings)

Measure 8-1 Marsh Restoration, Bessie Heights East , Orange County
Measure 8-2 Marsh Restoration, Old River Cove, Orange County
Measure 8-3 Marsh Restoration, Rose City East, Orange County

DESIGN ASSUMPTIONS

- Marshes would be constructed with maintenance material from Sabine-Neches Waterway (SNWW), Neches River Channel.
- The costs were originally developed for the SNWW Feasibility Report, and updated to current price levels.
- A standard 25% contingency, E&D of 8%, and CM of 6% were added to the cost.
- Containment levees would be constructed with in-situ material.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'.

- Measure 8-1: Marsh Restoration, Bessie Heights East, Orange County
  Total Estimated Real Estate Cost: $1,145,000 ®

- Measure 8-2: Marsh Restoration, Old River Cove, Orange County
  Total Estimated Real Estate Cost: $440,000 ®

- Measure 8-3: Marsh Restoration, Rose City East, Orange County
  Total Estimated Real Estate Cost: $205,000 ®

ENVIRONMENTAL

Badly degraded marshes on the Neches River would be restored using maintenance material from the SNWW – Neches River Channel. Environmental benefits are based upon the total acreage influenced by the beneficial use of dredged material. Some of the existing, open water areas would be converted to emergent marsh, existing marsh would be nourished with the fine-grained material in the effluent, and deeper water areas would be improved by the creation of shallower waters which are more suitable for submerged aquatic vegetation. Measures 8-1 and 8-3 would restore portions of the Lower Neches Wildlife Management Area (Nelda Stark and Old River Units).

Measure Description	Acres of Restored Marsh System
Measure 8-1 (Marsh Restoration, Bessie Heights East , Orange County)	2,076
Measure 8-2 (Marsh Restoration, Old River Cove , Orange County)	1,210
Measure 8-3 (Marsh Restoration, Rose City East , Orange County)	568

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

These costs do not include any real estate costs.

Measure 8-1: The estimated cost for this measure is $176,542,450.
Measure 8-2: The estimated cost for this measure is $23,365,000.
Measure 8-3: The estimated cost for this measure is $25,627,501.

The following cost assumptions were made for measure 8-1, 8-2, and 8-3:

- The costs were originally developed for the SNWW Feasibility Report, and updated to current price levels.
- A standard 25% contingency, E&D of 8%, and CM of 6% were added to the cost.

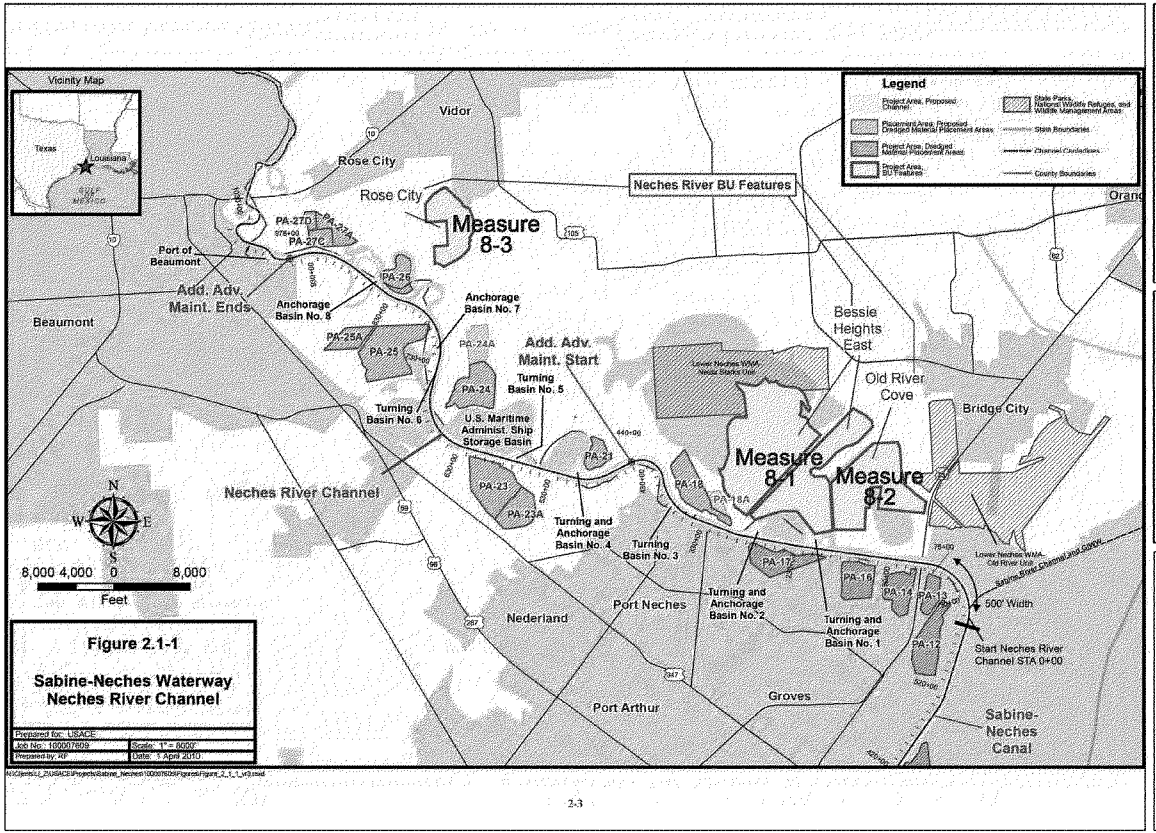
REFERENCE DOCUMENTS

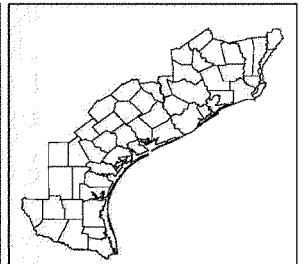
USACE. 2011. Final Feasibility Study and Environmental Impact Statement for the Sabine-Neches Waterway Channel Improvement Project, Southeast Texas and Southwest Louisiana. Galveston District.

RISKS

- Geotechnical and structural feasibility of the proposal was not reviewed.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.
- Implementation of this measure would require a revised Dredged Material Management Plan (DMMP) for the existing SNWW navigation project. Additional document preparation and coordination through USACE O&M would likely be required.

Measure 8-1 8-2 8-3:Marsh Restorations, Bessie Heights, Old River Cove, and Rose City





Legend

Measure

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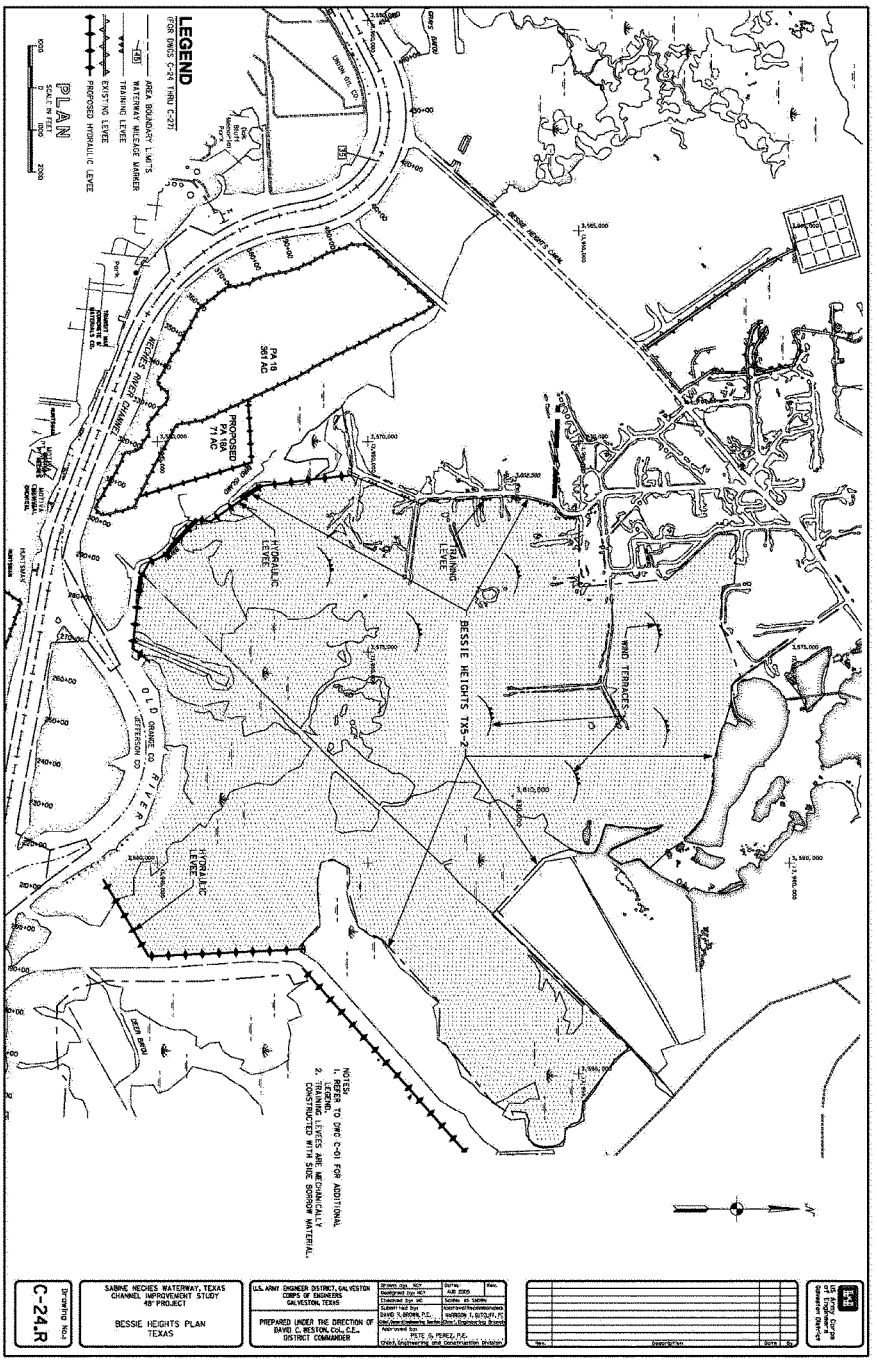
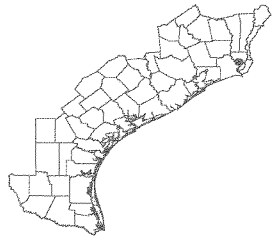
Date Created: 4/11/2013


LEGEND
(FOR DWGS C-24 THRU C-27)
AREA BOUNDARY LIMITS
WATERWAY MILEAGE MARKER
TRAINING LEVEE
EXISTING LEVEE
PROPOSED HYDRAULIC LEVEE
PLAN
SCALE IN FEET
BESSIE HEIGHTS TXS-2
HYDRAULIC LEVEE
TRAINING LEVEE
WIND TERRACES
PROPOSED PA 19 351 AC
PA 19 351 AC
OLD ORANGE CO
JEFFERSON CO
NECHES RIVER
NOTES:
1. REFER TO DWG C-01 FOR ADDITIONAL LEGEND.
2. TRAINING LEVEES ARE MECHANICALLY CONSTRUCTED WITH SIDE DUMPED MATERIAL.
SABINE NECHES WATERWAY, TEXAS
CHANNEL IMPROVEMENT STUDY
40' PROJECT
BESSIE HEIGHTS PLAN
TEXAS
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF
DAVID C. WESTON, COL, C.E.
DISTRICT COMMANDER
DAVID T. BROWN, P.E.
PETE G. PEREZ, P.E.
Chief, Engineering and Construction Division
C-24.R

Measure 8-1 - Marsh Restoration, Bessie Heights, Orange County



Legend

Marsh Restoration

0 550 1,100 2,200 3,300 4,400

Feet

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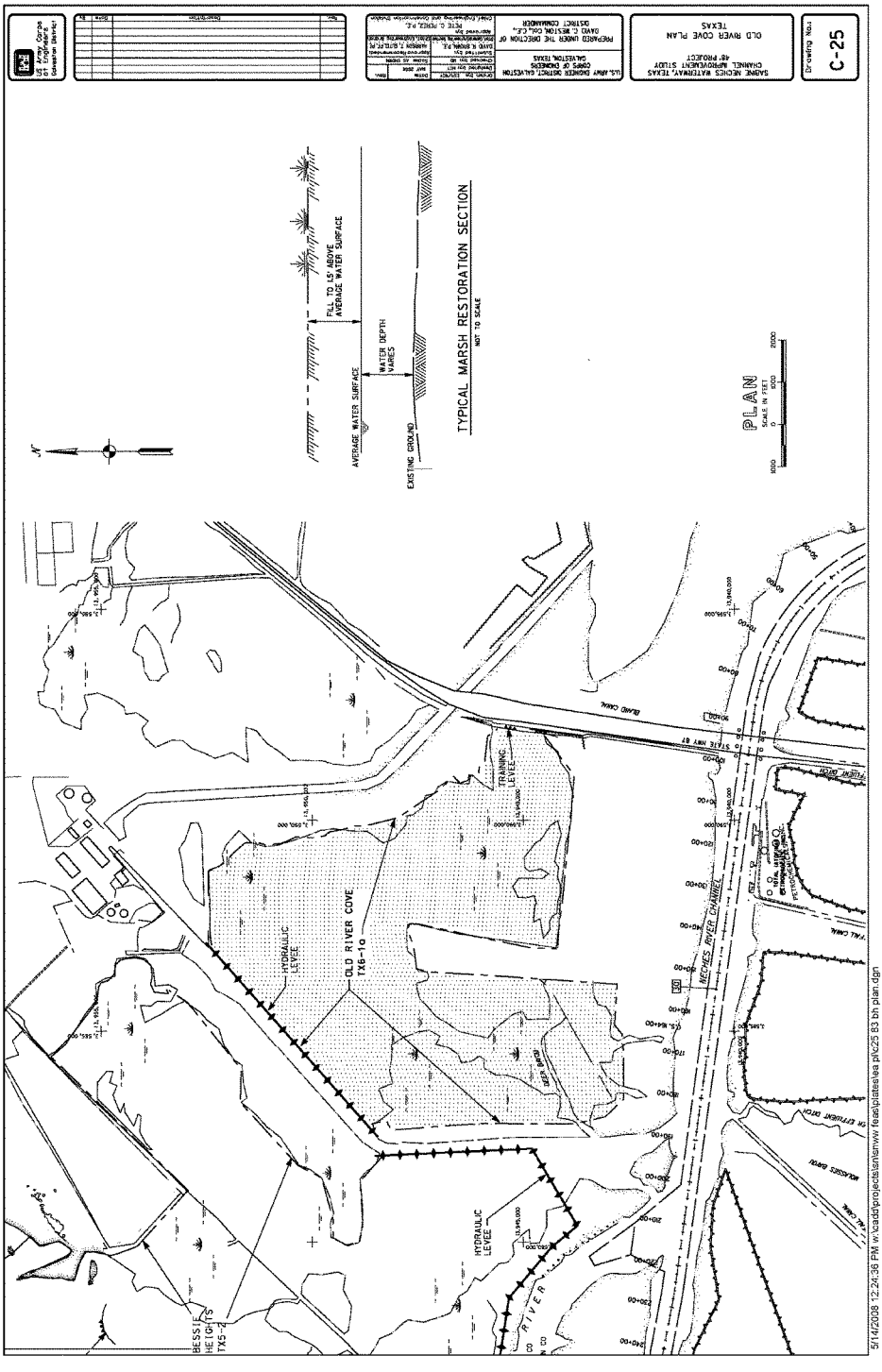
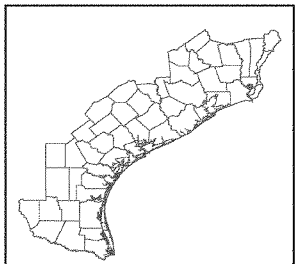
Date Created: 4/12/2013

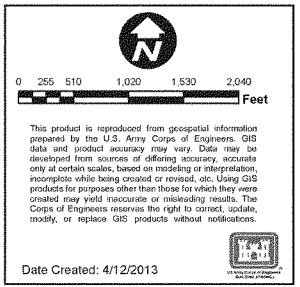

SABINE NECHES WATERWAY, TEXAS
CHANNEL IMPROVEMENT STUDY
AT PROJECT
OLD RIVER COVE PLAN
TEXAS
C-25
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF
DAVID C. BOYLAN, COL, C.E.
DISTRICT COMMANDER
TYPICAL MARSH RESTORATION SECTION
NOT TO SCALE
FILL TO 1.5' ABOVE AVERAGE WATER SURFACE
AVERAGE WATER SURFACE
WATER DEPTH VARIES
EXISTING GROUND
PLAN
SCALE IN FEET
OLD RIVER COVE
TX6-10
HYDRAULIC LEVEE
TRAINING LEVEE
NECHES RIVER CHANNEL
BESSIE HEIGHTS
TX5-4
BLIND CHANNEL
STATE HWY 87
5/14/2008 12:24:36 PM w:\cadd\projects\sns\wvw files\plates\wa pl\c25 83 bh plan.dgn

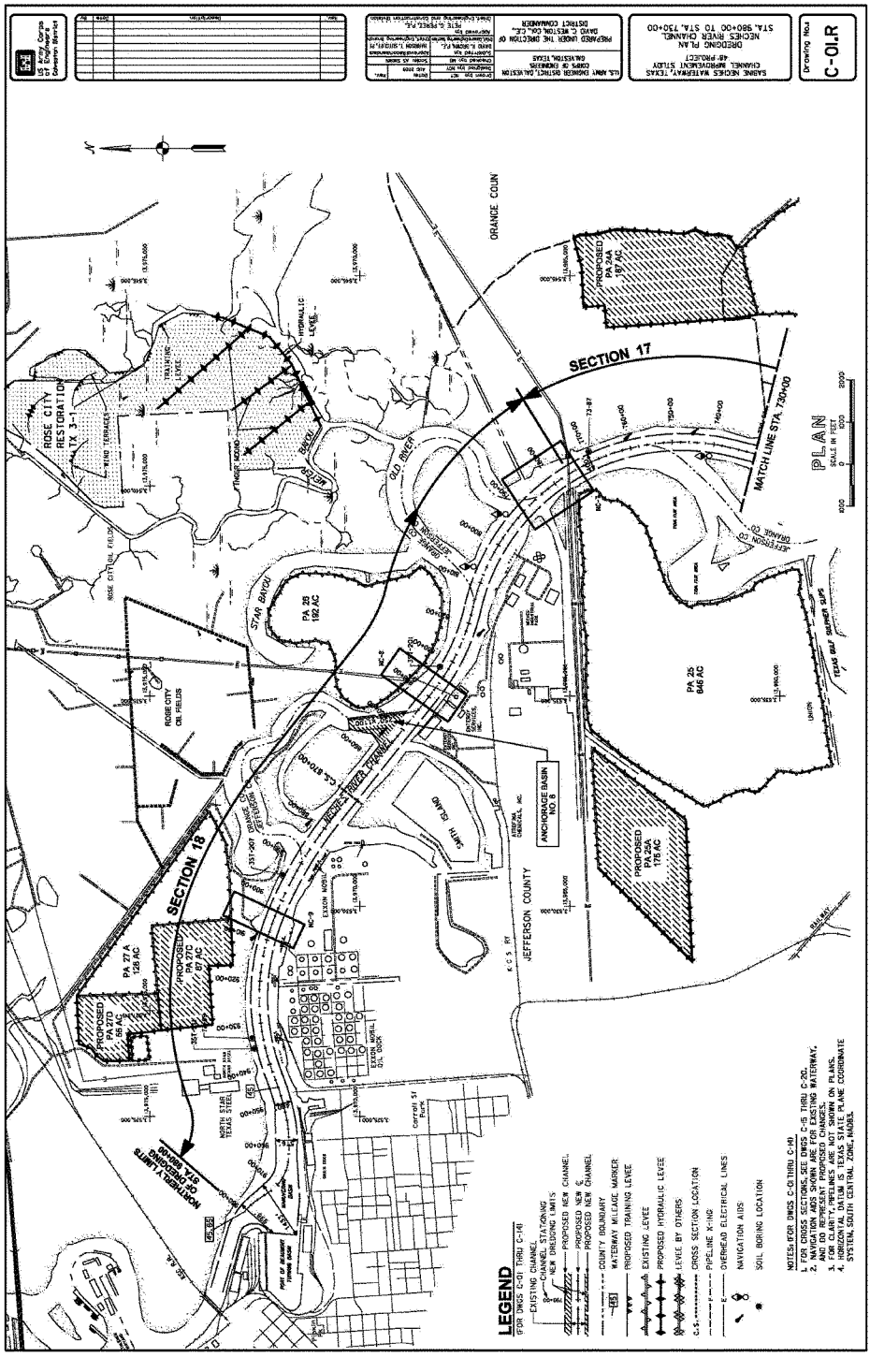
Measure 8-2 - Marsh Restoration, Old River Cove, Orange County



Legend

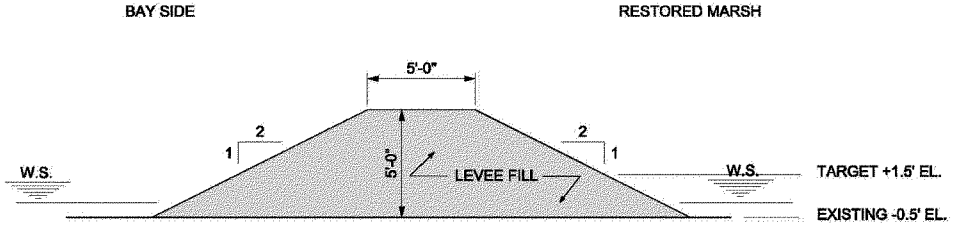
Marsh Restoration



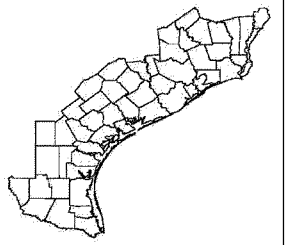

SABINE NECHES WATERWAY, TEXAS
CHANNEL IMPROVEMENT STUDY
48" PROJECT
DREDGING PLAN
NECHES RIVER CHANNEL
STA. 980+00 TO STA. 730+00
C-01.R
U.S. ARMY CORPS OF ENGINEERS
GALVESTON DISTRICT
PREPARED UNDER THE DIRECTION OF
DAVID C. WETSTON, COL, CE
DISTRICT COMMANDER
SECTION 17
SECTION 18
MATCH LINE STA. 730+00
PLAN
SCALE IN FEET
ROSE CITY RESTORATION
TX 3-1
PA 27 A
126 AC
PROPOSED
PA 27D
55 AC
PROPOSED
PA 27D
87 AC
PA 28
182 AC
PA 25
646 AC
PROPOSED
PA 28A
178 AC
PROPOSED
PA 28A
187 AC
ANCHORAGE BASIN
NO. 8
JEFFERSON COUNTY
ORANGE COUNTY
LEGEND
FOR DWGS C-01 THRU C-14
EXISTING CHANNEL
NEW DREDGING LIMITS
PROPOSED NEW CHANNEL
PROPOSED NEW &
PROPOSED NEW CHANNEL
COUNTY BOUNDARY
WATERWAY MILEAGE MARKER
PROPOSED TRAINING LEVEE
EXISTING LEVEE
PROPOSED HYDRAULIC LEVEE
LEVEE BY OTHERS
CROSS SECTION LOCATION
PIPELINE X-ING
OVERHEAD ELECTRICAL LINES
NAVIGATION AIDS
SOIL BORING LOCATION
NOTES:FOR DWGS C-01THRU C-14)
1. FOR CROSS SECTIONS,SEE DWGS C-15 THRU C-20.
2. NAVIGATION AIDS SHOWN ARE FOR EXISTING WATERWAY.
AIDS FOR PROPOSED WATERWAY TO BE DETERMINED.
3. FOR CLARITY, PIPELINES ARE NOT SHOWN ON PLANS.
4. HORIZONTAL DATUM IS TEXAS STATE PLANE COORDINATE
SYSTEM, SOUTH CENTRAL ZONE, NAD83.

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-16: Marsh Restoration Containment Levee



ASSUMPTIONS:
1: CONTAINMENT LEVEE FILL OBTAINED FROM ONSITE BORROW AREA
2: RESTORED MARSH FILL HYDRAULICALLY PUMPED
3: CONTAINMENT LEVEE FOUNDED ON -0.5' CONTOUR



Typical Section S-16

Measures:
8-4
8-5
8-6
8-7

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 8-4.1, 8-4.2, 8-5.1, 8-5.2, 8-6.1, 8-6.2, 8-6.3, 8-7.2, 8-7.3, 8-7.4, 8-7.5, 8-7.6
INFORMATION SHEET

DESCRIPTION OF MEASURES

These measures would reestablish emergent marshes at Sabine Pass and in East and West Bays of the Galveston Bay system which have been degraded or lost due to erosion. Some of the marshes would help restore and preserve National Wildlife Refuges and Wildlife Management Areas at Sabine Pass, and others would be managed by local non-governmental organizations as natural preserves (Sweetwater Preserve, Pierce Marsh, Greens Marsh). The majority are on private property and, in addition to their other significant ecological functions, would also serve as storm surge buffers to communities such as the City of Sabine Pass, and several small communities on the West End of Galveston Island. The measures on the West End of Galveston Island and the bay side of Bolivar Peninsula would improve the resiliency of the these barrier islands and help preserve their important role as the first line of defense. One measure at the Interstate Highway 10 (IH) Causeway would help protect a vital hurricane evacuation route from Galveston Island. Information on existing conditions and coastal processes affecting sediment use in some of these areas was taken from the recent West Galveston Bay Regional Sediment Plan, prepared by the Gulf of Mexico Foundation.

Measures 8-4.1 and 8-4.2
Two locations on the bayside of Bolivar Peninsula in Galveston County would use dredged material from sources such as the Gulf Intracoastal Waterway (GIWW), the Houston Ship Channel (HSC), and/or private channels. Dredged material would be pumped to fill open water within the breaking marsh. A containment dike would need to be constructed to hold hydraulic material until it settles. After the new marsh platform settles, a concrete bag wall protection would be installed along bay shoreline and dikes would be removed or degraded to the existing marsh elevation.

- **Measure 8-4.1 Marsh Restoration, Pepper Grove Cove, Galveston County**
  Restore 294 acres with a containment dike of 4.0 miles and shoreline protection of 1.7 miles.

- **Measure 8-4.2 Marsh Restoration, Long Point Marsh, Galveston County**
  Restore 1,661 acres of emergent marsh with a containment dike of 13.2 miles and 9.6 miles of shoreline protection.

Measures 8-5.1 and 8-5.2

These measures would restore marsh systems south of Keith Lake and in the Texas Point National Wildlife Refuge (NWR) in Jefferson County. Maintenance material would be pumped in from the nearby federal navigation channel (Sabine Neches Waterway) and private berths at Cheniere and Golden Pass LNG facilities. Containment dikes would be constructed with in-situ material. No shoreline protection is needed for these measures.

- **Measure 8-5.1 Marsh Restoration, South of Keith Lake, Jefferson County**
  Restore 4,132 acres of breaking marsh. A containment dike would only needed on the north and west sides (total of 7.5 mi) as a chenier ridge on southeast serves as barrier.

- **Measure 8-5.2 Marsh Restoration, Texas Point NWR, Jefferson County**
  Restore 5,172 acres of breaking marsh. A containment levee would only be needed on the east and south sides(total of 9.7 mi). A chenier ridge serves as a barrier.

Measures 8-6.1, 8-6.2, 8-6.3 8-6

These measures are located in Galveston County on the north shore of West Bay. Dredged material would be pumped from the GIWW and/or local canals to fill degraded marshes in three areas on the north shore of West Galveston Bay. A containment dike would be constructed from in-situ material to hold hydraulic material. After new marsh platforms are settled, concrete bag wall protection systems would be installed just in front of new bay shorelines, and dikes would be removed or degraded to existing marsh elevations.

- **Measure 8-6.1 Marsh Restoration, Pierce Marsh, Galveston County**
  Restore 2,076 acres of marsh. A 7.2-mile containment dike and bay shoreline protection of 1.6 miles would also be needed.

- **Measure 8-6.2 Marsh Restoration, IH-10 Causeway, Galveston County**
  Located south of causeway and east of Bayou Vista. It includes restoration of 633 acres of marsh, a containment dike of 4.8 miles, and bay shoreline protection of 1.6 miles.

- **Measure 8-6.3 Marsh Restoration, Greens Lake, Galveston County**
  Would restore 3,293 acres of restored marsh with a 15.9 mile containment dike. Assume shoreline protection under GIWW Shoreline Protection Measure 6-5.1.

Measures 8-7.1, 8-7.2, 8-7.3, 8-7.4, 8-7.5, and 8-7.6

Located bayside at the west end of Galveston Island in Galveston County, these measures would pump dredged material from the GIWW and/or local canals to fill degraded marshes in six separate areas. A containment dike constructed with in-situ material would be constructed to hold hydraulic material. After new marsh platforms are settled, a concrete bag wall protection would be installed just in front of the new bay shoreline. Dikes would be removed or degraded to existing marsh elevation.

- **Measure 8-7.1 Marsh Restoration, Gangs to Oxen Bayou, Galveston County** would restore 176 acres of marsh between Gangs and Oxen Bayous, and include a containment dike of 2.4 miles and bay shoreline protection 0.6 miles.

- **Measure 8-7.2 Marsh Restoration, Oxen to Mantel Bayou, Galveston County** would restore 390 acres of marsh and include a 4.0 mile containment dike and bay shoreline protection of 1.3 miles.

- **Measure 8-7.3 Marsh Restoration, Dana Cove, Galveston County** would restore 213 acres of marsh and include a 3.75 mile containment dike, and 1.2 miles of bay shoreline protection.

- **Measure 8-7.4 Marsh Restoration, Jumbile Cove, Galveston County** would restore 316 acres of marsh, and include a 11.4 mile containment dike and 1.25 miles of shoreline protection.

- **Measure 8-7.5 Marsh Restoration, Bird Island to Maggies Cove, Galveston County** would restore 467 acres of marsh, and include 7.5 miles of containment dike and 2. 1 miles of shoreline protection.

- **Measure 8-7.6 Marsh Restoration, Snake Island Cove, Galveston County** would restore 457 acres of marsh, and include 6.9 miles of containment dike and 1.7 miles of shoreline protection.

LOCATION OF MEASURES (See attached drawings)

Measures 8-4, 8-6, 8-7:

Typical Section S-15: GIWW Shore Protection

Typical Section S-16: Marsh Restoration Containment Levee

Measure 8-4.1 Marsh Restoration, Pepper Grove Cove, Galveston County

Measure 8-4.2 Marsh Restoration, Long Point Marsh, Galveston County
Measure 8-5 Marsh Restoration at Sabine Pass. Jefferson County
Measure 8-5.1 Marsh Restoration, South of Keith Lake, Jefferson County
Measure 8-5.2 Marsh Restoration, Texas Point NWR, Jefferson County
Measure 8-6 Marsh Restoration on North Shore of Galveston Bay, Galveston County
Measure 8-6.1 Marsh Restoration, Pierce Marsh, Galveston County
Measure 8-6.2 Marsh Restoration, IH-10 Causeway, Galveston County
Measure 8-6.3 Marsh Restoration, Greens Lake, Galveston County
Measure 8-7 West Galveston Island, Bay-Side Marsh, Galveston County
Measure 8-7.1 Marsh Restoration, Gangs to Oxen Bayou, Galveston County
Measure 8-7.2 Marsh Restoration, Oxen to Mantel Bayou, Galveston County
Measure 8-7.3 Marsh Restoration, Dana Cove, Galveston County
Measure 8-7.4 Marsh Restoration, Jumbile Cove, Galveston County
Measure 8-7.5 Marsh Restoration, Bird Island to Maggies Cove, Galveston County
Measure 8-7.6 Marsh Restoration, Snake Island Cove, Galveston County

DESIGN ASSUMPTIONS

Measures: 8-4.1, 8-4.2, 8-5.1, 8-5.2, 8-6.1, 8-6.2, 8-6.3, 8-7.1, 8-7.2, 8-7.3, 8-7.4, 8-7.5, 8-7.6.

- Construction of dike completed using a marsh buggy excavator with fill materials found on site.
- Existing marsh elevation is -0.5 feet MSL and the proposed elevation 1.5 feet MSL.
- Quantities provided are neat line based on available information, settlement of constructed items and bulking of dredged fill not accounted for.
- Geotechnical properties of fill and breakwater/levee foundation assumed to be adequate for the work being performed.
- Containment dike is 5' tall with a 5' crown and 2:1 slopes.
- Breakwater volume is based on cross sectional area multiplied by total length.
- Breakwater riprap size is W50-650.

Assumptions for Individual Measures

Measure 8-4.1 Marsh Restoration, Pepper Grove Cove, Galveston County

- Fill for marsh area hydraulically pumped from maintenance material from GIWW along side of project area and 12,000 feet to the east and west.
- The marsh volume is 948,640 CY.
- Breakwater follows lines shown for shoreline protection on measure 8-4.1.
- The breakwater volume is 33,909 CY.

- The containment dike requires a volume of 58,667Breakwater construction performed from barge whose access is via GIWW 4,200 feet away.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes are required for breakwater.
- Excavated material is side cast and left in place.

Measure 8-4.2 Marsh Restoration, Long Point Marsh, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from GIWW along side of project area and 12,000 feet to the east and west.
- The volume of marsh fill is 5,359,493 CY.
- The containment dike volume is 193,600 CY.
- Breakwater is placed in water 3 feet deep.
- Breakwater follows lines shown for shoreline protection on measure 8-4.2.
- The breakwater volume is 51,861 CY. 83,000 tons of rock.
- Geotechnical properties of fill assumed to be adequate for the work being performed.
- Breakwater construction performed from barge whose access is via GIWW 12,000 feet away.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

Measure 8-5.1 Marsh Restoration, South of Keith Lake, Jefferson County

- Fill for marsh area hydraulically pumped from maintenance material from GIWW, SNWW, and private berths on SNWW, pump distances can be up to 24,000 feet.
- A fill volume of 13,332,587 CY is needed for the marsh.
- The containment dike volume is 110,000 CY.
- Mobilization and demobilization distance is 12 miles (from Port Arthur).

Measure 8-5.2 Marsh Restoration, Texas Point NWR, Jefferson County:

- Fill for marsh area hydraulically pumped from maintenance material from GIWW, SNWW, and private berths on SNWW, pump distances can be up to 24,000 feet.
- The volume of the marsh is 16,688,320 CY.
- The volume of the containment dike is 142,267 CY.
- Mobilization and demobilization distance is 12 miles (from Port Arthur).

Measure 8-6.1 Marsh Restoration, Pierce Marsh, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from GIWW along side of project area and 12,000 feet to the east and west.
- The volume of the marsh is 6,698,560 CY.

- The volume of the containment dike is 105,600 CY.
- The breakwater is placed in 3 feet deep water.
- The breakwater volume is 31,915 CY. 51,100 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-6.1.
- Breakwater riprap size is W50-650.
- Breakwater construction performed from barge whose access is via GIWW 3,500 feet away.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

Measure 8-6.2 Marsh Restoration, IH-10 Causeway, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from GIWW. along side of project area and 12,000 feet to the east and west.
- The volume of the marsh is 2,042,480 CY.
- The volume of the containment dike is 70,400 CY.
- Breakwater is placed in 3 feet deep water.
- The breakwater volume is 31,915 CY. 51,100 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-6.2.
- Breakwater construction performed from barge whose access is via GIWW and access channel built for measure 8-6.1 600 feet away.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

Measure 8-6.3 Marsh Restoration, Greens Lake, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from GIWW along side of project area and 12,000 feet to the east and west.
- The volume of the marsh is 10,625,413 CY.
- The volume of the containment dike is 233,200 CY.
- Breakwater is placed in 3 feet deep water.
- The breakwater volume is 1,530,000 CY. 90,700 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-6.3
- Breakwater construction performed from barge whose access is via GIWW
- No access channels required.

Measure 8-7.1 Marsh Restoration, Gangs to Oxen Bayou, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from local channels and from GIWW up to 24,000 away.
- The volume of the marsh is 567,893 CY.

- The volume of the containment dike is 35,200 CY.
- Breakwater is placed in 3 feet deep water.
- The breakwater volume is 11,968 CY. 19,100 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-7.1.
- Breakwater construction performed from barge whose access is via local channels 500 feet away.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

Measure 8-7.2 Marsh Restoration, Oxen to Mantel Bayou, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from local channels and from GIWW up to 24,000 away.
- The volume of the marsh is 1,258,400 CY
- The volume of the containment dike is 58,667 CY.
- Breakwater is placed in 3 feet deep water.
- The breakwater volume is 25,931 CY. 41,500 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-7.2.
- Breakwater construction performed from barge whose access is via local channels 500 feet away.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

Measure 8-7.3 Marsh Restoration, Dana Cove, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from local channels and from GIWW up to 24,000 away.
- The volume of the marsh is 687,280 CY
- The volume of the containment dike is 55,000 CY.
- Breakwater is placed in 3 feet deep water.
- The breakwater volume is 23,936 CY. 38,300 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-7.3.
- Breakwater construction performed from barge whose access is via local channels.
- Additional 1,100 feet of access channel added because of gap between breakwaters.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

Measure 8-7.4 Marsh Restoration, Jumbile Cove, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from local channels and from GIWW up to 24,000 away.
- The volume of the marsh is 1,019,627,280 CY.
- The volume of the containment dike is 116,600 CY.
- Breakwater is placed in 3 feet deep water.
- The breakwater volume is 24,933 CY. 39,900 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-7.4.
- Breakwater construction performed from barge whose access is via local channels.
- Additional 1,100 feet of access channel added because of gap between breakwaters.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

Measure 8-7.5 Marsh Restoration, Bird Island to Maggies Cove, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from local channels and from GIWW up to 24,000 away.
- The volume of the marsh is 1,506,853 CY.
- The volume of the containment dike is 110,000 CY.
- Breakwater is placed in 3 feet deep water.
- The breakwater volume is 40,891 CY. 65,400 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-7.5.
- Breakwater construction performed from barge whose access is via local channels.
- Additional 2,000 feet of access channel added because of gap between breakwaters.
- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

Measure 8-7.6 Marsh Restoration, Snake Island Cove, Galveston County:

- Fill for marsh area hydraulically pumped from maintenance material from local channels and from GIWW up to 24,000 away.
- The volume of the marsh is 1,474,587 CY.
- The volume of the containment dike is 101,200 CY.
- Breakwater is placed in 3 feet deep water.
- The breakwater volume is 33,909 CY. 54,300 tons of rock.
- Breakwater follows lines shown for shoreline protection on measure 8-7.6.
- Breakwater construction performed from barge whose access is via local channels.
- Additional 2,000 feet of access channel added because of gap between breakwaters.

- Access channels 10 feet deep and 50 feet wide with 1:1 side slopes required for breakwater, excavated material is side cast and left in place.

REAL ESTATE

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'. Costs identified as $0 are generally associated with Federal and/or State lands.

- Measure 8-4.1: Marsh Restoration, Pepper Grove Cove, Galveston County
  Total Estimated Real Estate Cost: $111,000 ®

- Measure 8-4.2: Marsh Restoration, Long Point Marsh, Galveston County
  Total Estimated Real Estate Cost: $614,000 ®

- Measure 8-5.1: Marsh Restoration, South of Keith Lake, Jefferson County
  Total Estimated Real Estate Cost: $1,500,000 ®

- Measure 8-5.2: Marsh Restoration, Texas Point NWR, Jefferson County
  Total Estimated Real Estate Cost: $0

- Measure 8-6.1: Marsh Restoration, Pierce Marsh, Galveston County
  Total Estimated Real Estate Cost: $756,000 ®

- Measure 8-6.2: Marsh Restoration, IH-10 Causeway, Galveston County
  Total Estimated Real Estate Cost: $234,000 ®

- Measure 8-6.3: Marsh Restoration, Greens Lake, Galveston County
  Total Estimated Real Estate Cost: $1,205,000 ®

- Measure 8-7.1: Marsh Restoration, Gangs to Oxen Bayou, Galveston County
  Total Estimated Real Estate Cost: $66,300 ®

- Measure 8-7.2: Marsh Restoration, Oxen to Mantel Bayou, Galveston County
  Total Estimated Real Estate Cost: $146,000 ®

- Measure 8-7.3: Marsh Restoration, Dana Cove, Galveston Island
  Total Estimated Real Estate Cost: $81,200 ®

- Measure 8-7.4: Marsh Restoration, Jumbile Cove, Galveston County
  Total Estimated Real Estate Cost: $124,000 ®

- Measure 8-7.5: Marsh Restoration, Bird Island to Maggies Cove, Galveston County
  Total Estimated Real Estate Cost: $178,000 ®

- Measure 8-7.6: Marsh Restoration, Snake Island Cove, Galveston County
  Total Estimated Real Estate Cost of Measure 8-7.6: $173,000 ®

ENVIRONMENTAL ASSUMPTIONS

Marshes serve as buffers for storm surge, water storage, improve water quality and provide important nursery habitat. The environmental benefits for these measures are assumed to be equivalent to the total acres restored (see table below).

Environmental Benefits

Measure Number and Location	Restored Marsh (acres)
Measure 8-4.1 (Marsh Restoration, Pepper Grove Cove, Galveston Co.)	294
Measure 8-4-2 (Marsh Restoration, Long Point Marsh, Galveston Co.)	1,661
Measure 8-5.1 (Marsh Restoration, South of Keith Lake, Jefferson Co.)	4,132
Measure 8-5.2 (Marsh Restoration, Texas Point NWR, Jefferson Co.)	5,172
Measure 8-6.1 (Marsh Restoration, Pierce Marsh, Galveston Co.)	2,076
Measure 8-6.2 (Marsh Restoration, IH-10 Causeway, Galveston Co.)	633
Measure 8-6.3 (Marsh Restoration, Greens Lake, Galveston Co.)	3,293
Measure 8-7.1 (Marsh Restoration, Gangs to Oxen Bayou, Galveston Co.)	176
Measure 8-7.2 (Marsh Restoration, Oxen to Mantel Bayou, Galveston Co.)	390
Measure 8-7.3 (Marsh Restoration, Dana Cove, Galveston Co.)	213
Measure 8-7.4 (Marsh Restoration, Jumbile Cove, Galveston Co.)	316
Measure 8-7.5 (Marsh Restoration, Bird Island to Maggies Cove, Galveston Co.)	467
Measure 8-7.6 (Marsh Restoration, Snake Island Cove, Galveston Co.)	457

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

These costs do not include Real Estate.

Measure 8-4.1: The estimated cost for this measure is $16,936,000
Measure 8-4.2: The estimated cost for this measure is $44,947,000
Measure 8-5.1: The estimated cost for this measure is $64,131,000
Measure 8-5.2: The estimated cost for this measure is $80,098,000
Measure 8-6.1: The estimated cost for this measure is $51,417,000
Measure 8-6.2: The estimated cost for this measure is $21,245,000
Measure 8-6.3: The estimated cost for this measure is $69,513,000
Measure 8-7.1: The estimated cost for this measure is $7,596,000
Measure 8-7.2: The estimated cost for this measure is $15,533,000
Measure 8-7.3: The estimated cost for this measure is $12,220,000
Measure 8-7.4: The estimated cost for this measure is $14,528,000
Measure 8-7.5: The estimated cost for this measure is $21,996,000
Measure 8-7.6: The estimated cost for this measure is $19,538,000

Cost Assumptions used for breakwater measures 8- 4.1, 8-4.2, 8-6.1, 8-6.2, 8-6.3, 8-7.1, 8-7.2, 8-7.3, 8-7.4, 8-7.5, 8-7.6

- Breakwater Construction:
- Riprap will be barged into area.
- A 10 ft deep access channel will be excavated as needed to bring in the rock barge.
- Riprap will be placed from the barge.
- Marsh Work:
- The containment dike will be constructed from material excavated at site.
- Marsh fill will be hydraulically pumped maintenance material from the GIWW next time maintenance dredging occurs in the area.
- A standard 25% contingency, E&D of 8%, and CM of 6% were added to the cost.

Cost Assumptions used for measures 8-5.1, and 8-5.2

- The containment dike will be constructed from material excavated at the site.
- Dredge fill from maintenance material from GIWW, SNWW, and private berths on SNWW will be used to fill the area to the required elevation.
- A standard 25% contingency, E&D of 8%, and CM of 6% was used with the cost.

REFERENCE DOCUMENT

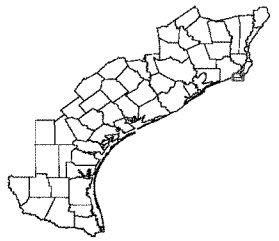
Gulf of Mexico Foundation. no date. West Galveston Bay Regional Sediment Management Plan Report. Prepared for Habitat Conservation and Restoration Team, Gulf of Mexico Alliance by Atkins Global.

RISKS

- Geotechnical properties of fill assumed to be adequate for the work being performed.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.
- Implementation of this measure would require a revised Dredged Material Management Plan (DMMP) for the existing SNWW and GIWW navigation projects. Additional document preparation and coordination through USACE O&M would likely be required.

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-4.1: Marsh Restoration, Pepper Grove Cove, Galveston County



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Marsh Restoration

Shoreline Protection

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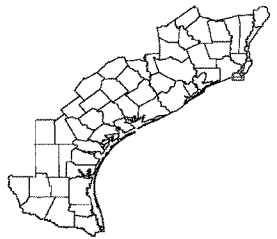
Date Created: 5/1/2013

Measure 8-4.2: Marsh Restoration, Long Point Marsh, Galveston County



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Marsh Restoration

Shoreline Protection

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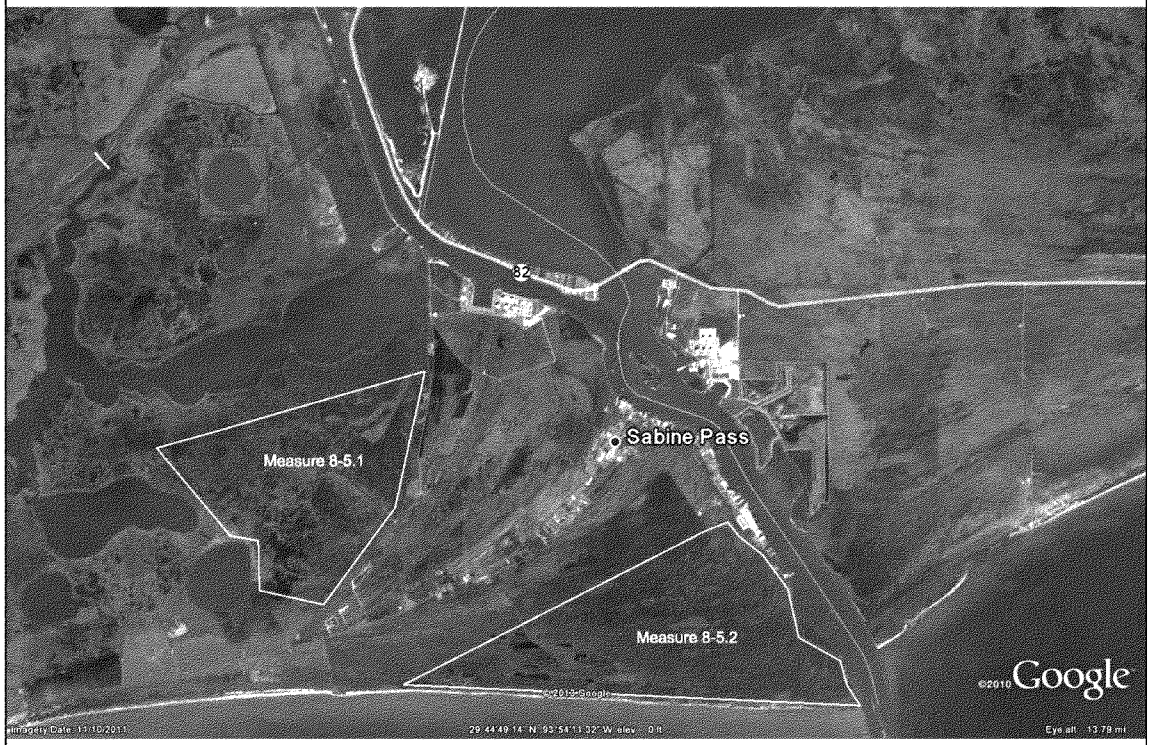
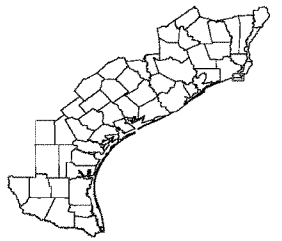
Date Created: 5/1/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-5: Marsh Restoration at Sabine Pass, Jefferson County





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Measure 8-5

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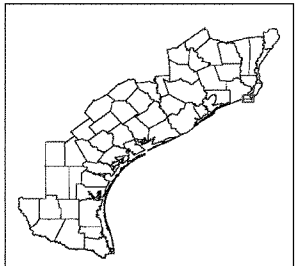
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-5.1: Marsh Restoration, South of Keith Lake, Jefferson County



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Measure 8-5.1

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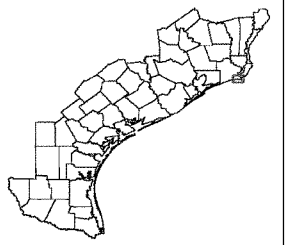
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-5.2: Marsh Restoration, Texas Point NWR, Jefferson County



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Measure 8-5.2

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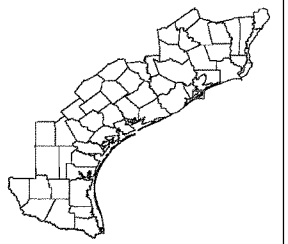
Date Created: 4/11/2013

Measure 8-6: Marsh Restoration on North Shore of Galveston Bay, Galveston County



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Measure 8-6

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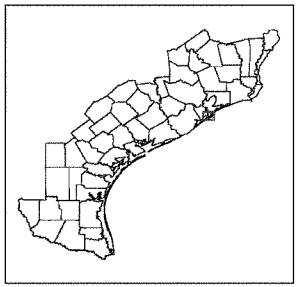
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-6.1: Marsh Restoration, Pierce Marsh, Galveston County



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Measure 8-6.1

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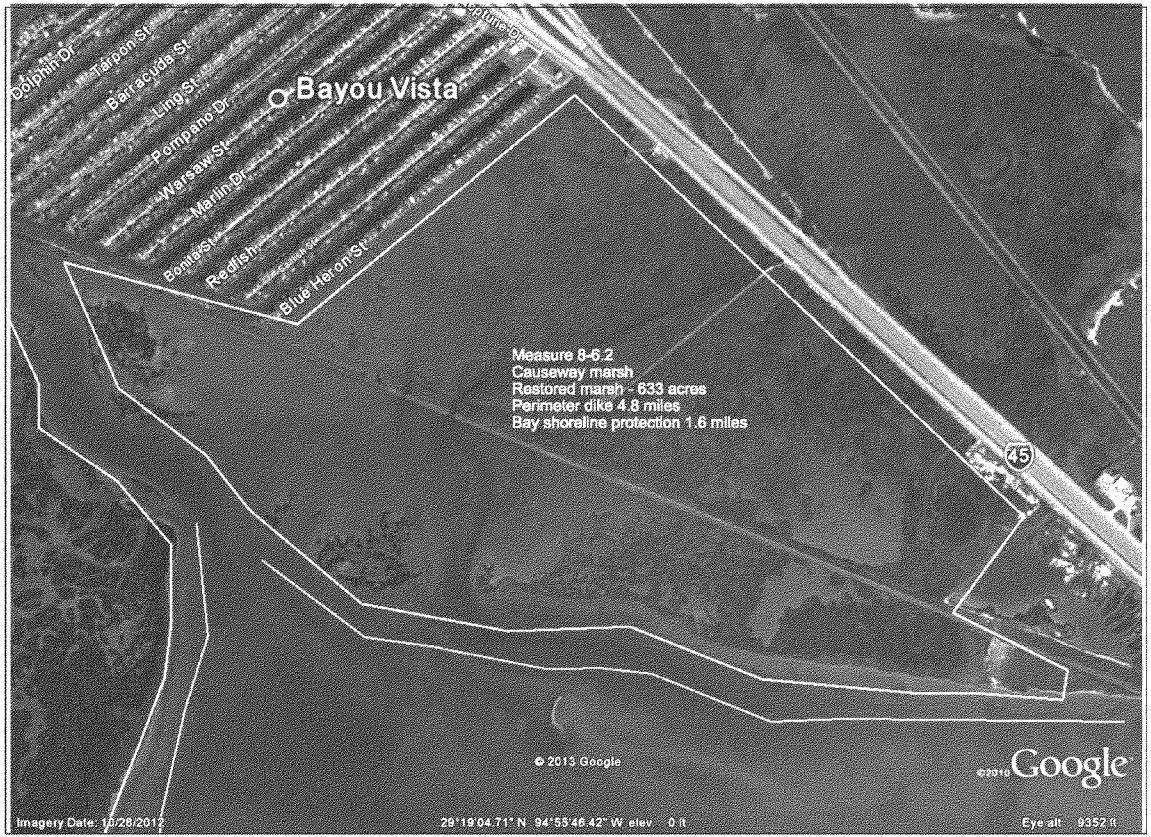
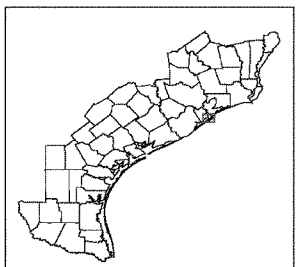
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-6.2: Marsh Restoration, IH-45 Causeway, Galveston County





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Measure 8-6.2

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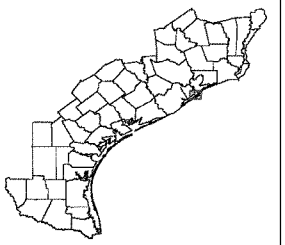
Date Created: 4/11/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-6.3: Marsh Restoration, Greens Lake, Galveston County



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Measure 8-6.3

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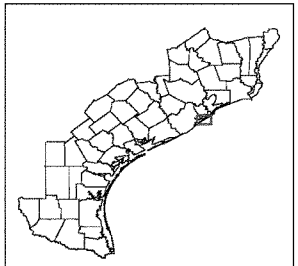
Date Created: 4/11/2013

Measure 8-7: Marsh Restoration, West Galveston Island Bay-Side Marsh, Galveston County



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Measure 8-7

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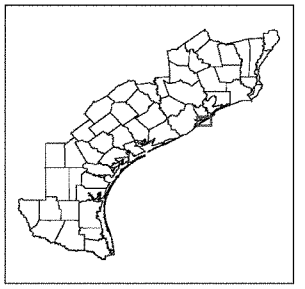
Date Created: $DATE$

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-7.1: Marsh Restoration, Gangs to Oxen Bayou, Galveston County



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Measure 8-7.1

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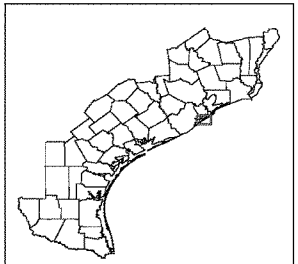
Date Created: $DATE$

Measure 8-7.2: Marsh Restoration, Oxen to Mantel Bayou, Galveston County



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Measure 8-7.2

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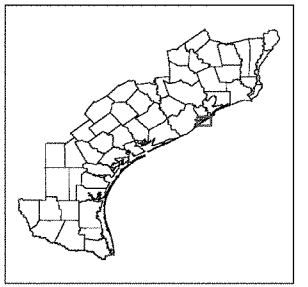
Date Created: $DATE$

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-7.3: Marsh Restoration, Dana Cove, Galveston County



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Measure 8-7.3

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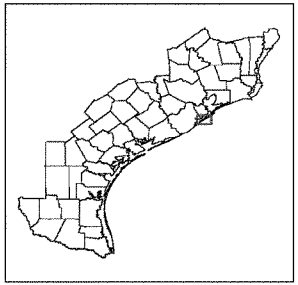
Date Created: $DATE$

Measure 8-7.4: Marsh Restoration, Jumbile Cove, Galveston County



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Measure 8-7.4

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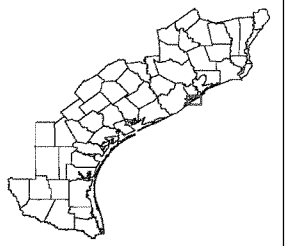
Date Created: $DATE$

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-7.5: Marsh Restoration, Bird Island to Maggies Cove, Galveston County



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Measure 8-7.5

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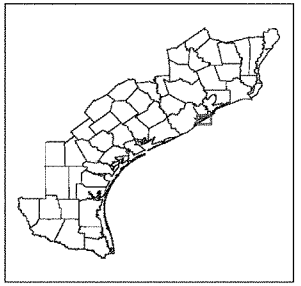
Date Created: $DATE$

Measure 8-7.6: Marsh Restoration, Snake Island Cove, Galveston County



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Measure 8-7.6

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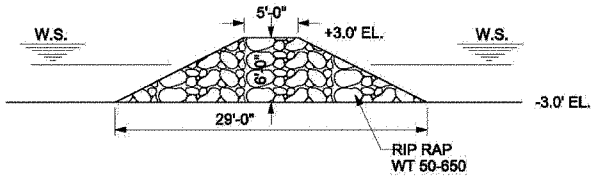
Date Created: $DATE$

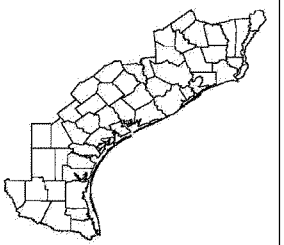
Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-15: GIWW Shore Protection



RIP RAP END AREA = 102 FT²

ASSUMPTIONS:
1: BREAKWATER IS PLACED IN 3 FT DEEP WATER
2: BREAKWATER IS CONTINUOUS
3: VOLUME IS BASED ON CROSS SECTION AREA MULTIPLIED BY LENGTH



Typical Section S-15

Measures:
6-1.1
6-2
6-4.1
6-5.1
6-6.1
7-1
7-2
8-4
8-6
8-7

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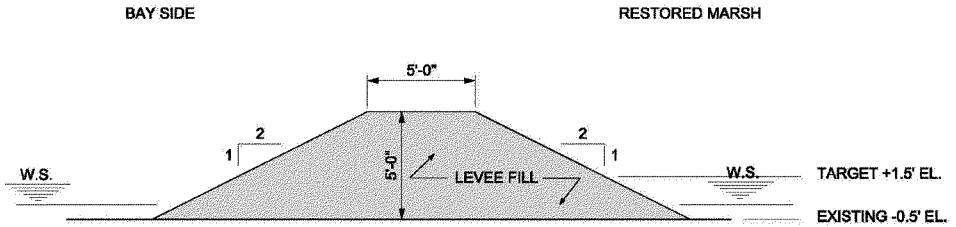
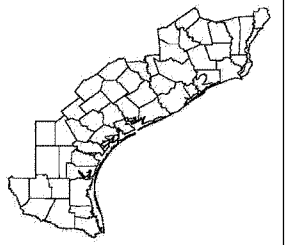
Date Created: 4/24/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-16: Marsh Restoration Containment Levee



ASSUMPTIONS:
1: CONTAINMENT LEVEE FILL OBTAINED FROM ONSITE BORROW AREA
2: RESTORED MARSH FILL HYDRAULICALLY PUMPED
3: CONTAINMENT LEVEE FOUNDED ON -0.5' CONTOUR



Typical Section S-16

Measures:
8-4
8-5
8-6
8-7

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURE 8-7.7
INFORMATION SHEET

DESCRIPTION OF MEASURE

Measure 8-7.7 Marsh and Bayou Restoration, Sweetwater Preserve, Galveston County: This measure would restore a marsh and bayou system in the Sweetwater Preserve by establishing marsh elevations in disturbed uplands and reducing the width and depth of the bayou to dampen tidal intrusion. Current areas that are now higher than the marsh elevation would be excavated to an average target marsh elevation of 1.5 ft MSL. A survey would be required to determine the amount of disturbed uplands requiring excavation and to identify the areas to add excavated fill to reduce width of Sweetwater Bayou. Excavated material would be used to reduce the width of bayou connecting Sweetwater Lake with West Bay. Reclaimed land in the former bayou would be built up to an average target marsh elevation 1.5 ft MSL. The total area is 447 acres and the footprint perimeter is 4.1 miles. No shoreline protection on Galveston Bay is needed as it has already been installed.

LOCATION OF MEASURE 8-7.7: (SEE ATTACHED DRAWING)
Measure 8-7.7: Marsh and Bayou Restoration, Sweetwater Preserve, Galveston County

DESIGN ASSUMPTIONS

Measure 8-7.7:

- Total area 447 acres, of which 323 acres needs to be degraded an average of two feet to meet target elevation of 1.5' MSL.
- The volume of excavated material is 1,042,300 CY.
- Excavated material moved to remaining portions of work area and used to reduce width of bayou connecting Sweetwater Lake to West Bay.
- Access via local roads, bulldozers and dump trucks can be used to complete work.
- No additional maintenance work will need to be performed for the 50 year.

REAL ESTATE:

A detailed breakdown of Real Estate costs can be found in the supplemental document 'Sabine Pass to Galveston Bay, Texas Preliminary Real Estate Cost Estimate'. Costs identified as $0 are generally associated with Federal and/or State lands.

- Measure 8-7.7: Marsh and Bayou Restoration, Sweetwater Preserve, Galveston County

Total Estimated Real Estate Cost: $122,000 ®

ENVIRONMENTAL:

This marsh would serve as a buffer for storm surge, water storage, improve water quality and provide important nursery habitat. The environmental benefits are equivalent to the total acres restored (447 acres).

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

No real estate cost is included.
The estimated cost for Measure 8-7.7 is $7,135,000.

The following Cost Assumptions were used for measures: 8-7.7

- The existing area will be degraded using a dozer to move the existing material around to the required elevation,
- reduce the width of the bayou connecting Sweetwater Lake and West Bay.
- A standard 25% contingency, E&D of 8%, and CM of 6% was used with the cost

REFERENCE DOCUMENT

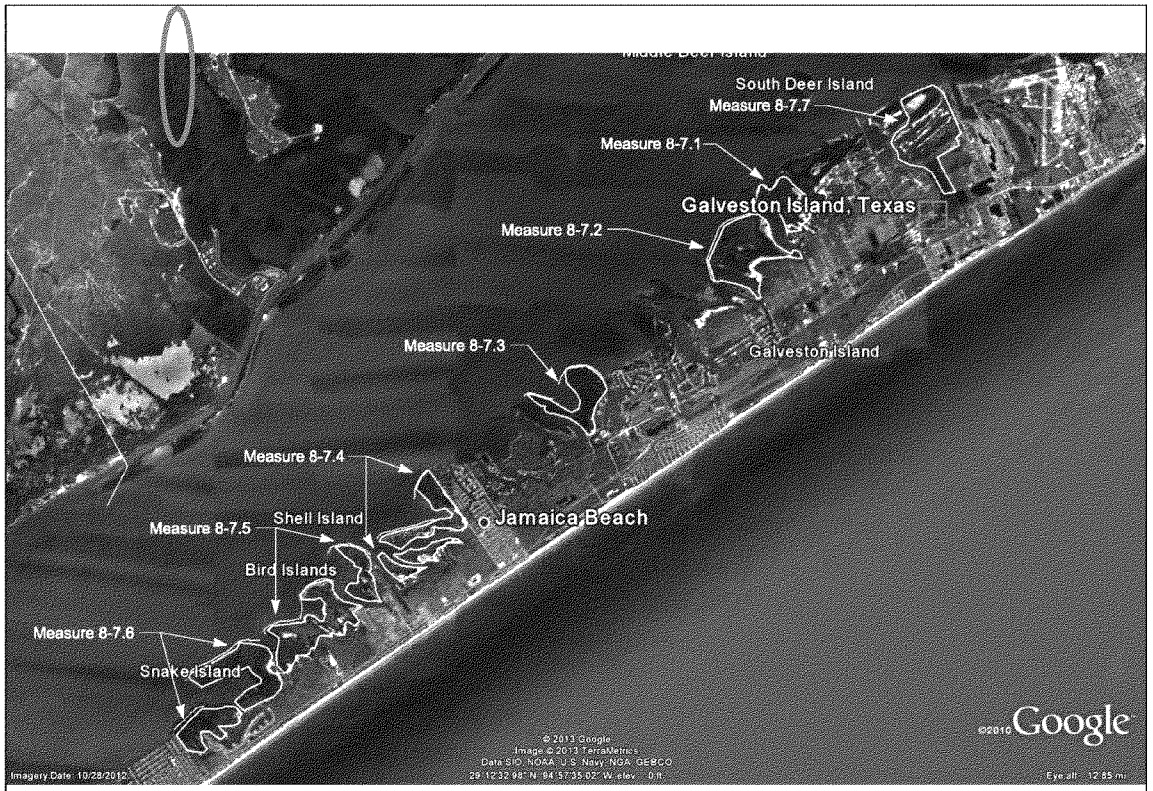
Gulf of Mexico Foundation. no date. West Galveston Bay Regional Sediment Management Plan Report. Prepared for Habitat Conservation and Restoration Team, Gulf of Mexico Alliance by Atkins Global.

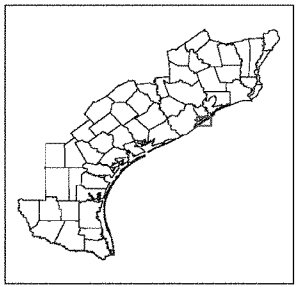
RISKS

- Geotechnical properties of fill assumed to be adequate for the work being performed.
- No review of available public information or data from in-house files relative to the general geology and soil conditions for the proposed features was conducted.

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 8-7: Marsh Restoration, West Galveston Island Bay-Side Marsh, Galveston County





Legend

Measure 8-7

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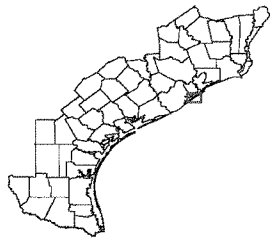
Date Created: $DATE$

Measure 8-7.7: Marsh and Bayou Restoration, Sweetwater Preserve, Galveston County



Legend

Measure 8-7.7

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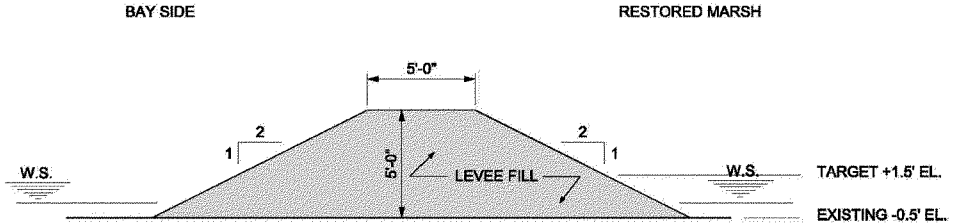
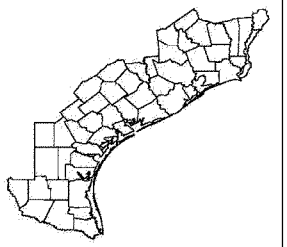
Date Created: $DATE$

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Typical Section S-16: Marsh Restoration Containment Levee



ASSUMPTIONS:
1: CONTAINMENT LEVEE FILL OBTAINED FROM ONSITE BORROW AREA
2: RESTORED MARSH FILL HYDRAULICALLY PUMPED
3: CONTAINMENT LEVEE FOUNDED ON -0.5' CONTOUR



Typical Section S-16

Measures:
8-4
8-5
8-6
8-7

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Date Created: 4/24/2013

SABINE PASS TO GALVESTON BAY, TEXAS
MEASURES 9-1 and 9-2
INFORMATION SHEET

DESCRIPTION OF MEASURES 9-1 and 9-2

The purpose of these measures is hydrological restoration of the Salt Bayou Watershed. A combination of natural processes and human activities, most notably construction of the GIWW and the Sabine-Neches Waterway navigation channels, has modified the landscape connecting what was once a predominantly freshwater wetland system to tidal waters with marine salinities. Over time, the influx of saline water has contributed to a significant change in and loss of freshwater marsh vegetation throughout a wide area of the wetland. At the same time, there has been an increase in the production of estuarine fish and shellfish species as access points facilitate ingress and egress through various control structures and the Keith Lake Fish Pass. Under current conditions, the system serves as an important site for wetland flora, migratory waterfowl, and estuarine species. The restoration proposed here strikes a balance between the historical freshwater wetland function and the more contemporary estuarine functions which are controlled by the balance of fresh and salt water in the system.

This measure includes 2 separate items which together will decrease salinity in the Salt Bayou watershed south of the GIWW:

Measure 9-1 Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County
Involves the construction of a water control structure within the Keith Lake Fish Pass (KLFP), an artificial channel which connects a network of freshwater and brackish lakes and bayous in the Salt Bayou marsh system south of the GIWW to the 40-foot deep draft Sabine-Neches Waterway navigation channel. The structure would reduce salinity intrusion and tidal energy through the KLFP and help preserve about 50,000 acres of significant emergent coastal marsh while maintaining the marsh's accessibility and value as an important estuarine nursery.

Measure 9-2 Inverted Siphons Under GIWW, Jefferson County
Restore freshwater inflows into the Salt Bayou system by hydrologically connecting the Taylor Bayou watershed north of the GIWW to the Salt Bayou system south of the GIWW. Natural stream and sheet flows once moved from north to south into the Salt Bayou watershed. This flow was blocked when the GIWW was constructed. The siphons would reestablish some of the lost freshwater flow to the now isolated wetlands south of the GIWW. Water would flow through two sets of pipes acting as inverted siphons under the GIWW. One (9-2A) would take

water from Magnolia Cut and discharge it into the Salt Bayou watershed . The second (9-2B) would move water from Oil Field Cut into marshes near Barnett Lake.

The majority of the area affected by this measure is part of the U.S. Fish and Wildlife Service's (USFWS) McFaddin National Wildlife Refuge (NWR), Texas Parks and Wildlife's (TPWD) J.D. Murphree Wildlife Management Area (WMA) and Sea Rim State Park. This complex of state and federal lands protects one of the largest remaining freshwater marshes on the Texas coast and thousands of acres of intermediate to brackish marsh (USFWS, 2005).

Attached are engineering drawings and maps showing the location and details of the 9-1 (the Keith Lake Fish Pass structure) and 9-2 (A and B; the siphons). The design for the 9-1 structure was developed by USACE in conjunction with a proposed but suspended CAP study. The designs for the siphons were prepared by the USFWS as part of their permit application SWG-2010-00016. The permit has been issued, but funding has not been available.

LOCATION OF MEASURE 9-1, 9-2 (See attached Drawings)

Measure 9: Saltwater Control Structure and Inverted Siphons, Jefferson County
Measure 9-1: Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County
Measure 9-2A: Inverted Siphons Under GIWW, Magnolia Cut, Jefferson County
Measure 9-2B: Inverted Siphons Under GIWW, Oil Field Cut, Jefferson County
Keith Lake Fish Pass Plan View F-02
Keith Lake Fish Pass Plan View F-03
Keith Lake Fish Pass Plan View F-04
McFaddin Drawings pgs. 1-12

DESIGN ASSUMPTIONS

Measure 9-1 Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County
Consists of a rock weir crossing the midpoint of KLFP (reference the measure map). The opening in the rock weir would have a sill at -5.42 feet (MLLW) by 80 feet wide at the base with a triangular cross-section opening about 100 ft wide at the top. The upstream and downstream approaches to the sill would have a very gradual slope to smooth water flow over the sill. Rock levees, approximately 100 feet wide (from the weir to the bank) and 150 feet long (longitudinally in the channel), would flank the opening and connect to each bank. The crest of these levees would match adjoining bank elevations. The foot print of the control structure at Keith Lake will be approximately 350' x 300'. The height of the structure is proposed from EL -12 to EL +1. Datum is NAVD88 and MLLW See attached drawings. All construction would be performed from the north bank of KLFP to minimize impacts to wetlands that line both banks of the KLFP.

MATERIAL	QUANTITY
Dolometric Limestone riprap (40 – 650 lbs)	23,000 tons
Geotextile	3,000 square yards
Excavation	8,000 cubic yards
Backfill	80 cubic yards
Borings	5 borings

Measure 9-2 Inverted Siphons Under GIWW, Jefferson County

Inverted siphons under GIWW consists of two sets of two 66-inch diameter pipes installed to cross beneath the GIWW, with flap gates north and screw gates south of the waterway. The first set of pipes would cross the GIWW at Oil Field Cut, and the second at Magnolia Cut. The pipelines would be placed in trenches that would be dredged to 33 feet deep using a dragline on a barge anchored on the south side of the GIWW in each location respectively. The dredge material would be placed behind existing breakwaters on the south side of the GIWW, behind breakwaters on the north side of the GIWW, and on the shoreline of the north side of the GIWW. The entrance of Oil Field Cut would have a rock groin installed on either side of the shoreline. This measure would also involve excavation of a diversion pond and channel on the southern portion of the Oil Field Cut pipelines on the south side of the GIWW. The materials excavated for the creation of the diversion pond and channel would be placed on the adjacent southern GIWW shoreline. See attached drawings.

Assumptions

1. Construction is completed from barges using a clamshell dredge, no access roads to this area
2. Pipeline trench is 18' wide at bottom, 21' below the ground surface, with 1:1 side slopes,
3. Quantities provided are neat line
4. Trench cross sectional area stays constant across the length of the cut and trench elevation follows the elevation of the surface above.
5. Two high density polyethylene pipes size 72" OD, 66" ID and 1000' long
6. Siphons have aluminum box on north end (no flap gates), screwgate on south end
7. Aluminum box intake is 10' wide, 10' long, and 8' deep with aluminum grating on top
8. Siphon anchors are wooden piling with an embedment length of 16', 6 piles for each siphon pipe on both north and south ends
9. Box intakes are supported by nine 12" diameter 16' long wooden piles

A. Magnolia cut Siphon quantity Summary

Work Detail	Quantity	Length	Volume	Total
Pipeline Excavation Trench (21' deep)	1 ea	1000 ft	819000 FT^3	30333 CYD
Pipeline Backfill	1 ea	1000 ft	762451 FT^3	28239 CYD
Pipe (3" thick and 66" inside diameter)	2 ea	1000 ft		2000ft
Box intake (10'x10' aluminum box with grate)	2 ea			2 ea
Aluminum/Stainless Steel Screwgates (South of GIWW)	2 ea			2 ea
Siphon Anchor Piling (12" diameter, 24' length)	24 ea			24 ea
Box Intake Piling (12"diameter, 16' length)	18 ea			18 ea

Assumptions B

1. Diversion channel is 4 feet deep, 6 feet wide at base, 22 feet wide at top and 2200 feet long
2. Diversion pond will be 30' diameter with a depth of 8 feet
3. Breakwaters are existing and in place. Removal and reinstallation will be required during trench construction.
4. Assume 650 lb graded riprap resting on geotextile fabric with 4' crest width, 1:2 side slopes, and 5' height.
5. Construction is completed from barges using a clamshell dredge, no access roads to this area.
6. Pipeline trench is 18' wide at bottom, 21' below the ground surface, with 1:1 side slopes, quantities provided are neatline
7. Trench cross sectional area stays constant across the length of the cut and trench elevation follows the elevation of the surface above.
8. Two high density polyethylene pipes size 72" OD, 66" ID and 1000' long
9. Siphons have aluminum box on north end (no flap gates), screwgate on south end
10. Aluminum box intake is 10' wide, 10' long, and 8' deep with aluminum grating on top
11. Siphon anchors are wooden piling with an embedment length of 16', 6 piles for each siphon pipe on both north and south ends
12. Box intakes are supported by nine 12" diameter 16' long wooden piles

B. Oil Field Cut Siphon Quantity Summary

Work Detail	Quantity	Length	Volume	Total
Diversion Pond and Channel Excavation	1 ea	2200 ft	128855 FT^3	4772 CYD
Breakwaters (removal and reinstallation)		230 ft	8400	311

			FT^3	CYD
Pipeline Excavation Trench (21' deep)	1 ea	1000 ft	819000 FT^3	30333 CYD
Pipeline Backfill	1 ea	1000 ft	762451 FT^3	28239 CYD
Pipe (3" thick and 66" inside diameter)	2 ea	1000 ft		2000 FT
Box Intake (10'x10' aluminum box with grate)	2 ea			2 ea
Aluminum/Stainless Steel Screwgates (South of GIWW)	2 ea			2 ea
Siphon Anchor Piling (12" diameter, 24' length)	24 ea			24 ea
Box Intake Piling (12"diameter, 16' length)	18 ea			18 ea

HYDRAULICS & HYDROLOGY

Hydrodynamic and particle modeling were conducted by ERDC (Brown and Lackey, 2011) to identify the structure most effective in reducing tidal energy and salinity, while minimizing adverse effects on larval recruitment through the structures into the Salt Bayou system.

Hydrologic modeling exploring the effectiveness of the proposed siphons was conducted by the Texas Water Development Board (TWDB, 2009). Bathymetric, water quality, water level and velocity data were collected and used to develop and calibrate a high resolution, three-dimensional hydrodynamic and salinity transport model for the region.

REAL ESTATE

- Measure 9-1: Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County.
  Total Estimated Real Estate Cost of Measure 9-1: $15,400 ®

- Measure 9-1: Inverted Siphons Under GIWW, Jefferson County.
  Total Estimated Real Estate Cost of Measure 9-1: $71,000 ®

ENVIRONMENTAL

Historically, Salt Bayou was a fresh to intermediate wetland that transitioned into brackish conditions near the downstream confluence with Taylor Bayou and Sabine Lake. Construction of the GIWW in1933, however, severed Salt Bayou from the upper drainage basin, and eliminated the primary source of freshwater inflow to the wetland. For decades, rainfall has been the main

source of freshwater for this wetland and the only source available to ameliorate salinity intrusion. Presently, two sources of saline water contribute to sustained increases in salinity throughout the system. These two sources are (1) the Keith Lake Fish Pass which connects Keith Lake/Salt Bayou to the SNWW and the Sabine Lake estuary and (2) erosion of the beach ridge along the McFaddin NWR property which allows Gulf seawater to wash into interior marshes during high tides and storm surges (addressed by measures 4-2.1 and 5-3).

Measure 9-1 (Keith Lake Fish Pass Structure) would reduce the frequency of salinity spikes over the 50,000 acres of the Salt Bayou system, while maintaining an acceptable level of fishery and larval access through the structure. Modeling indicates that the frequency of these high salinity episodes would be reduced by about 20 percent, lowering stress on the fresher portions of the marsh and preserving the health of the marsh system (ERDC, 2011).

Measure 9-2 (Siphons Under the GIWW) would restore hydrologic connectivity to freshwater flows and help to reduce salinities across the 50,000-acre Salt Bayou system. Modeling results have shown that both siphon locations are able to reduce salinities, but that the extent of salinity reduction would vary throughout the year (TWDB, 2009).

Both measures affect the same 50,000-acre Salt Bayou system. Environmental benefits are presented in wetland acres that would be protected by this measure. The wetland acres were calculated with a GIS analysis of National Wetland Inventory wetland maps (USFWS, 2012). The environmental benefit for both measures (taken together) are 20,200 wetland acres (emergent marsh, bottomland hardwood forest, swamp and scrub-shrub). The Salt Bayou System has national, state and local significance and restoration to the system would contribute to numerous Federal, state and local programs and plans.

BENEFITS

All benefits are assumed be environmental for this phase of analysis.

COSTS

No real estate cost have been included. The cost estimate for measure 9-1 is $ 7,254,000.

Cost Assumptions for 9-1:

- Construction would require clearing and grubbing
- No access road available
- Wood Pallets need for construction
- 12" Cutter-Suction Pipeline Dredge (and/or Clamshell Dredge/Barge)
- Backfill and Compact, Geotextile, and Limestone

- Prime 8(a) with Sub (LB), markups in unit prices,
- Contingency was increased to 30% to account for unspecified dredge material placement area requirements; type of access (water and/or road)

The cost estimate for measure 9-2 is $ 11,711,000.

Cost Assumptions for 9-2:

- All water access.
- Construction is completed from barges using a clamshell dredge.
- Large hopper scows with 4 extra, resting on GIWW (one-way traffic) for each site with an additional 10 large hopper scows to account for grounding at 12 ft depth. i.e half filled.
- Start and finish Site before starting and finishing site 2.
- Prime 8(a) with Sub (LB), markups in unit prices,
- Contingency was increased to 45% to account for GIWW traffic; ability to acquire 20 large hopper scows and scow tie-ups/grounding along GIWW not to impede traffic and potential de-grounding of each scow and maintenance dredging of grounding disturbance; type of access (all water); slumping of trench cut in GIWW; control of water structures at levee/marsh breach (fresh/salt mix).

REFERENCES

Evaluation of Proposed Salinity Mitigation Measures Modifications at Keith Lake Fish Pass Gary L Brown and Tahirih Lackey, USACE-ERDC-CHL, November 30, 2011

SWG-2010-00016 USWFS Permit Application, public notice date 19 April 2010.

TWDB (D. Pothina and C. Guthrie). 2009. Evaluating Inverted Siphons as a Means of Mitigating Salinity Intrusion in the Keith Lake/Salt Bayou System, Jefferson County, Texas. Report submitted to U.S. Environmental Protection Agency, Gulf of Mexico Program.

RISKS

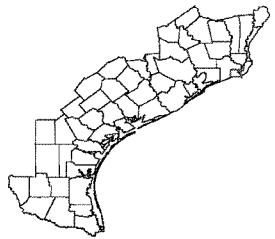
1. Measure 9-2 there is no road access. All water access.

2. The existing design does not include shoreline protection to prevent flanking; H&H modeling indicated that erosion could be a problem east of the structure. Rock armoring of the KLFP shoreline would need to be added on both sides east of the structure to prevent erosion during

high ebb flows. Armoring is not needed west (upstream) of the structure as flows are not expected to exceed existing conditions with the structure in place

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 9: Saltwater Control Structure and Inverted Siphons, Jefferson County



Legend

Measure 9

PLACEMENT AREA LIMITS
CHANNEL CURVE LIMIT DIMENSION
CHANNEL TOE
CHANNEL CENTERLINE
CHANNEL TOE
CHANNEL STATIONS

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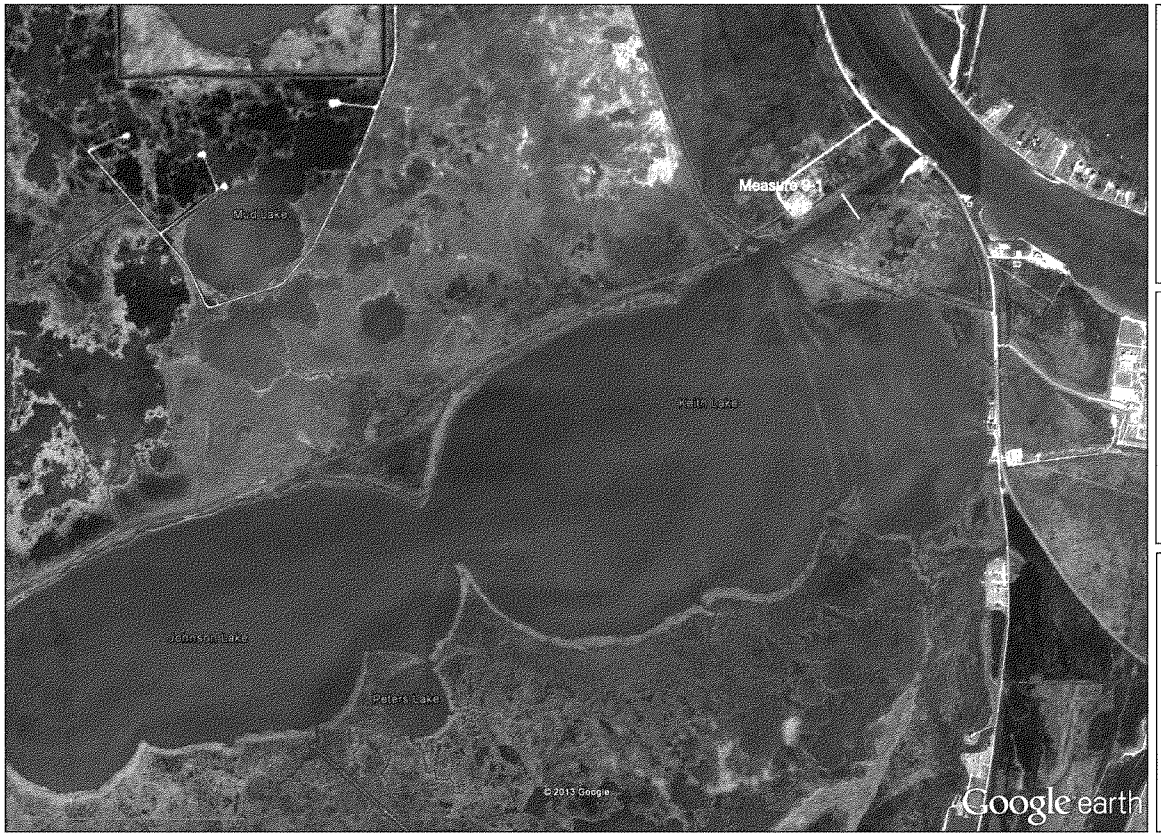
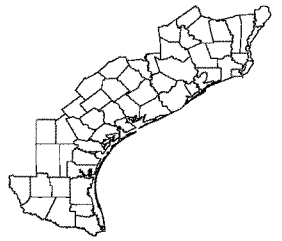
Date Created: 4/15/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 9-1: Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County





Legend

Measure 9-1

PLACEMENT AREA LIMITS

CHANNEL CURVE LIMIT DIMENSION

CHANNEL TOE

CHANNEL CENTERLINE

CHANNEL TOE

CHANNEL STATIONS

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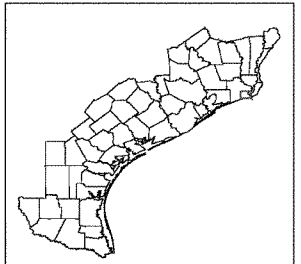
Date Created: 4/15/2013

Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 9-2: Inverted Siphons Under GIWW, Magnolia Cut, Jefferson County



Legend

Measure 9-2A

PLACEMENT AREA LIMITS
CHANNEL CURVE LIMIT DIMENSION
CHANNEL TOE
CHANNEL CENTERLINE
CHANNEL TOE
CHANNEL STATIONS

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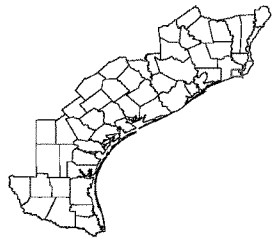
Sabine Pass to Galveston Bay Texas, Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study

Measure 9-2: Inverted Siphons Under GIWW, Oil Field Cut, Jefferson County



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Measure 9-2B

PLACEMENT AREA LIMITS
CHANNEL CURVE LIMIT DIMENSION
CHANNEL TOE
CHANNEL CENTERLINE
CHANNEL TOE
CHANNEL STATIONS

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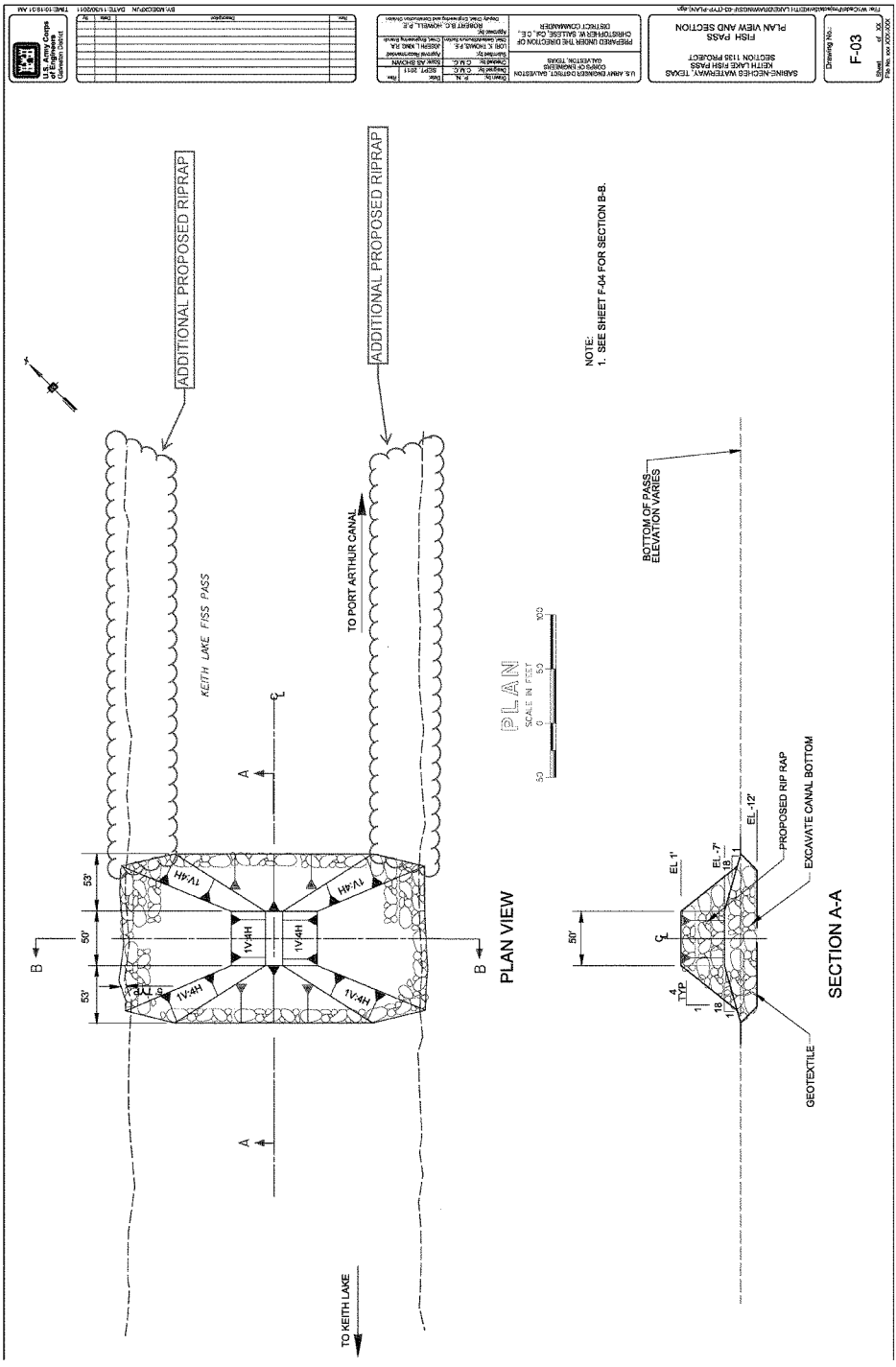
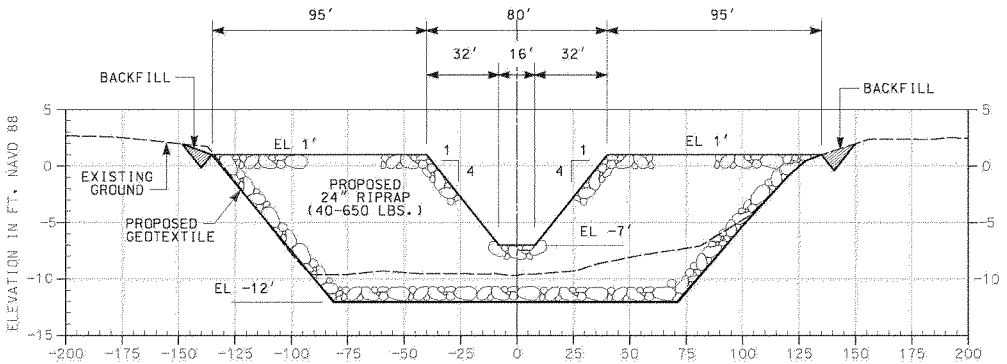
Date Created: 4/15/2013

ISLAND
PORT ARTHUR CANAL
KEITH LAKE
NAVIGATION TOWER
EXISTING SALT WATER BARRIER
ROUTE FOR NEW ACCESS ROAD, TEMPORARY WOOD PALLETS APPROX. WIDTH: 25', APPROX. ROAD LENGTH: 1500'.
STRUCTURE LOCATION APPROX. FOOTPRINT 350' X 300'
TEMPORARY WOOD PALLETS FOR ACCESS ROAD OVER WETLAND APPROX. 233' X 150'
PLACEMENT AREA FOR EXCAVATION MATERIAL APPROX. 200' X 200'
EXISTING PRIVATE COUNTY ROAD (ATOP OLD LEVEE); ACCESS TO STAGING AREA APPROX. WIDTH: 25 FEET, APPROX. ROAD LENGTH: 3,000 FEET.
TEMPORARY WOOD PALLETS FOR ACCESS ROAD OVER WETLAND APPROX. 233' X 150'
STAGING AREA APPROX. 140'X125'
ROUTE FOR NEW ACCESS ROAD ATOP OLD LEVEE APPROX. WIDTH: 25 FEET, APPROX. ROAD LENGTH: 1000 FEET.
10+00
15+00
20+00
25+00
82
87
LEGEND:
EXISTING ROAD
NEW ROAD
HIGHWAY
GRAVEL ROAD
PIPELINE
PLAN
SCALE IN FEET
0
400
800
1,200
13,862,500
3,565,500
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF
CHRISTOPHER W. BALLESE, CW, CLE,
DISTRICT COMMANDER
GABLINE-NECHES WATERWAY, TEXAS
KEITH LAKE FISH PASS
SECTION 1135 PROJECT
PLAN VIEW
Drawing No.
F-02
Sheet 1 of 1 SHEETS
File No. 001-0002


ADDITIONAL PROPOSED RIPRAP
ADDITIONAL PROPOSED RIPRAP
KEITH LAKE FISS PASS
TO PORT ARTHUR CANAL
TO KEITH LAKE
PLAN VIEW
PLAN
SCALE IN FEET
NOTE:
1. SEE SHEET F-04 FOR SECTION B-B.
BOTTOM OF PASS
ELEVATION VARIES
SECTION A-A
PROPOSED RIP RAP
EXCAVATE CANAL BOTTOM
GEOTEXTILE
EL. 1'
EL. -7'
EL. -12'
50'
53'
1V:4H
SABINE-NECHES WATERWAY, TEXAS
KEITH LAKE FISH PASS
SECTION 1135 PROJECT
FISH PASS
PLAN VIEW AND SECTION
Drawing No.
F-03



SECTION B-B

SCALE: AS SHOWN

DATUM	
NAVD 88	MLLW
0′	0.42′
-7.0′	-7.42′

NOTE:
1. SEE SHEET F-03 FOR PLAN VIEW.
2. GEOTEXTILE FABRIC TO BE TURNED DOWN 2′ AT 1V:1H SLOPE.

U.S. Army Corps of Engineers
Galveston District

SABINE/ANCHOR WATERWAY, TEXAS
KEITH LAKE FISH PASS
SECTION 1135 PROJECT

FISH PASS
SECTION B-B

Drawing No.
F-04
Sheet 4 of XX
File No. xxx-xxx-xxxx

APR 22 200

SWG-2010-00016
USFWS-McFaddin NWR
Page 4 of 12

APR 22 2009

North End of Siphons – Box intake

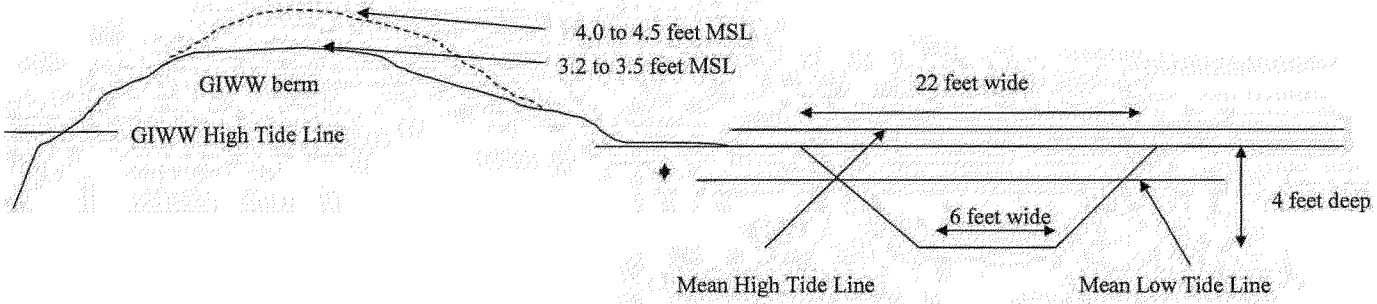
SWG-2010-00016
USFWS-McFaddin NWR
Page 5 of 12

Trench will have a depth of 33 feet (6'for pipe + 15' below channel depth + 12' channel) and bottom width of 18 feet.
Trench side slope with will be a 1:1 ratio and extend 21 feet either side of center of trench.
Total Trench width will be 60 feet wide.

APR 22 2009

SWG-2010-00016
USFWS-McFaddin NWR
Page 10 of 12

Cross Section View of Diversion Channel

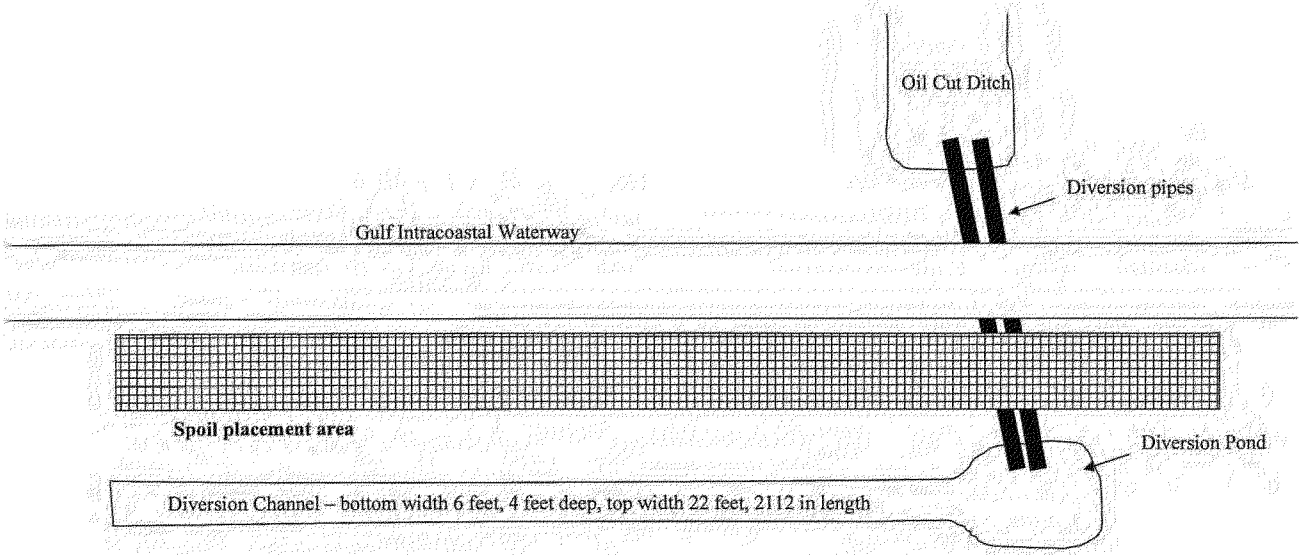


- Water depth at mean high tide is 2 inches above marsh elevation.
- Water depth at mean low tide is 6 inches above marsh elevation.
- Tidal exchange limited to sheet flow across the marsh from Barnett Lake located over 2200 feet away.
- Channel construction will require 4646 cubic yards of spoil to be removed from ditch, to be placed on the existing GIWW spoil shoreline
- Diversion channel moves water to the west into the Wild Cow Bayou marsh then through structures into the marsh surrounding Barnett Lake.
- GIWW shoreline will be elevated between 1 to 2 feet with spoil material to help stop salt water intrusion from the GIWW.

Notice: These water levels are inside a structurally controlled area.

APR 22 200

Aerial View of Siphon and Diversion Channel



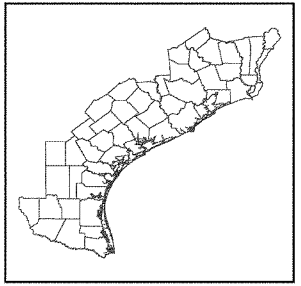
Diversion Channel's spoil material will be place on the existing shoreline to increase GIWW elevation to stop salt water intrusion.
Diversion channel will create 4646 cubic yards of material from the ditch will be placed on the existing shoreline berm.
Pond will be 30 feet diameter with a depth of 8 feet. Spoil material to be placed on GIWW shoreline berm.
Pond will create 267 cubic yards of material from the pond site which will be placed on the existing shoreline berm.

SWG-2010-00016
USFWS-McFaddin NWR
Page 12 of 12

APR 2 9 200

472

Measure 5-15: Brazoria County - Segmented Near-Shore Breakwaters



Legend

Submerged Breakwaters

0 160 320 640 960 1,280

Feet

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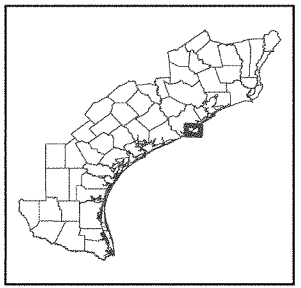
Date Created: 2/26/2013

Measure 5-15: Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria County



Legend

Nearshore Breakwaters

Nearshore Breakwaters

0 2,800 5,600 11,200 16,800 22,400

Feet

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Date Created: 4/24/2013

Sabine Pass to Galveston Bay, Texas
Coastal Storm Risk Management and Ecosystem Restoration
Final Integrated Feasibility Report and Environmental Impact Study

Appendix B

Plan Formulation

May 2017

TABLE OF CONTENTS

1 PLAN FORMULATION RATIONALE 1-1

2 MANAGEMENT MEASURES 2-1

2.1 NONSTRUCTURAL MEASURES 2-2
2.2 STRUCTURAL MEASURES 2-2

3 SUMMARY OF ALTERNATIVE ANALYSIS 3-1

3.1 INITIAL SCREENING OF MEASURES 3-1
3.1.1 Initial Screening of Measures Criteria 3-1
3.1.2 Initial Screening of Measures Prior to Alternative Formulation 3-1

4 BASIS FOR CHOICE 4-1

4.1 METHODOLOGY TO ANALYZE TECHNICAL CRITERIA 4-1
4.2 METHODOLOGY TO ANALYZE ECONOMIC CRITERIA 4-2
4.3 METHODOLOGY TO ANALYZE ENVIRONMENTAL CRITERIA 4-2
4.4 METHODOLOGY TO ANALYZE SOCIAL AND OTHER CRITERIA 4-3
4.5 KEY UNCERTAINTIES 4-3

5 INITIAL ARRAY OF ALTERNATIVE PLANS 5-1

5.1 FUTURE WITHOUT-PROJECT CONDITION (NO ACTION ALTERNATIVE) 5-1
5.2 INITIAL ARRAY OF ALTERNATIVES 5-1
5.2.1 Sabine Region 5-1
5.2.2 Galveston Region 5-2
5.2.3 Brazoria Region 5-4
5.3 INITIAL SCREENING CRITERIA 5-5
5.3.1 Economic Benefit Criterion 5-5
5.3.2 Environmental Benefit Criterion 5-6
5.3.3 Implementation Costs Criterion 5-6
5.3.4 Environmental Impacts Criterion 5-6
5.4 INITIAL SCREENING OF ALTERNATIVES 5-6
5.5 EVALUATION ARRAY OF ALTERNATIVE PLANS CARRIED FORWARD 5-20

6 EVALUATION ARRAY OF ALTERNATIVE PLANS 6-1

6.1 EVALUATION ARRAY OF ALTERNATIVES 6-1
6.2 EVALUATION SCREENING OF ALTERNATIVES 6-1
6.2.1 Development of Alternative Alignments 6-2
6.2.2 Hydraulic and Hydrology (H&H) Analysis 6-5
6.2.3 Geotechnical and Structures Analysis 6-9
6.2.4 Environmental Impacts 6-9
6.2.5 Wetlands and Hydrology 6-9
6.2.6 HTRW 6-13
6.2.7 Real Estate Analysis 6-14
6.2.8 Economic Analysis 6-15
6.2.9 Cost Estimates 6-16
6.2.10 Port of Beaumont: Evaluation of Storm Surge Impacts on Functionality and Operations of Port 6-17
6.2.11 Conclusion of Gate/No-Gate Screening 6-18
6.3 SCOPING OF STUDY UNDER 3X3X3 GUIDELINES 6-18

6.4 IDENTIFICATION OF FINAL ARRAY OF ALTERNATIVES 6-19

7 COMPARISON OF FINAL ARRAY OF ALTERNATIVE PLANS AND DECISION CRITERIA 7-1

7.1 FINAL ARRAY OF ALTERNATIVES 7-1
7.1.1 Final Screening Criteria 7-2
7.1.2 Final Array Evaluation Results 7-3
7.1.3 FWOP Conditions Updates for the Final Array of Alternatives 7-3
7.1.4 Existing Hurricane Flood Protection Facilities 7-6
7.1.5 Economic Evaluation 7-10
7.1.6 Life Safety 7-19
7.1.7 Critical Infrastructure 7-19
7.1.8 Relative Sea Level Change 7-22
7.2 FINAL ARRAY EVALUATION RESULTS 7-23
7.2.1 Orange-Jefferson CSRM 7-23
7.2.2 Port Arthur and Vicinity 7-29
7.2.3 Freeport and Vicinity CSRM 7-31
7.2.4 Sabine and Brazoria Nonstructural Buyouts 7-36
7.3 COMPARISON OF ALTERNATIVE PLANS 7-36
7.4 IDENTIFYING A TENTATIVELY SELECTIVE PLAN (TSP) 7-42
7.5 SELECTION OF THE RECOMMENDED PLAN 7-43
7.5.1 SELECTION OF THE RECOMMENDED PLAN SUMMARY 7-48
7.5.2 COST SUMMARY OF THE RECOMMENDED PLAN 7-49
7.5.3 SEPARABLE ELEMENTS 7-55
7.5.4 CHANGES TO TSP AND SELECTION OF THE RECOMMENDED PLAN SUMMARY 7-55
7.5.5 REMOVAL OF BEAUMONT A NEW LEVEE (12-FOOT) AND JEFFERSON MAIN NEW LEVEE (11-FOOT) FROM RECOMMENDED PLAN 7-56
7.5.6 REEVALUATION OF ORANGE 3 AS A COMPONENT OF THE RECOMMENDED NED PLAN 7-57
7.5.6.1 REVALUATION OF ORANGE 3 VS GATE 7-57
7.5.6.2 REEVALUATION OF ORANGE 3 VS RING LEVEES OR NONSTRUCTURAL MEASURES 7-58
7.5.7 CONFIRMATION OF ORANGE 3 AS A COMPONENT OF THE RECOMMENDED NED PLAN 7-62

LIST OF FIGURES

Figure 2-1. Study Area showing 100-year storm surge and Economic Regions for benefits 2-7
Figure 5-1. Maeslantkering Closure Structure, Netherlands 5-3
Figure 6-1. Gate Alternative 6-3
Figure 6-2. No-Gate Alternative 6-4
Figure 6-3. Sabine Region 100-Year Flood Inundation – Without-Project Condition 6-6
Figure 6-4. Sabine Region – No-Gate Alternative 6-7
Figure 6-5. Sabine Region – Gate Alternative 6-8
Figure 6-6. Joint probability of discharge (Q) and water level. 6-9
Figure 6-7. Impact of Wetlands with Gate Alternative 6-11
Figure 6-8. Impact of Wetlands with No-Gate Alternative 6-12
Figure 7-1. Orange-Jefferson CSRM and Port Arthur and Vicinity CSRM Project Areas 7-4

Figure 7-2. Freeport and Vicinity CSRM Project Areas 7-5
Figure 7-3. Existing Floodwall in the Orange-Jefferson CSRM Project Areas 7-7
Figure 7-4. Port Arthur and Vicinity CSRM Failure Locations 7-8
Figure 7-5. Existing HFPP in Freeport and Vicinity CSRM 7-9
Figure 7-6. Orange-Jefferson Alternative Reaches 7-13
Figure 7-7. Port Arthur and Vicinity Failure Locations 7-15
Figure 7-8. Freeport and Vicinity CSRM Failure Locations 7-18
Figure 7-9. Location of Optimization Alternatives in the Orange-Jefferson CSRM Project Area 7-25
Figure 7-10. Optimization Alternatives - Port Arthur and Vicinity CSRM Project Area 7-30
Figure 7-11. Location of Optimization Alternatives in the Freeport and Vicinity CSRM Project Area 7-33
Figure 7-12. Orange County Critical Infrastructure 7-46
Figure 7-13. Jefferson County Critical Infrastructure 7-47
Figure 7-14. Orange-Jefferson CSRM Plan 7-52
Figure 7-15. Port Arthur and Vicinity CSRM Plan 7-53
Figure 7-16. Freeport and Vicinity CSRM Plan 7-54
Figure 7-17. Local industrial CSRM Improvements near Beaumont A 7-57
Figure 7-18. Orange 3 Structures in 100 yr Flood Plain 7-59
Figure 7-19. Orange 3 Evaluation of Adams and Cow Bayou 7-60
Figure 7-20. Orange 3 Evaluation of Adams and Cow Bayou Structures Removed 7-62

LIST OF TABLES

Table 2-1. Sabine Pass to Galveston Bay, Texas Structural Measures 2-3
Table 3-1. Initial Screening Criteria 3-1
Table 3-2. Measures Eliminated from Further Consideration 3-1
Table 5-1. Sabine Region, Initial Array of Alternative Plans 5-2
Table 5-2. Galveston Region, Initial Array of Alternative Plans 5-4
Table 5-3. Brazoria Region, Initial Array of Alternative Plans 5-5
Table 5-4. Criteria for Screening Initial Array 5-5
Table 5-5. Sabine Region Initial Alternatives Array 5-8
Table 5-6. Galveston Region Initial Alternatives Array 5-12
Table 5-7. Brazoria Region Initial Alternatives Array 5-16
Table 5-8. Ranking by Net Excess Benefits for Sabine Region Initial Array 5-17
Table 5-9. Ranking by Net Excess Benefits for Galveston Region Initial Array 5-18
Table 5-10. Ranking by Net Excess Benefits for Brazoria Region Initial Array 5-19
Table 5-11. Qualitative Analysis of Environmental Impacts Sabine Region 5-21
Table 5-12. Qualitative Analysis of Environmental Impacts Galveston Region 5-23
Table 5-13. Qualitative Analysis of Environmental Impacts Galveston Region 5-25
Table 5-14. Summary of Screening of Sabine Region Alternatives for Evaluation Array* 5-26
Table 5-15. Summary of Screening of Galveston Region Alternatives for Evaluation Array* 5-27
Table 5-16. Summary of Brazoria Region Alternatives Eliminated or Carried Forward to Evaluation Array* 5-28
Table 6-1. Evaluation Array of Alternatives 6-1
Table 6-2. Wetland Impacts Comparison of Potential Construction Impact Areas Neches River Gate and No-Gate Alternatives 6-13
Table 6-3. 100-Year HAZUS-MH Development by County 6-15
Table 6-4. 100-Year HAZUS-MH "Benefits" by County 6-16
Table 6-5. Estimated Total Cost (For Each Alternative) 6-17
Table 6-6. Final Array of Alternatives 6-20
Table 7-1. Final Array of Alternatives 7-1

Table 7-2. Relationship with Project Area, Alternative Reaches and Optimization Alternatives 7-2
Table 7-3. Expected Annual Damages Future Without-Project Condition for Orange-Jefferson CSRM (2015 price level) 7-14
Table 7-4. Expected Annual Damages Future Without-Project Conditions for Port Arthur and Vicinity CSRM (2015 price level) 7-17
Table 7-5. Expected Annual Damages Future Without-Project Conditions for Freeport and Vicinity CSRM (2015 price level) 7-20
Table 7-6. Population at Risk by Project Area.....7-20
Table 7-7. Estimated RSLC over the First 20 Years of the Project Life (2030-2050).....7-23
Table 7-8. Estimated RSLC over the First 50 Years of the Project Life (2030-2080).....7-23
Table 7-9. Estimated RSLC over the First 100 Years of the Project Life (2030-2130).....7-23
Table 7-10. Economic Performance of New Levees at Orange and Jefferson Counties 7-26
Table 7-11. Economic Performance of New Levees at Orange and Jefferson Counties 7-27
Table 7-12 Economic Performance of New Levees at Orange and Jefferson Counties 7-28
Table 7-13. Economic Performance of Port Arthur and Vicinity CSRM 7-32
Table 7-14. Economic Performance of Freeport and Vicinity 7-37
Table 7-15. Comparison of Final Array of Alternative by Planning Objectives 7-39
Table 7-16. Average Recommended Relative Sea Level Change (RSLC), Feet NAVD 7-42
Table 7-17. Cost Analyses Comparison for Optimization Alternatives in the Orange-Jefferson Project Area 7-44
Table 7-18. Ranges for RSLC for the Orange-Jefferson CSRM Project Area 7-48
Table 7-19. Economic Summary of the TSP for Orange-Jefferson CSRM 7-49
Table 7-20. Economic Summary of the TSP for Port Arthur and Vicinity CSRM.....7-50
Table 7-21. Economic Summary of the TSP for Freeport and Vicinity CSRM 7-51
Table 7-22: Overview of changes since release of DIFR-EIS 7-55
Table 7-23: Planning Review of "gate" alternative 7-58
Table 7-24 Evaluation of Orange Ring Levees.....7-61

1 PLAN FORMULATION RATIONALE

Plan formulation is the process of building alternative plans that meet planning objectives and develop alternatives within the planning constraints. Alternative plans are a set of one or more management measures functioning together to address one or more planning objectives. A management measure is a feature or activity that can be implemented at a specific geographic site to address one or more planning objectives. A feature is a structural element that requires construction, whereas an activity is a nonstructural action.

The planning process for this feasibility study is driven by the overall objective of developing a comprehensive plan that will help manage risks associated with coastal storms within the study counties while avoiding and minimizing impacts on the area's environmental resources.

Preliminary plans were formulated by combining management measures. Each plan was formulated in consideration of the following four criteria described in the Principles and Guidelines (P&G):

- Completeness: Extent to which the plan provides and accounts for all necessary investments or actions to ensure realization of the planning objectives
- Effectiveness: Extent to which the plan contributes to achieving the planning objectives
- Efficiency: Extent to which the plan is the most cost-effective means of addressing the specified problems and realizing the specified opportunities, consistent with protecting the nation's environment
- Acceptability: Workability and viability of the alternative plan with respect to acceptance by Federal and non-federal entities and the public, and compatibility with existing laws, regulations, and public policies

Initial study efforts involved a determination of the magnitude and extent of the problems within the study area in order to develop and evaluate an array of alternative solutions that meet the existing and long-range future needs of the non-Federal sponsor and the public. At the initiation of the feasibility phase of the project, lines of communication were opened with Federal, state, and local agencies, private groups, and the affected public. Four regional public scoping meeting were held across the study area during February to March 2012.

2 MANAGEMENT MEASURES

The initial array of measures was developed with public, local government, and agency input gathered during the four scoping meetings. During the scoping process, the measures were grouped geographically into the three major regions (Sabine, Galveston, and Brazoria).

Potential structural and nonstructural measures considered in this study were:

- Structural (raising roadways, levees, flood walls, flood gates, breakwaters, marsh/dune/shoreline restoration, hardening of infrastructure, etc.)
- Nonstructural (buyouts, raising structures, flood warning systems, floodplain management, regional sediment management, etc.)

Potential projects for the Sabine area include Gulf shoreline protection and restoration measures such as beach nourishment, dune restoration, Chenier ridge restoration, sediment management, shoreline armoring, and submerged near-shore breakwaters. Potential projects for the Galveston area include various Gulf shoreline protection and restoration measures such as beach nourishment, dune restoration, beach ridge restoration, sediment management, shoreline armoring, and submerged near-shore segmented breakwaters. Specific targets include but are not limited to the shoreline west of Rollover Pass and near Fort Travis. Projects may include development of a comprehensive regional sediment management plan for the Galveston Bay system and Gulf shoreline. Viability of Gulf shoreline projects is dependent on the General Land Office's (GLO) ability to acquire easements. Potential projects for the Brazoria area include various Gulf shoreline protection and restoration measures such as beach nourishment, dune restoration, sediment management, shoreline armoring and submerged near-shore breakwaters. Specific targets include Quintana/Bryan Beach, Surfside beach, and Follets Island.

At the SMART Planning Charrette, the full Vertical Team (USACE District, Division, Headquarters, and Office of Water Project Review) worked through an abbreviated version of the six-step planning process, considering a full array of measures and alternatives, and then formulated comprehensive (regional) plans to include in the Initial Alternative Plans Array. Information gathered during the public scoping process combined with work conducted at the Charrette resulted in identification of approximately 39 individual implementable measures; and five comprehensive regional alternative plans addressing the entire six-county area. Each plan included structural and nonstructural measures that would address CSRM and ER objectives.

During the Charrette, the team identified three criteria that would be utilized to evaluate the initial array of alternatives. The three criteria are: 1) Implementation Costs; 2) Damages Reduced; and 3) Environmental Benefits.

It was envisioned at the Charrette that these criteria would be used to evaluate the five alternatives that were developed from the measures during the Charrette. After the FCSA was signed and efforts began on data collection, the study team determined that many of the components of the different alternatives were redundant and that information on the measures was incomplete. The

Project Delivery Team (PDT) decided to deconstruct the alternatives, collect available targeted information, and refine/reformulate the measures for completeness and to eliminate redundancies.

This resulted in a list of about 75 reformulated initial measures that served as the building blocks of alternative plans. These nonstructural and structural measures are discussed in more detail in the sections below.

Nonstructural and structural measures were considered as part of the study analysis and were developed to address study objectives. These measures can be combined with other measures, nonstructural or structural, to form alternatives to be evaluated in this study process. Should additional measures be identified during the Plan Formulation Phase, measures will be appropriately reviewed and considered in the alternative analysis. These alternatives are screened in the Plan Formulation Phase, as discussed in the next chapter.

2.1 NONSTRUCTURAL MEASURES

The nonstructural measures considered included:

- Buyouts and Relocations; and
- Recreational / Conservation Areas

2.2 STRUCTURAL MEASURES

The structural measures included new coastal and inland structural barriers, reconstruction of existing and construction of new regional hurricane protection systems, local surge protection systems, and raising roads as surge or overwash protection barriers, Gulf shoreline protection (beach and dune restoration, nearshore breakwaters, chenier ridge restoration), Gulf Intracoastal Waterway (GIWW) erosion protection, marsh restoration, and salinity/water control structures.

Details on specific proposals were requested from proponents of several regional measures, in particular Measures 1, 2, and 3-3 through 3-9. Only the proponents of the existing Freeport and Vicinity Hurricane Flood Protection project (3-3) and Countywide Protection System for Orange (Measures 3-4 through 3-9) provided feasibility-level details. The information collected on other measures, including the Galveston Bay Coastal Barrier (Measure 1) and the Surge Gate and Barrier at the Hartman Bridge (Measure 2), were based on conference presentations or other publicly available information.

Using the criteria developed during the Charrette, the reformulated measures were screened and ranked. Table 2-1 presents the reformulated initial array of measures with initial implementation costs, economic benefits, and environmental benefits.

Table 2-1. Sabine Pass to Galveston Bay, Texas Structural Measures

Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Environmental Benefits* ($)
1	Galveston Bay Coastal Barrier, Chambers, Galveston and Harris Co.	6,232,500,000	14,042,424,000	121,000
2	Surge Gate and Barrier at Hartman Bridge, Harris Co.	801,842,000	3,054,181,000	3,200
3-1	Port Arthur and Vicinity, Texas Hurricane Flood Protection	64,148,000	4,446,704,000	0
3-2	Texas City, Texas Hurricane Flood Protection	36,985,000	2,139,339,000	0
3-3	Freeport and Vicinity, Texas Hurricane Flood Protection	123,784,000	2,195,837,000	0
3-4	Co.-Wide Protection System on Sabine River and East Bank of Neches River, Orange Co.	1,487,800,000	1,492,324,000	7,000
3-5	Co.-Wide Protection System on the East and West Bank of the Neches River, Orange Co. and Part of Jefferson Co.	1,743,500,000	1,535,553,000	7,400
3-6	Co.-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In, Orange Co. and Part of Jefferson Co.	1,549,463,000	1,849,554,000	31,500
3-7	Sabine River Crossing, Orange Co. and Calcasieu Parish	1,842,580,000	1,869,790,000	37,000
3-8	Orange Co. Industrial Complex Protection System, Orange Co.	212,970,000	115,004,000	650
3-9	Galveston Ring Levee, Galveston Co.	556,116,000	3,296,295,000	300
3-10.1	Local Surge Protection, Houston Ship Channel North, Harris Co.	1,161,307,000	624,822,000	2,000
3-10.2	Local Surge Protection, Houston Ship Channel South, Harris Co.	1,267,906,000	1,089,324,000	400
3-10.3	Local Surge Protection, Baytown, Harris Co.	327,545,000	2,368,000	6
3-10.4	Local Surge Protection, NASA, Harris Co.	154,571,000	15,276,000	20
3-10.5	Local Surge Protection, UTMB, Galveston Co.	85,661,000	34,832,000	0
3-10.6	Local Surge Protection, Chocolate Bayou, Brazoria Co.	472,997,000	5,109,000	125
4-1	Raise State Highway 146, Galveston and Harris Co.	563,090,000	3,073,296,000	2,900
4-2.1	Raise State Highway 87 from Sabine Pass to High Island, Jefferson and Chambers Co.	427,054,000	83,752,000	65,500
4-2.2	Raise State Highway 87 from High Island to Port Bolivar, Galveston Co.	366,947,000	15,432,000	10,400
4-2.3	Raise Co. Road 257, Brazoria Co.	177,974,000	35,709,000	4,100
5-1	Chenier Ridge Restoration, Jefferson Co.	328,136,000	-	1,200
5-2	BU of Dredged Material for Shoreline Nourishment at Texas Point, Jefferson Co.	256,210,000	-	250
5-3	Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Co.	3,351,642,000	-	65,500
5-4	Restore Beach Ridge, Sabine Pass to High Island, Jefferson and Chambers Co.	33,027,000	83,752,000	65,500

Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Environmental Benefits* ($)
5-5	Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Co.	226,676,000	-	65,500
5-6	Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston Co.	1,660,837,000	-	530
5-7	Beach Nourishment, East Galveston Island Seawall, Galveston Island	453,368,000	-	235
5-8	Dune Restoration and Beach Nourishment, West Galveston Island, Galveston Co.	1,201,816,000	-	420
5-9	Segmented Nearshore Breakwaters, West Galveston Island to San Luis Pass	165,435,000	-	420
5-10	Closing of Rollover Pass, Galveston Co.	6,873,000	-	42
5-11	Dune Restoration and Beach Nourishment, San Luis Pass to Surfside, Brazoria Co.	667,903,000	-	500
5-12	Dune Restoration and Beach Nourishment, Surfside to Brazos River, Brazoria Co.	247,862,000	-	45
5-13	Dune Restoration and Beach Nourishment, Brazos River to Brazos River Diversion channel, Brazoria Co.	409,410,000	-	540
5-15	Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria Co.	137,217,000	-	1,415
5-16	Groin at State Highway 332, Brazoria Co.	4,010,000	-	50
6-1.1	GIWW Breakwater at Old River Cove, Orange Co.	20,480,000	-	50
6-1.2	GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange Co.	10,215,000	-	131
6-2	GIWW Breakwaters, Neches River to High Island, Jefferson Co.	181,509,000	-	761
6-3	GIWW Barrier Island Restoration, North Pleasure Island, Jefferson Co.	3,542,000	-	64
6-4.1	GIWW Breakwaters, Bolivar Peninsula, Galveston Co.	141,782,000	-	867
6-4.2	GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston Co.	10,017,000	-	246
6-5.1	GIWW Breakwaters, West Bay, Galveston Co.	43,406,000	-	222
6-5.2	GIWW Barrier Island Restoration, West Bay 1, Galveston Co.	9,764,000	-	112
6-5.3	GIWW Barrier Island Restoration, West Bay 2, Galveston Co.	4,037,000	-	35
6-6.1	GIWW Breakwaters, Brazoria Co.	219,877,000	-	1,110
6-6.2	GIWW Barrier Island Restoration, West Bay, Brazoria Co.	18,202,000	-	215
7-1	Shoreline Protection, East Bay, Chambers Co.	137,121,000	-	600
7-2	Shoreline Protection, Bastrop Bay , Brazoria Co.	20,420,000	-	40
7-3	Island Restoration, Vingt-et-un, Chambers Co.	5,386,000	-	27

Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Environmental Benefits* ($)
8-1	Marsh Restoration, Bessie Heights East , Orange Co.	177,687,000	-	2,076
8-2	Marsh Restoration, Old River Cove , Orange Co.	23,805,000	-	1,210
8-3	Marsh Restoration, Rose City East , Orange Co.	25,833,000	-	568
8-4.1	Marsh Restoration, Pepper Grove Cove, Galveston Co.	17,047,000	-	294
8-4.2	Marsh Restoration, Long Point Marsh, Galveston Co.	45,561,000	-	1,661
8-5.1	Marsh Restoration, South of Keith Lake, Jefferson Co.	65,631,000	-	4,132
8-5.2	Marsh Restoration, Texas Point NWR, Jefferson Co.	80,098,000	-	5,172
8-6.1	Marsh Restoration, Pierce Marsh, Galveston Co.	52,173,000	-	2,076
8-6.2	Marsh Restoration, IH-10 Causeway, Galveston Co.	21,478,000	-	633
8-6.3	Marsh Restoration, Greens Lake, Galveston Co.	70,718,000	-	3,293
8-7. 1	Marsh Restoration, Gangs to Oxen Bayou, Galveston Co.	7,662,000	-	176
8-7.2	Marsh Restoration, Oxen to Mantel Bayou, Galveston Co.	15,679,000	-	390
8-7.3	Marsh Restoration, Dana Cove, Galveston Co.	12,301,000	-	213
8-7.4	Marsh Restoration, Jumbile Cove, Galveston Co.	14,652,000	-	316
8-7.5	Marsh Restoration, Bird Island to Maggies Cove, Galveston Co.	22,174,000	-	467
8-7.6	Marsh Restoration, Snake Island Cove, Galveston Co.	19,711,000	-	457
8-7.7	Marsh and Bayou Restoration, Sweetwater Preserve, Galveston Co.	7,257,000	-	447
9-1 & 9-2	9-1 Salt Water Control Structure, Keith Lake Fish Pass, Jefferson Co. 9-2 Inverted Siphons Under GIWW, Jefferson Co.	19,051,000	-	20,200
9-3	Sabine River Levee and Surge Gate including Louisiana levee extension	293,117,000	20,236,000	5,500
10-1.1	Sabine area buyouts			
10-1.2	Galveston area buyouts			
10-1.3	Brazoria County area buyouts			
10-2.1	Sabine area conservation area			
10-2.2	Galveston area conservation area			
10-2.3	Brazoria County area conservation area			

*Environmental Benefits calculated as number of wetland acres protected by measure

Measure Information Sheets with descriptions and maps of each measure are presented in Appendix A. Underlying assumptions and details for the benefit and cost estimates are provided in the Measure Information Sheets.

The economic benefits are the difference between without-project damages that would occur under the existing condition, and residual damages that would occur with a given measure in place. The extent of potential storm surge impacts were mapped using existing ADCIRC modeling (100-year storm event) recently completed by FEMA under the Flood Plain Map Modernization effort. Future-with (FWP) and without-project (FWOP) damages to structures, contents, and vehicles were calculated using the HEC-FIA (Flood Impact Analysis) software package which analyzes consequences for a given flood event, in this case, a 1% annual exceedance probability (100-year). Figure 2-1 shows the area for which economic damages were calculated. It is the economics map for the six-county region with cross-hatching that corresponds to the footprint of the 100-year event.

Environmental benefits for structural measures providing protection from a 100-year storm event were calculated using the acreages of wetlands impacted as identified by the ADCIRC modeling. Acreages for wetland benefits were calculated using GIS shape files based on the FWP flood depth grids. The shape files were used to clip wetland acreage from the 2012 National Wetlands Inventory (NWI) dataset. Some measures are intended to improve the resiliency of barrier islands and floodplains by preserving and/or restoring marsh or preventing marsh erosion. The effectiveness of these areas in attenuating storm surge could not be modeled with the 100-year storm event. Therefore, the acres of marsh restoration were based on the acres of marsh or barrier islands that would be restored. Other measures would raise roadways on barrier islands and headlands by about 6 feet. These barriers would have minimal protective effect against a 100-year storm, but they would have a significant effect as a first line of defense for storms of lower magnitude such as 10-, 20-, 30-year events. The higher roadbeds would prevent scouring and salinity insults to fresher wetland environments over a large area inland from the roadway. No H&H modeling was conducted to determine areas that would be protected by measures for the smaller but more frequent storm events. The wetland acre benefits for these measures assume that the raised highways would protect the marshes inland up to the vicinity of the Gulf Intracoastal Waterway.

Estimated costs for each measure are also provided in each table. These are Class 5 estimates, suitable for screening of concepts only. Some are based on total estimated costs provided by others and others were developed by analogy to other costs.

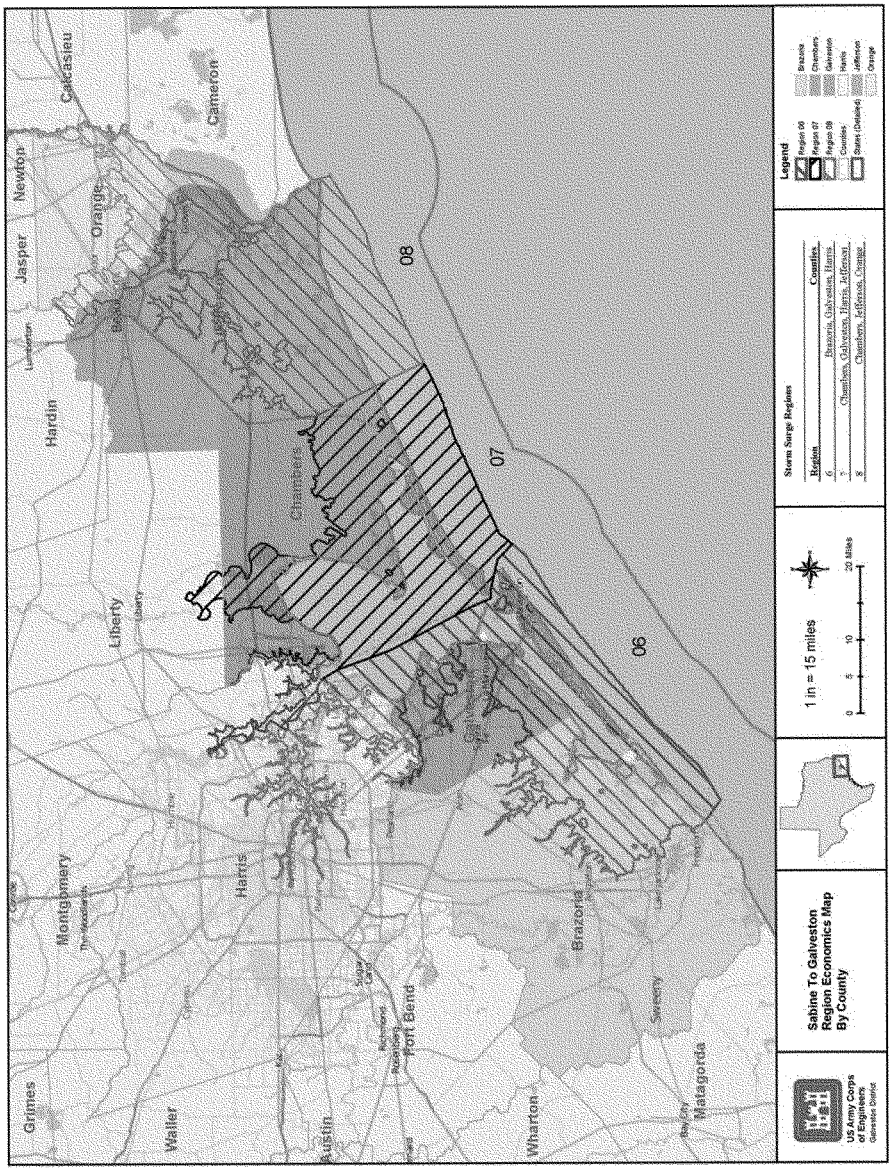


Figure 2-1. Study Area showing 100-year storm surge and Economic Regions for benefits

3 SUMMARY OF ALTERNATIVE ANALYSIS

3.1 INITIAL SCREENING OF MEASURES

3.1.1 Initial Screening of Measures Criteria

To evaluate and screen the initial measures to determine those that best meet the study and non-Federal sponsor objectives, an initial screening matrix was developed during the Planning Charette. Table 3-1 lists the screening criteria and metrics used in screening the measures.

Table 3-1. Initial Screening Criteria

Criteria	Metric
Damages reduced	Economic damages reduced based on water surface elevation
Environmental benefits	Acres habitat protected/restored by the plan
Implementation costs	Order of magnitude parametric (Class 5 cost estimates)

3.1.2 Initial Screening of Measures Prior to Alternative Formulation

After reformulation of the measures, each measure was evaluated to determine whether it would address one or more of the planning objectives, alone or in combination with other measures. Table 3-2 lists each measure that was eliminated from further consideration and the reason for elimination. If a measure could not meet at least one objective, the measure was dropped from further consideration in plan formulation.

Table 3-2. Measures Eliminated from Further Consideration

Measure Number	Measure Name	Reason for Elimination
Measure 3-4	County-Wide Protection System on Sabine River and East Bank of Neches River, Orange Co.	Reduces risk for Orange County only. Other measures retained that protected same areas while also protecting adjacent areas at risk in Jefferson and Orange County and Calcasieu Parish, Louisiana.
Measure 3-8	Orange Co. Industrial Complex Protection System, Orange Co.	Provides risk reduction for one industrial complex in Orange County. Does not reduce risk for other vulnerable areas of Orange or Jefferson County.
Measure 3-10.1	Local Surge Protection, Houston Ship Channel North, Harris Co.	Would be built in conjunction with Measure 3-10.2 and Measure 3-10.3. When combined, measures would reduce risk covered by Measure 2 but at higher cost.
Measure 3-10.2	Local Surge Protection, Houston Ship Channel South, Harris Co.	See Measure 3-10.1 Reason for Elimination
Measure 3-10.3	Local Surge Protection, Baytown, Harris Co.	See Measure 3-10.1 Reason for Elimination
Measure 3-10.4	Local Surge Protection, NASA, Harris Co.	Further examination of 100-year surge maps show only small undeveloped portion of NASA property would be impacted; therefore not expected to generate significant economic benefits

Table 3-2, continued

Measure Number	Measure Name	Reason for Elimination
Measure 3-10.5	Local Surge Protection, UTMB, Galveston Co.	UTMB area would be protected by Galveston ring levee or coastal barrier; therefore UTMB specific ring levee would be redundant. UTMB has also been undertaking measures to harden their facilities.
Measure 4-2.1	Raise State Highway 87 from Sabine Pass to High Island, Jefferson and Chambers Co.	Preferred measure for reach of coastline is to restore beach ridge (Measure 5-4) instead of rebuilding highway. Measure 5-4 reduces risk in same area but is much less expensive and restores natural feature.
Measure 4-2.2	Raise State Highway 87 from High Island to Port Bolivar, Galveston Co.	Houses in area behind reach are raised above level of protection provided by Measure 4-2.1. Minimal marsh area protected.
Measure 4-2.3	Raise Co. Road 257, Brazoria Co.	Measure is located on Follets Island from San Luis Pass to City of Freeport. TXGLO recently armored road. Little or no development exists north (bayside) of road; houses in area behind reach are raised above level of protection provided by measure; and natural barrier island system functioning well.
Measure 5-1	Chenier Ridge Restoration, Jefferson Co.	Considered to be technically infeasible and would not result in significant environmental risk reduction benefits.
Measure 5-2	BU of Dredged Material for Shoreline Nourishment at Texas Point, Jefferson Co.	Dredged material is fine-grained sediment and not expected to significantly reduce risk.
Measure 5-9	Segmented Nearshore Breakwaters, West Galveston Island to San Luis Pass	Segmented breakwaters were initially proposed along most of Gulf coastline within project area. Purpose of breakwaters was to retain sand and increase life of beach nourishment. Shoreline response with breakwaters is very sensitive to ambient climate, making it difficult to predict performance. Such large-scale application has never before been attempted. Therefore, measure was excluded from further consideration. Segmented breakwaters will be considered as part of beach nourishment design in places with extreme beach erosion, such as coast of Jefferson County.
Measure 5-15	Segmented Nearshore Breakwaters, San Luis Pass to Brazos River Diversion Channel, Brazoria Co.	See Measure 5-9 Reason for Elimination.
Measure 7-3	Island Restoration, Vingt-et-un, Chambers Co.	Measure would have restored former island (approximately 26 acres) off Smith Point. Eliminated because island provided little to no storm surge protection for mainland.

4 BASIS FOR CHOICE

As noted above, the measures were screened to determine if they adequately addressed the problems with Sabine to Galveston study and meet the objectives for this study. The remaining measures were then formed into arrays of alternatives plans, which were screened to determine the most effective alternatives. The screening consisted of three levels:

- Initial Array of Alternatives;
- Evaluation Array of Alternatives; and
- Final Array of Alternatives.

Each level consisted of more detailed analysis when compared to the previous level. The initial array was screened on a qualitative level, using screening criteria, scientific judgment from use of mapping and alternative footprints, as well as the professional expertise of the PDT to identify the implications of each alternative. No detailed environmental and economic analysis was included at this level. With the evaluation array, a screening matrix was developed, which included quantitative criteria such as quantities, costs, net excess benefits, environmental benefits and Benefit-to-Cost Ratios (BCRs). The final array of alternatives will be evaluated on more detailed calculations for BCRs and on their ability to effectively meet the four criteria in the P&G.

During analysis of the evaluation array of alternatives, a preliminary economic analysis was performed to calculate the net excess benefits and BCRs for each of the alternative plans.

The following are the methodology and evaluations that were used to develop the criteria used for screening the measures.

4.1 METHODOLOGY TO ANALYZE TECHNICAL CRITERIA

Technical criteria require reduction of CSRM while minimizing environmental impacts. These criteria require plans to comply with current USACE design standards for CSRM projects including future maintenance requirements. Technical criteria also require measures be compatible with the needs of Federal projects within the study areas.

The plans must consider specific environmental conditions of the area including soil conditions, topography, and terrestrial and aquatic ecosystems. Initial and evaluation screening of the alternatives was completed using existing information readily available and professional expertise and scientific judgment of the PDT. More detailed technical information (both historical data and specific information and analyses prepared for this project) will be used during screening of the final arrays of alternatives. Technical information with the corresponding screening level in which this information was used includes, but is not limited to, the following:

- Existing information prepared by others used by PDT to develop preliminary designs and quantities (all arrays);
- Aerial photography (all arrays);
- Previously published scientific reports related to the study area (all arrays);

- Marine and estuarine resource investigations (all arrays);
- Hydrodynamic Modeling (final array only);
- Salinity Modeling (final array only);
- RSLR Analysis (final array only);
- Storm Surge Modeling (final array only);
- Sediment and water quality analysis (final array only);
- 50-year life cycle (O&M requirements) (final array);
- Endangered and threatened species impact assessments (final array), and
- Habitat Evaluation Procedure/Habitat Suitability Models (final array only)

4.2 METHODOLOGY TO ANALYZE ECONOMIC CRITERIA

The economic criteria require that tangible benefits attributable to projects exceed project costs. Project benefits and costs are reduced to average annual equivalent values and related in a BCR. This ratio must exceed unity to meet the NED objective. Selected plans, whether structural, nonstructural, or a combination of both, should maximize excess benefits over costs; however, unquantifiable features must be addressed subjectively. These criteria are used to develop plans that achieve the objective of NED and provide a base condition for consideration of economically unquantifiable factors, which may impact project proposals.

The USACE planning guidelines required that the alternative that most reasonably maximizes net economic benefits, consistent with protecting the Nation's environment, be identified as the NED Plan. This NED Plan may be selected as the TSP. This process is addressed in more detail later in this report.

All structural and nonstructural measures for CSRM projects should be evaluated using the appropriate 50-year period of analysis beginning in 2017 and the applicable interest rate at the time of analysis. Total annual costs should include amounts for operation, maintenance, major replacements, and mitigation, as well as amortization and interest on the investment.

4.3 METHODOLOGY TO ANALYZE ENVIRONMENTAL CRITERIA

The general environmental criteria for projects are identified in Federal environmental statutes, executive orders, and planning guidelines. It is national policy that fish and wildlife resource conservation be given equal consideration with other study purposes in the formulation and evaluation of alternative plans. Care must be taken to preserve and protect significant ecological, aesthetic, and cultural values, and to conserve natural resources. These efforts also should provide the means to maintain and restore, as applicable, the desirable qualities of the human and natural environments. Alternative plans formulated to reduce the risk of damages from coastal storms should avoid damaging the environment to the extent practicable and contain measures to minimize or mitigate unavoidable environmental damages.

Throughout the study process, USACE Environmental Operating Principles (EOP) should be considered. The re-energized EOP principles, are considered at the same level as economic issues. The seven EOP principles are:

- Foster a culture of sustainability throughout the organization;
- Proactively consider environmental consequences of all USACE activities and act accordingly;
- Create mutually supporting economic and environmental solutions;
- Continue to meet our corporate responsibility and accountability under the law for activities undertaken by the USACE which may impact human and natural environments;
- Consider the environment in employing a risk management and systems approach throughout life cycles of projects and programs;
- Leverage scientific, economic, and social knowledge to understand the environmental context and effects of Corps actions in a collaborative manner; and
- Employ an open, transparent process that respects views of individuals and groups interested in USACE activities.

4.4 METHODOLOGY TO ANALYZE SOCIAL AND OTHER CRITERIA

Plans proposed for implementation should have an overall favorable impact on the social well-being of affected interests and have overall public acceptance. Structural and nonstructural alternatives must reflect close coordination with interested Federal and State agencies and the affected public. The effects of these alternatives on the environment must be carefully identified and compared with technical, economic, and social considerations and evaluated in light of public input.

4.5 KEY UNCERTAINTIES

The key uncertainties for this study are:

- Hydraulics and Hydrology (H&H) Modeling
- Environmental Impacts
- RSLR - While the future rate of RSLR in the study area is uncertain, it must be considered in project planning. RSLR consists of two components: global (eustatic) sea level rise and local subsidence. The uncertainty in the rates of eustatic sea level rise is evident in the variability of the different modeled rates given for the National Research Council (NRC, 1987) projections and the 2007 Intergovernmental Panel on Climate Change (IPCC). A similar degree of uncertainty exists with the rate of local subsidence although it is considered minor in this area of the coast.

5 INITIAL ARRAY OF ALTERNATIVE PLANS

Individual measures were developed and previously screened to satisfy the planning objectives in providing CSRM along the upper Texas Coast. Alternative plans were formulated through combinations of remaining management measures.

5.1 FUTURE WITHOUT-PROJECT CONDITION (NO ACTION ALTERNATIVE)

The No Action Alternative provides a baseline against which the benefits and impacts of action alternatives may be measured, and it is required by NEPA to be included among the alternative plans in the final array of alternatives. It is described in more detail in Section 3 of the main report.

5.2 INITIAL ARRAY OF ALTERNATIVES

In this phase, comprehensive alternative plans were formulated for each of the three regions in the six-county study area. This was done to make this task of formulating alternatives for such a large and diverse area more manageable. The alternatives are meant to be stand-alone plans that can be compared directly to one another. Alternatives have been included that are anchored to existing or proposed structural projects (or "hard" structures) as well as "soft" structural alternatives that could reduce impacts with ER or protection measures and improve the resiliency of the system. Some alternatives were intended to provide all-inclusive plans, and others were drafted to focus more closely on traditional structural or ER measures.

5.2.1 Sabine Region

The initial array of alternatives included eleven alternatives for the Sabine region, including alternatives which addressed CSRM and ER in combination and individually. These alternatives included plans to include evaluation of the existing HFP system, construction of additional levees to protect Orange County, the use of gated surge barrier structures in combination with the new levees, as well as environmental restoration measures such as beach and dune restoration, marsh and barrier island restoration, shoreline protection along the Gulf and the GIWW, nearshore breakwaters, and hydrologic restoration. Nonstructural alternatives were also considered.

The initial plans for the Sabine region are described in Table 5-1. These alternatives comprised the initial array of alternatives to which preliminary analyses were performed. Screening of the initial array of alternatives resulted in an evaluation array of alternative plans, which were carried forward for more detailed analysis and evaluation, and identification of a final array from which selection of the recommended plan was made. The evaluation array of alternative plans and its screening is presented in the next section of this report.

Table 5-1. Sabine Region, Initial Array of Alternative Plans

Alternative Number	Alternative Name	Description
S1	Sabine Inland Barrier All-Inclusive CSRM (Sabine & Neches Levees/HFP) and ER	Sabine and Neches Levees, Port Arthur HFP, beach and dune restoration, restore beach ridge, nearshore breakwaters, GIWW shoreline protection, marsh restoration on Neches River, Keith Lake and Texas Point, Salt Bayou hydrologic restoration
S2	Sabine Inland Barrier All-Inclusive CSRM (Neches Gate/Sabine Levees/HFP) and ER (without Salt Bayou measures)	Neches River Navigation Gate and Sabine Levees, Port Arthur HFP, beach and dune restoration, restore beach ridge, nearshore breakwaters, GIWW shoreline protection and barrier island restoration, marsh restoration on Neches River, Keith Lake, and Texas Point, Salt Bayou hydrologic restoration
S3	Sabine Inland Barrier All-Inclusive CSRM (Neches &Sabine Gates/Sabine Levees/HFP) and ER	Neches River Navigation Gate, Sabine Levees and Gate, Port Arthur HFP beach and dune restoration, restore beach ridge, nearshore breakwaters, GIWW shoreline protection, marsh restoration on Neches River, Keith Lake, and Texas Point, Salt Bayou hydrologic restoration
S4	Sabine Inland Barrier CSRM Focus (Sabine & Neches Levees/HFP)	Sabine and Neches Levees, Port Arthur HFP
S5	Sabine Inland Barrier CSRM Focus(Neches Gate/Sabine Levees/HFP)	Neches River Navigation Gate, Sabine Levees, Port Arthur HFP
S6	Sabine Inland Barrier CSRM Focus (Neches &Sabine Gates/Sabine Levees/HFP)	Neches River Navigation Gate, Sabine Levees and Sabine River Gate, Port Arthur HFP
S7	Sabine ER (without Neches River marsh restoration)	Sabine Living Shoreline, beach and dune restoration, restore beach ridge, nearshore breakwaters, GIWW shoreline protection Neches River to High Island, marsh restoration at Keith Lake and Texas Point, Salt Bayou hydrologic restoration
S8	Sabine ER (with surge barrier on upper Sabine River)	Beach and dune restoration, restore beach ridge, nearshore breakwaters, GIWW shoreline protection, marsh restoration on Neches River and at Keith Lake and Texas Point, Salt Bayou hydrologic restoration, Sabine River levees and gate
S9	Sabine Inland Barrier (Neches Gate/Sabine Levees/HFP) and ER	Neches River Navigation Gate and Sabine Levees, Port Arthur HFP, beach and dune restoration, restore beach ridge, GIWW shoreline protection Neches River to High Island, marsh restoration at Keith Lake and Texas Point, Salt Bayou hydrologic restoration
S10	Sabine GIWW Shoreline Protection	All GIWW shoreline protection measures
S11	Sabine Nonstructural Alternative	Buyouts and Lone Star-type Conservation Plan

5.2.2 Galveston Region

The initial array of alternatives included nine alternatives for the Galveston region, including alternatives which addressed CSRM and ER in combination and individually. These alternatives included plans to include evaluation of the existing HFP system, a coastal barrier, ring levees, gated surge barrier structures, as well as environmental restoration measures such as beach and dune restoration, marsh and barrier island restoration, shoreline protection along the Gulf and the GIWW, and nearshore breakwaters. Nonstructural alternatives were also considered.

Alternatives G1 and G4 (within the Galveston region) begin with the assumption that a new coastal barrier or new inland barrier, respectively, would be constructed and connected to raised roadways or an existing hurricane protection system to provide protection to all or part of the region. ER/CSRM measures are also included that would increase resiliency of the structural components. The alternatives are called all-inclusive because they contain every measure we believe would actively contribute to the effectiveness of the alternative. Alternatives G2 and G5 focus primarily on structural measures, while Alternative G7 focuses on ER measures. Some measures combine a more limited number of hard and soft structures in an attempt to identify more efficient alternatives. For example, Alternative G3 combines a hard structure (the Galveston Bay Coastal Barrier) with soft structures such as measures to reduce erosion of the GIWW and restore marshes, both of which would improve the resiliency of the barrier island on which the hard structure measure is located.

For Galveston Bay, the team included competing plans for large surge protection structures that have been proposed by Texas A&M University at Galveston and by the Severe Storm Prediction, Education, and Evacuation from Disasters (SSPEED) Center based at Rice University. The largest of the proposed structures would affect Galveston Bay, an economically important and environmentally sensitive bay system of almost 800 square miles. For Sabine Lake, the team also included a large surge protection plan that has been developed by Orange County, Texas and the Texas Water Development Board (TWDB). The proposed project closure structures are also equal to or larger than the Maeslantkering closure structure (Figure 5-1) located in the Netherlands and would be potentially constructed in multiple locations.

Figure 5-1. Maeslantkering Closure Structure, Netherlands

The PDT coordinated with Texas A&M University at Galveston, the SSPEED Center, and Orange County and utilized existing information and data during the initial evaluation of the project alternatives, including economic data and parametric cost estimates.

The initial plans for the Galveston region are described in Table 5-2. These alternatives comprised the initial array of alternatives to which preliminary analyses were performed. Screening of the initial array of alternatives resulted in an evaluation array of alternative plans, which were carried forward for more detailed analysis and evaluation, and identification of a final array from which selection of the recommended plan was made. The evaluation array of alternative plans and its screening is presented in the next section of this report.

Table 5-2. Galveston Region, Initial Array of Alternative Plans

Alternative Number	Alternative Name	Description
G1	Galveston Coastal Barrier All-Inclusive CSRM and ER (without GIWW Protection)	Coastal barrier and gates, and buyouts/relocations within a 500 ft buffer, beach and dune restoration, closing Rollover Pass, all marsh restoration, East Bay shoreline protection
G2	Galveston Coastal Barrier CSRM Focus	Coastal barrier and gates, and buyouts/relocations within a 500 ft buffer
G3	Galveston Coastal Barrier All-Inclusive CSRM and ER	Coastal barrier and gates, and buyouts/relocations within a 500 ft buffer, beach and dune restoration, closing Rollover Pass, all GIWW shoreline protection, all marsh restoration
G4	Galveston Inland Barriers Comprehensive CSRM and ER	Surge barrier and gates near Hartman Bridge, Texas City HFP, Galveston Ring Levee, Chocolate Bayou ring levee, Raise Hwy 146 and buyouts/relocations within a 500 ft buffer, beach and dune restoration, all GIWW shoreline protection, all marsh restoration, East Bay shoreline protection
G5	South Galveston Bay Inland Barriers CSRM Focus	Surge barrier and gates near Hartman Bridge, Texas City HFP, Galveston Ring Levee, Chocolate Bayou Ring Levee, Raise Hwy 146 and buyouts/relocations within a 500 ft buffer
G6	South Galveston Bay Local Protection CSRM Focus	Texas City HFP, Galveston Ring Levee, and Chocolate Bayou Ring Levee
G7	Galveston ER Barrier Island Protection	Beach and dune restoration, GIWW shoreline protection, marsh restoration, East Bay shoreline protection, closing Rollover Pass
G8	Galveston GIWW Shoreline Protection	All GIWW shoreline protection measures
G9	Galveston Nonstructural Alternative	Buyouts and Lone Star-like conservation plan

5.2.3 Brazoria Region

The initial array of alternatives included five alternatives for the Brazoria region, including alternatives which addressed CSRM and ER in combination and individually. These alternatives included plans to include evaluation of the existing HFP system, as well as environmental restoration measures such as beach and dune restoration, shoreline protection along the GIWW, and a groin. Nonstructural alternatives were also considered.

The initial plans for the Brazoria region are described in Table 5-3. These alternatives comprised the initial array of alternatives to which preliminary analyses were performed. Screening of the initial array of alternatives resulted in an evaluation array of alternative plans, which were carried forward for more detailed analysis and evaluation, and identification of a final array from which

selection of the recommended plan was made. The evaluation array of alternative plans and its screening is presented in the next section of this report.

Table 5-3. Brazoria Region, Initial Array of Alternative Plans

Alternative Number	Alternative Name	Description
B1	Brazoria Coastal Barrier All-Inclusive CSRM and ER	Freeport FHP, beach and dune restoration, groin, GIWW shoreline protection
B2	Brazoria Coastal Barrier CSRM Focus (revised)	Freeport HFP
B3	Brazoria ER	Beach and dune restoration, groin and GIWW shoreline protection
B4	Brazoria GIWW Shoreline Protection	All GIWW shoreline protection measures
B5	Brazoria Nonstructural Alternative	Buyouts and Lone Star-type conservation plan

5.3 INITIAL SCREENING CRITERIA

The Initial Alternatives were screened using three quantitative criteria (economic benefits, environmental benefits and implementation costs) and one qualitative criterion (environmental impacts) (Table 5-4) to develop the Evaluation Array of Alternatives.

Table 5-4. Criteria for Screening Initial Array

Criteria	Metric
Damages reduced	Economic damages reduced based on water surface elevation
Environmental benefits	Acres habitat protected/restored by the plan
Implementation costs	Order of magnitude parametric (Class 5 cost estimates)
Environmental Impacts	Qualitative Analysis using construction impacts on wetlands and sensitive habitat, system-wide hydrologic impacts, and endangered species impacts

5.3.1 Economic Benefit Criterion

It was assumed that economic benefits would equal the cost of storm damages that could be prevented by each measure. The footprint and flood depths of a 100-year storm event in the six-county region were determined using FEMA's ADCIRC models of the upper Texas coast. Economic damages were estimated by linking Hazus and HEC-FIA (Flood Impact Analysis). Hazus is standardized FEMA methodology for estimating potential losses from hurricanes and other natural disasters. HEC-FIA is a software package developed by the USACE Hydrologic Engineering Center that analyzes the consequences a flood events. These damages are roughly equivalent to insured losses, and do not include damages to the economy as a whole. The benefits for each measure in an alternative will be summed to calculate the total economic benefits for the alternative.

5.3.2 Environmental Benefit Criterion

It was assumed that environmental benefits would be equal to the acres protected from storm surge damages, and further that this acreage would be equivalent to the total acres of wetlands protected by each structural measure, or restored/protected by marsh restoration or erosion control measures. The benefits for each measure in an alternative were summed to calculate the environmental benefits for the alternative. The same impact footprint of a 100-year event that was used to develop the Economic benefits was used as the future without-project condition for the environmental analysis. Wetland acres protected by each measure were determined by clipping measure footprints from the 2012 National Wetlands Inventory.

5.3.3 Implementation Costs Criterion

Rough order of magnitude costs were refined for some measures with new information developed during this phase. Where no additional information was obtainable, costs provided by proponents were used. In general, costs used to select the final array equivalent to Class 5 or conceptual costs. All measure costs for both structural and ER measures were added together and compared to total economic benefits to develop the net excess benefits estimate in Table 5-5, Table 5-6, and Table 5-7 below. This is not customary; generally, costs for only those measures for which economic benefits have been calculated would be compared to economic benefits. This non-traditional approach was used in an effort to identify the strongest performing alternatives.

5.3.4 Environmental Impacts Criterion

This qualitative criterion was intended to provide information about the relative environmental impacts that could result from the implementation of each alternative. This is needed because the environmental benefit analysis does not consider either construction impacts or impacts to the environment that could occur during the period of analysis. Alternatives were scored as potentially having high, medium, or low environmental impacts based on the best professional judgment of the PDT and input from the resource agencies.

5.4 INITIAL SCREENING OF ALTERNATIVES

The economic and cost criteria were applied to screen the alternatives as shown in Table 5-5, Table 5-6, and Table 5-7. Table 5-8, Table 5-9, and Table 5-10 summarize the results of the economic and cost screening and rank the alternatives by net excess benefits.

The Environmental benefits criterion (acres protected) was used to inform decisions to retain or eliminate alternatives in the final array. For example, Alternatives S5 and G2 were retained, in part, because they have the potential to beneficially affect very large areas of significant coastal wetland habitats. Additional study is needed, as described below, to determine if the environmental effects of these surge barriers will be positive or negative.

Table 5-5. Sabine Region Initial Alternatives Array

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland acres)	
S1	**Sabine Inland Barrier All-Inclusive CSRM (Sabine & Neches Levees/HFP) and ER**							
	3-1	Port Arthur and Vicinity, Texas Hurricane Flood Protection	64,148,000	4,446,704,000	4,382,556,000	69.32	0	
	3-5	Co.-Wide Protection System on Sabine River and East Bank of Neches River, Orange Co.	1,743,500,000	1,535,553,000	-207,947,000	0.88	7,400	
	5-3	Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties	3,351,642,000				65,500	
	5-4	Restore Beach Ridge, Sabine Pass to High Island, Jefferson and Chambers Co.	33,027,000	83,752,000	50,725,000	2.54	65,500	*
	5-5	Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties	226,676,000				65,500	*
	6-1.1	GIWW Breakwater at Old River Cove, Orange County	20,480,000				50	
	6-1.2	GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County	10,215,000				131	
	6-2	GIWW Breakwaters, Neches River to High Island, Jefferson County	181,509,000				761	
	6-3	GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County	3,542,000				64	
	8-1	Marsh Restoration, Bessie Heights East , Orange County	177,687,000				2,076	
	8-2	Marsh Restoration, Old River Cove , Orange County	23,805,000				1,210	
	8-3	Marsh Restoration, Rose City East , Orange County	25,833,000				568	
	8-5.1	Marsh Restoration, South of Keith Lake, Jefferson County	65,631,000				4,132	*
	8-5.2	Marsh Restoration, Texas Point NWR, Jefferson County	80,098,000				5,172	*
	9-1	Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County	7,254,000				10,100	*
	9-2	Inverted Siphons Under GIWW, Jefferson County	11,711,000				10,100	*
		Total Alt S1	**6,026,758,000**	**6,066,009,000**	**39,251,000**	**1.01**	**77,760**	
S2	**Sabine Inland Barrier All-Inclusive CSRM (Neches Gate/Sabine Levees/HFP) and ER (without Salt Bayou measures**							
	3-1	Port Arthur and Vicinity, Texas Hurricane Flood Protection	64,148,000	4,446,704,000	4,382,556,000	69.32	0	
	3-6	County-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In, Orange County and Part of Jefferson County	1,549,463,000	1,849,554,000	300,091,000	1.19	31,500	
	5-3	Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties	3,351,642,000				65,500	
	5-4	Restore Beach Ridge, Sabine Pass to High Island, Jefferson and Chambers Co.	33,027,000	83,752,000	50,725,000	2.54	65,500	*
	5-5	Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties	226,676,000				65,500	*
	6-1.1	GIWW Breakwater at Old River Cove, Orange County	20,480,000				50	
	6-1.2	GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County	10,215,000				131	
	6-2	GIWW Breakwaters, Neches River to High Island, Jefferson County	181,509,000				761	
	6-3	GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County	3,542,000				64	
	8-1	Marsh Restoration, Bessie Heights East , Orange County	177,687,000				2,076	*

Table 5-5, continued

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland acres)	
	8-2	Marsh Restoration, Old River Cove , Orange County	23,805,000				1,210	*
	8-3	Marsh Restoration, Rose City East , Orange County	25,833,000				568	*
	8-5.1	Marsh Restoration, South of Keith Lake, Jefferson County	65,631,000				4,132	*
	8-5.2	Marsh Restoration, Texas Point NWR, Jefferson County	80,098,000				5,172	*
	9-1	Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County	7,254,000				10,100	*
	9-2	Inverted Siphons Under GIWW, Jefferson County	11,711,000				10,100	*
		Total Alt S2	**5,832,721,000**	**6,380,010,000**	**547,289,000**	**1.09**	**98,006**	
S3	**Sabine Inland Barrier All-Inclusive CSRM (Neches Gate/Sabine Levees/HFP) and ER**							
	3-1	Port Arthur and Vicinity, Texas Hurricane Flood Protection	64,148,000	4,446,704,000	4,382,556,000	69.32	0	
	3-7	Sabine River Crossing, Orange County and Calcasieu Parish	1,842,580,000	1,869,790,000	27,210,000	1.01	37,000	
	5-3	Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties	3,351,642,000				65,500	
	5-4	Restore Beach Ridge, Sabine Pass to High Island, Jefferson and Chambers Co.	33,027,000	83,752,000	50,725,000	2.54	65,500	*
	5-5	Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties	226,676,000				65,500	*
	6-1.1	GIWW Breakwater at Old River Cove, Orange County	20,480,000				50	
	6-1.2	GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County	10,215,000				131	
	6-2	GIWW Breakwaters, Neches River to High Island, Jefferson County	181,509,000				761	
	6-3	GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County	3,542,000				64	
	8-1	Marsh Restoration, Bessie Heights East , Orange County	177,687,000				2,076	*
	8-2	Marsh Restoration, Old River Cove , Orange County	23,805,000				1,210	*
	8-3	Marsh Restoration, Rose City East , Orange County	25,833,000				568	*
	8-5.1	Marsh Restoration, South of Keith Lake, Jefferson County	65,631,000				4,132	*
	8-5.2	Marsh Restoration, Texas Point NWR, Jefferson County	80,098,000				5,172	*
	9-1	Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County	7,254,000				10,100	*
	9-2	Inverted Siphons Under GIWW, Jefferson County	11,711,000				10,100	*
		Total Alt S3	**6,125,838,000**	**6,400,246,000**	**274,408,000**	**1.04**	**103,506**	*
S4	**Sabine Inland Barrier CSRM Focus (Sabine & Neches Levees/HFP)**							
	3-1	Port Arthur and Vicinity, Texas Hurricane Flood Protection	64,148,000	4,446,704,000	4,382,556,000	69.32	0	
	3-5	County-Wide Protection System on Sabine River and East Bank of Neches River, Orange County	1,743,500,000	1,535,553,000	(207,947,000)	0.88	7,400	
		Total Alt S4	**1,807,648,000**	**5,982,257,000**	**4,174,609,000**	**3.31**	**7,400**	

Table 5-5, continued

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland acres)	
S5	**Sabine Inland Barrier CSRM Focus(Neches Gate/Sabine Levees/HFP)**							
	3-1	Port Arthur and Vicinity, Texas Hurricane Flood Protection	64,148,000	4,446,704,000	4,382,556,000	69.32	0	
	3-6	County-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In, Orange County and Part of Jefferson County	1,549,463,000	1,849,554,000	300,091,000	1.19	31,500	
		Total Alt S5	**1,613,611,000**	**6,296,258,000**	**4,682,647,000**	**3.90**	**31,500**	
S6	**Sabine Inland Barrier CSRM Focus (Neches & Sabine Gates/Sabine Levees/HFP)**							
	3-1	Port Arthur and Vicinity, Texas Hurricane Flood Protection	64,148,000	4,446,704,000	4,382,556,000	69.32	0	
	3-7	Sabine River Crossing, Orange County and Calcasieu Parish	1,842,580,000	1,869,790,000	27,210,000	1.01	37,000	
		Total Alt S6	**1,906,728,000**	**6,316,494,000**	**4,409,766,000**	**3.31**	**37,000**	
S7	**Sabine ER (without Neches River marsh restoration)**							
	5-3	Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties	3,351,642,000				65,500	
	5-4	Restore Beach Ridge, Sabine Pass to High Island, Jefferson and Chambers Co.	33,027,000	83,752,000	50,725,000	2.54	65,500	*
	5-5	Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties	226,676,000				65,500	*
	6-2	GIWW Erosion Protection, Neches River to High Island, Jefferson County	181,509,000				761	
	8-5.1	Marsh Restoration, South of Keith Lake, Jefferson County	65,631,000				4,132	*
	8-5.2	Marsh Restoration, Texas Point NWR, Jefferson County	80,098,000				5,172	*
	9-1	Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County	7,254,000				10,100	*
	9-2	Inverted Siphons Under GIWW, Jefferson County	11,711,000				10,100	*
		Total Alt S7	**3,957,548,000**	**83,752,000**	**NA**	**NA**	**72,006**	
S8	**Sabine ER (with surge barrier on upper Sabine River)**							
	5-3	Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties	3,351,642,000				65,500	
	5-4	Restore Beach Ridge, Sabine Pass to High Island, Jefferson and Chambers Co.	33,027,000	83,752,000	50,725,000	2.54	65,500	*
	5-5	Segmented Nearshore Breakwaters, Sabine Pass to High Island, Jefferson and Chambers Counties	226,676,000				65,500	*
	6-1.1	GIWW Erosion Protection at Old River Cove, Orange County	20,480,000				50	
	6-1.2	GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County	10,215,000				131	
	6-2	GIWW Erosion Protection, Neches River to High Island, Jefferson County	181,509,000				761	
	6-3	GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County	3,542,000				64	
	8-1	Marsh Restoration, Bessie Heights East , Orange County	177,687,450				2,076	*
	8-2	Marsh Restoration, Old River Cove , Orange County	23,805,000				1,210	*

Table 5-5, continued

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland acres)	
	8-3	Marsh Restoration, Rose City East , Orange County	25,833,000				568	*
	8-5.1	Marsh Restoration, South of Keith Lake, Jefferson County	65,631,000				4,132	*
	8-5.2	Marsh Restoration, Texas Point NWR, Jefferson County	80,098,000				5,172	*
	9-1	Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County	7,254,000				10,100	*
	9-2	Inverted Siphons Under GIWW, Jefferson County	11,711,000				10,100	*
	10	Sabine River Levee and Gate	293,117,000	20,236,000	NA		5,500	
		Total Alt S8	**4,512,227,000**	**103,988,000**	**NA**	**NA**	**72,006**	
S9	**Sabine Inland Barrier (Neches Gate/Sabine Levees/HFP) and ER**							
	3-1	Port Arthur and Vicinity, Texas Hurricane Flood Protection	64,148,000	4,446,704,000	4,382,556,000	69.32	0	
	3-6	County-Wide Protection System with Neches River Closure and Port Arthur Levee Tie-In, Orange County and Part of Jefferson County	1,549,463,000	1,849,554,000	300,091,000	1.19	31,500	
	5-3	Dune Restoration and Beach Nourishment, Sabine Pass to High Island, Jefferson and Chambers Counties	3,351,642,000				65,500	
	5-4	Restore Beach Ridge, Sabine Pass to High Island, Jefferson and Chambers Co.	33,027,000	83,752,000	50,725,000	2.54	65,500	*
	6-2	GIWW Erosion Protection, Neches River to High Island, Jefferson County	181,509,000				761	
	8-5.1	Marsh Restoration, South of Keith Lake, Jefferson County	65,631,000				4,132	*
	8-5.2	Marsh Restoration, Texas Point NWR, Jefferson County	80,098,000				5,172	*
	9-1	Salt Water Control Structure, Keith Lake Fish Pass, Jefferson County	7,254,000				10,100	*
	9-2	Inverted Siphons Under GIWW, Jefferson County	11,711,000				10,100	*
		Total Alt S9	**5,344,483,000**	**$6,380,010,000**	**1,035,527,000**	**1.19**	**97,761**	
S10	**Sabine GIWW Shoreline Protection**							
	6-1.1	GIWW Erosion Protection at Old River Cove, Orange County	20,480,000	NA			50	
	6-1.2	GIWW Barrier Island Restoration, Old River and Hickory Coves, Orange County	10,215,000	NA			131	
	6-2	GIWW Erosion Protection, Neches River to High Island, Jefferson County	181,509,000	NA			761	
	6-3	GIWW Barrier Island Restoration, North Pleasure Island, Jefferson County	3,542,000	NA			64	
		Total Alt S11	**215,746,000**				**1,006**	
S11	**Sabine Nonstructural Alternative**							
	10-1.1	Buy-outs in Sabine Region (to be developed)	TBD					
	10-2.1	Lone Star Recreation and Conservation Area (to be developed)	TBD					

* Not included in total acreage because of overlap in Environmental Benefits for some measures

Table 5-6. Galveston Region Initial Alternatives Array

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland ac)	
G1	**Galveston Coastal Barrier All-Inclusive CSRM and ER (without GIWW Protection)**							
	1	Galveston Bay Coastal Barrier, Chambers, Galveston and Harris Co.	6,232,500,000	14,042,424,000	7,809,924,000	2.25	121,000	
	5-6	Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston County	1,660,837,000				530	
	5-7	Beach Nourishment, East Galveston Island Seawall, Galveston Island	453,368,000				235	
	5-8	Dune Restoration and Beach Nourishment, West Galveston Island, Galveston County	1,201,816,000				420	
	5-10	Closing of Rollover Pass, Galveston County	6,873,000				42	
	7-1	Shoreline Protection, East Bay, Chambers County	137,121,000				600	*
	8-4.1	Marsh Restoration, Pepper Grove Cove, Galveston County	17,047,000				294	*
	8-4.2	Marsh Restoration, Long Point Marsh, Galveston County	45,561,000				1,661	*
	8-6.1	Marsh Restoration, Pierce Marsh, Galveston County	52,173,000				2,076	*
	8-6.2	Marsh Restoration, IH-10 Causeway, Galveston County	21,478,000				633	*
	8-6.3	Marsh Restoration, Greens Lake, Galveston County	70,718,000				3,293	*
	8-7.1	Marsh Restoration, Gangs to Oxen Bayou, Galveston County	7,662,000				176	*
	8-7.2	Marsh Restoration, Oxen to Mantel Bayou, Galveston County	15,679,000				390	*
	8-7.3	Marsh Restoration, Dana Cove, Galveston County	12,301,000				213	*
	8-7.4	Marsh Restoration, Jumbile Cove, Galveston County	14,652,000				316	*
	8-7.5	Marsh Restoration, Bird Island to Maggies Cove, Galveston County	22,174,000				467	*
	8-7.6	Marsh Restoration, Snake Island Cove, Galveston County	19,711,000				457	*
	8-7.7	Marsh and Bayou Restoration, Sweetwater Preserve, Galveston County	7,257,000				447	*
		Total Alt G1	**9,998,928,000**	**14,042,424,000**	**4,043,496,000**	**1.40**	**122,227**	
G2	**Galveston Coastal Barrier CSRM Focus**							
	1	Galveston Bay Coastal Barrier, Chambers, Galveston and Harris Counties	6,232,500,000	14,042,424,000	7,809,924,000	2.25	121,000	
		Total Alt G2	**6,232,500,000**	**14,042,424,000**	**7,564,224,000**	**2.17**	**121,000**	
G3	**Galveston Coastal Barrier All-Inclusive CSRM and ER**							
	1	Galveston Bay Coastal Barrier, Chambers, Galveston and Harris Counties	6,232,500,000	14,042,424,000	7,809,924,000	2.25	121,000	
	5-6	Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston County	1,660,837,000				530	
	5-7	Beach Nourishment, East Galveston Island Seawall, Galveston Island	453,368,000				235	
	5-8	Dune Restoration and Beach Nourishment, West Galveston Island, Galveston County	1,201,816,000				420	
	5-10	Closing of Rollover Pass, Galveston County	6,873,000				42	
	6-4.1	GIWW Breakwaters, Bolivar Peninsula, Galveston County	141,782,000				867	*

Table 5-6, continued

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland ac)	
	6-4.2	GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County	10,017,000				246	*
	6-5.1	GIWW Breakwaters, West Bay, Galveston County	43,406,000				222	*
	6-5.2	GIWW Barrier Island Restoration, West Bay 1, Galveston County	9,764,000				112	*
	6-5.3	GIWW Barrier Island Restoration, West Bay 2, Galveston County	4,037,000				35	*
	6-6.2	GIWW Barrier Island Restoration, West Bay, Brazoria County	18,202,000				215	*
	8-4.1	Marsh Restoration, Pepper Grove Cove, Galveston County	17,047,000				294	*
	8-4.2	Marsh Restoration, Long Point Marsh, Galveston County	45,561,000				1,661	*
	8-6.1	Marsh Restoration, Pierce Marsh, Galveston County	52,173,000				2,076	*
	8-6.2	Marsh Restoration, IH-10 Causeway, Galveston County	21,478,000				633	*
	8-6.3	Marsh Restoration, Greens Lake, Galveston County	70,718,000				3,293	*
	8-7.1	Marsh Restoration, Gangs to Oxen Bayou, Galveston County	7,662,000				176	*
	8-7.2	Marsh Restoration, Oxen to Mantel Bayou, Galveston County	15,679,000				390	*
	8-7.3	Marsh Restoration, Dana Cove, Galveston County	12,301,000				213	*
	8-7.4	Marsh Restoration, Jumbile Cove, Galveston County	14,652,000				316	*
	8-7.5	Marsh Restoration, Bird Island to Maggies Cove, Galveston County	22,174,000				467	*
	8-7.6	Marsh Restoration, Snake Island Cove, Galveston County	19,711,000				457	*
	8-7.7	Marsh and Bayou Restoration, Sweetwater Preserve, Galveston County	7,257,000				447	*
		Total Alt G3	**10,089,015,000**	**14,042,424,000**	**3,953,409,000**	**1.39**	**122,227**	
G4	**Galveston Inland Barriers Comprehensive CSRM and ER**							
	2	Surge Gate and Barrier at Hartman Bridge, Harris County	801,842,000	3,054,181,000	2,252,339,000	3.81	3,200	
	3-2	Texas City, Texas Hurricane Flood Protection	36,985,000	2,139,339,000	2,102,354,000	57.84	0	
	3-9	Galveston Ring Levee, Galveston County	556,116,000	3,296,295,000	2,740,179,000	5.93	300	
	3-10.6	Local Surge Protection, Chocolate Bayou, Brazoria County	472,997,000	5,109,000	(467,888,000)	0.01	125	
	4-1	Raise State Highway 146, Galveston and Harris Counties	563,090,000	3,073,296,000	2,510,206,000	5.46	2,900	
	5-6	Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston County	1,660,837,000				530	
	5-7	Beach Nourishment, East Galveston Island Seawall, Galveston Island	453,368,000				235	
	5-8	Dune Restoration and Beach Nourishment, West Galveston Island, Galveston County	1,201,816,000				420	
	6-4.1	GIWW Breakwaters, Bolivar Peninsula, Galveston County	141,782,000				867	
	6-4.2	GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County	10,017,000				246	
	6-5.1	GIWW Breakwaters, West Bay, Galveston County	43,406,000				222	
	6-5.2	GIWW Barrier Island Restoration, West Bay 1, Galveston County	9,764,000				112	
	6-5.3	GIWW Barrier Island Restoration, West Bay 2, Galveston County	4,037,000				35	

Table 5-6, continued

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland ac)
	6-6.2	GIWW Barrier Island Restoration, West Bay, Brazoria County	18,202,000				215
	7-1	Shoreline Protection, East Bay, Chambers County	137,121,000				600
	8-4.1	Marsh Restoration, Pepper Grove Cove, Galveston County	17,047,000				294
	8-4.2	Marsh Restoration, Long Point Marsh, Galveston County	45,561,000				1,661
	8-6.1	Marsh Restoration, Pierce Marsh, Galveston County	52,173,000				2,076
	8-6.2	Marsh Restoration, IH-10 Causeway, Galveston County	21,478,000				633
	8-6.3	Marsh Restoration, Greens Lake, Galveston County	70,718,000				3,293
	8-7.1	Marsh Restoration, Gangs to Oxen Bayou, Galveston County	7,662,000				176
	8-7.2	Marsh Restoration, Oxen to Mantel Bayou, Galveston County	15,679,000				390
	8-7.3	Marsh Restoration, Dana Cove, Galveston County	12,301,000				213
	8-7.4	Marsh Restoration, Jumbile Cove, Galveston County	14,652,000				316
	8-7.5	Marsh Restoration, Bird Island to Maggies Cove, Galveston County	22,174,000				467
	8-7.6	Marsh Restoration, Snake Island Cove, Galveston County	19,711,000				457
	8-7.7	Marsh and Bayou Restoration, Sweetwater Preserve, Galveston County	7,257,000				447
		Total Alt G4	**6,417,793,000**	**11,568,220,000**	**5,150,427,000**	**1.80**	**20,431**
G5	**South Galveston Bay Inland Barriers CSRM Focus**						
	2	Surge Gate and Barrier at Hartman Bridge, Harris County	801,842,000	3,054,181,000	2,252,339,000	3.81	3,200
	3-2	Texas City, Texas Hurricane Flood Protection	36,985,000	2,139,339,000	2,102,354,000	57.84	-
	3-9	Galveston Ring Levee, Galveston County	556,116,000	3,296,295,000	2,740,179,000	5.93	300
	3-10.6	Local Surge Protection, Chocolate Bayou, Brazoria County	472,997,000	5,109,000	-467,888,000	0.01	125
	4-1	Raise State Highway 146, Galveston and Harris Counties	563,090,000	3,073,296,000	2,510,206,000	5.46	2,900
		Total Alt G5	**2,431,030,000**	**11,568,220,000**	**9,137,190,000**	**4.76**	**6,525**
G6	**South Galveston Bay Local Protection CSRM Focus**						
	3-9	Galveston Ring Levee, Galveston County	36,985,000	2,139,339,000	2,102,354,000	57.84	-
	3-2	Texas City, Texas Hurricane Flood Protection	556,116,000	3,296,295,000	2,740,179,000	5.93	300
	3-10.6	Local Surge Protection, Chocolate Bayou, Brazoria County	472,997,000	5,109,000	-467,888,000	0.01	125
		Total Alt G6	**1,066,098,000**	**5,440,743,000**	**4,374,645,000**	**5.10**	**425**
G7	**Galveston ER Barrier Island Protection**						
	5-6	Dune Restoration and Beach Nourishment, High Island to Galveston East Jetty, Galveston County	1,660,837,000				530
	5-7	Beach Nourishment, East Galveston Island Seawall, Galveston Island	453,368,000				235

Table 5-6, continued

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland ac)
	5-8	Dune Restoration and Beach Nourishment, West Galveston Island, Galveston County	1,201,816,000				420
	5-10	Closing of Rollover Pass, Galveston County	6,873,000				42
	6-4.1	GIWW Breakwaters, Bolivar Peninsula, Galveston County	141,782,000				867
	6-4.2	GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County	10,017,000				246
	6-5.1	GIWW Breakwaters, West Bay, Galveston County	43,406,000				222
	6-5.2	GIWW Barrier Island Restoration, West Bay 1, Galveston County	9,764,000				112
	6-5.3	GIWW Barrier Island Restoration, West Bay 2, Galveston County	4,037,000				35
	6-6.2	GIWW Barrier Island Restoration, West Bay, Brazoria County	18,202,000				215
	7-1	Shoreline Protection, East Bay, Chambers County	137,121,000				600
	8-4.1	Marsh Restoration, Pepper Grove Cove, Galveston County	17,047,000				294
	8-4.2	Marsh Restoration, Long Point Marsh, Galveston County	45,561,000				1,661
	8-7.1	Marsh Restoration, Gangs to Oxen Bayou, Galveston County	7,662,300				176
	8-7.2	Marsh Restoration, Oxen to Mantel Bayou, Galveston County	15,679,000				390
	8-7.3	Marsh Restoration, Dana Cove, Galveston County	12,301,200				213
	8-7.4	Marsh Restoration, Jumbile Cove, Galveston County	14,652,000				316
	8-7.5	Marsh Restoration, Bird Island to Maggies Cove, Galveston County	22,174,000				467
	8-7.6	Marsh Restoration, Snake Island Cove, Galveston County	19,711,000				457
	8-7.7	Marsh and Bayou Restoration, Sweetwater Preserve, Galveston County	7,257,000				447
		Total Alt G7	**3,849,267,500**	**NA**	**NA**	**NA**	**7,946**
G8	**Galveston GIWW Shoreline Protection**						
	6-4.1	GIWW Breakwaters, Bolivar Peninsula, Galveston County	141,782,000				867
	6-4.2	GIWW Barrier Island Restoration, Bolivar Peninsula, Galveston County	10,017,000				246
	6-5.1	GIWW Breakwaters, West Bay, Galveston County	43,406,000				222
	6-5.2	GIWW Barrier Island Restoration, West Bay 1, Galveston County	9,764,000				112
	6-5.3	GIWW Barrier Island Restoration, West Bay 2, Galveston County	4,037,000				35
	6-6.2	GIWW Barrier Island Restoration, West Bay, Brazoria County	18,202,000				215
		Total Alt G9	**227,208,000**	**NA**	**NA**	**NA**	**1,698**
G9	**Galveston Nonstructural Alternative**						
	10-1.2	Buy-outs in Galveston Region (to be developed)	TBD				
	10-2.2	Lone Star Recreation and Conservation Area (to be developed)	TBD				

* Not included in total acreage because of overlap in Environmental Benefits for some measures

Table 5-7. Brazoria Region Initial Alternatives Array

Alternative Number	Measure Number	Measure Name	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland ac)
B1	**Brazoria Coastal Barrier All-Inclusive CSRM and ER**						
	3-3	Freeport and Vicinity, Texas Hurricane Flood Protection	123,784,000	2,195,837,000	2,072,053,000	17.74	0
	5-11	Dune Restoration and Beach Nourishment, San Luis Pass to Surfside, Brazoria County	667,903,000				500
	5-12	Dune Restoration and Beach Nourishment, Surfside to Brazos River, Brazoria County	247,862,000				45
	5-13	Dune Restoration and Beach Nourishment, Brazos River to Brazos River Diversion channel, Brazoria County	409,410,000				540
	5-16	Groin at State Highway 332, Brazoria County	4,010,000				50
	6-6.1	GIWW Erosion Protection, Brazoria County	219,877,000				1,110
	7-2	Shoreline Protection, Bastrop Bay , Brazoria County	20,420,000				40
		Total Alt B1	**1,693,266,000**	**2,195,837,000**	**502,571,000**	**1.30**	**2,285**
B2	**Brazoria Coastal Barrier CSRM Focus (revised)**		-	-	-	-	-
	3-3	Freeport and Vicinity, Texas Hurricane Flood Protection	123,784,000	2,195,837,000	2,072,053,000	17.74	0
		Total Alt B2	**123,784,000**	**2,195,837,000**	**2,072,053,000**	**17.74**	
B3	**Brazoria ER and Coastal Marsh Protection**						
	5-11	Dune Restoration and Beach Nourishment, San Luis Pass to Surfside, Brazoria County	667,903,000	-			500
	5-12	Dune Restoration and Beach Nourishment, Surfside to Brazos River, Brazoria County	247,862,000	-			45
	5-13	Dune Restoration and Beach Nourishment, Brazos River to Brazos River Diversion channel, Brazoria County	409,410,000	-			540
	5-16	Groin at State Highway 332, Brazoria County	4,010,000				50
	6-6.1	GIWW Erosion Protection, Brazoria County	219,877,000				1,110
	7-2	Shoreline Protection, Bastrop Bay , Brazoria County	20,420,000				40
		Total Alt B3	**1,569,482,000**	**NA**	**NA**	**NA**	**2,285**
B4	**Brazoria GIWW Shoreline Protection**						
	6-6.1	GIWW Erosion Protection, Brazoria County	219,877,000				1,110
	7-2	Shoreline Protection, Bastrop Bay , Brazoria County	20,420,000				40
		Total Alt B4	**240,297,000**	**NA**	**NA**	**NA**	**1,150**
B5	**Brazoria Nonstructural Alternative**						
	10-1.3	Buy-outs in Brazoria (to be developed)	TBD				
	10-2.3	Lone Star Recreation and Conservation Area (to be developed)	TBD				
		Total Alt B5					

Table 5-8. Ranking by Net Excess Benefits for Sabine Region Initial Array

Alternative Number	Description	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland ac.)
S5	Sabine Inland Barrier CSRM Focus(Neches Gate/Sabine Levees/HFP)	1,613,611,000	6,296,258,000	4,682,647,000	3.90	31,500
S6	Sabine Inland Barrier CSRM Focus (Neches &Sabine Gates/Sabine Levees/HFP)	1,906,728,000	6,316,494,000	4,409,766,000	3.31	37,000
S4	Sabine Inland Barrier CSRM Focus (Sabine & Neches Levees/HFP)	1,807,648,000	5,982,257,000	4,174,609,000	3.31	7,400
S9	Sabine Inland Barrier (Neches Gate/Sabine Levees/HFP) and ER	5,344,483,000	6,380,010,000	1,035,527,000	2.54	97,761
S2	Sabine Inland Barrier All-Inclusive CSRM (Neches Gate/Sabine Levees/HFP) and ER (without Salt Bayou measures)	5,832,721,000	6,380,010,000	547,289,000	1.09	98,006
S3	Sabine Inland Barrier All-Inclusive CSRM (Neches &Sabine Gates/Sabine Levees/HFP) and ER	6,125,838,000	6,400,246,000	274,408,000	1.04	103,506
S1	Sabine Inland Barrier All-Inclusive CSRM (Sabine & Neches Levees/HFP) and ER	6,026,758,000	6,066,009,000	39,251,000	1.01	77,760
S10	Sabine GIWW Shoreline Protection	215,746,000	NA	NA	NA	1,006
S7	Sabine ER (without Neches River marsh restoration)	3,957,548,000	83,752,000	NA	NA	66,261
S8	Sabine ER (with surge barrier on upper Sabine River)	4,512,227,000	103,988,000	NA	NA	72,006
S11	Sabine Nonstructural Alternative	TBD				

Table 5-9. Ranking by Net Excess Benefits for Galveston Region Initial Array

Alternative Number	Description	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland ac)
G5	South Galveston Bay Inland Barriers CSRM Focus	2,495,830,000	11,568,219,620	9,072,389,620	4.64	6,525
G2	Galveston Coastal Barrier CSRM Focus	6,478,200,000	14,042,424,000	7,564,224,000	2.17	121,000
G4	Galveston Inland Barriers Comprehensive CSRM and ER	6,417,793,000	11,568,220,000	5,150,427,000	1.80	20,431
G6	South Galveston Bay Local Protection CSRM Focus	966,298,000	5,440,742,620	4,474,444,620	5.63	425
G1	Galveston Coastal Barrier All-Inclusive CSRM and ER (without GIWW Protection)	9,998,928,000	14,042,424,000	4,043,496,000	1.40	122,227
G3	Galveston Coastal Barrier All-Inclusive CSRM and ER	10,089,015,000	14,042,424,000	3,953,409,000	1.39	122,227
G8	Galveston Bay GIWW Shoreline Protection	227,208,000	NA	NA	NA	1,698
G7	Galveston Bay ER	3,809,994,500	NA	NA	NA	7,904
G9	Galveston Bay Nonstructural Alternative	TBD				

Table 5-10. Ranking by Net Excess Benefits for Brazoria Region Initial Array

Alternative Number	Description	Total Cost ($)	Economic Benefits ($)	Net Excess Benefits ($)	BCR	Env Benefits (wetland ac)
B2	Brazoria Coastal Barrier CSRM Focus (revised)	123,784,337	2,195,837,080	2,072,052,743	17.74	0
B1	Brazoria Coastal Barrier All-Inclusive CSRM and ER	1,693,266,337	2,195,837,080	502,570,743	1.30	2,140
B4	Brazoria GIWW Shoreline Protection	240,297,000	0	-240,297,000	0.00	1,160
B3	Brazoria ER	1,569,482,000	NA	NA	NA	2,140
B5	Brazoria Nonstructural Alternative	TBD				

The qualitative environmental impacts criterion was utilized to screen the initial array of alternatives to determine if any contained significant environmental impacts which could not be mitigated or which could render an alternative non-implementable (Table 5-11, Table 5-12, and Table 5-13). None of the alternatives would have construction footprint impacts that could not be mitigated. While several alternatives potentially cause significant changes to salinity, tidal circulation, sediment transport, aquatic organism access and erosion, further analysis will be needed to determine the extent of these changes and whether they have positive or negative effects. For example, all alternatives scored as "high" impacts for System-wide Hydrologic Effects contain Measure 1 (Galveston Bay Coastal Barrier) which could decrease the cross-sectional area of the mouth of the Galveston Bay, creating a reduction in the volume of the tidal prism and reducing salinity. Depending on the amount of salinity reduction, this could have a beneficial effect on the estuary. Furthermore, the PDT believed that all of the surge barrier measures can potentially be designed to minimize effects on the tidal prism, circulation and erosion. Endangered species impacts were evaluated to determine if construction could jeopardize the continued existence of any endangered species in the study area. It was determined that construction impacts could be minimized, but that small areas of piping plover critical habitat would be impacted by alternatives including Measure 1. It is assumed that construction and critical habitat impacts could be mitigated. Therefore, none of the alternatives was screened out on the basis of this criterion.

All of the ER Alternatives (S8, G9, B3) were retained because it is assumed that some mix of these measures will be needed to increase the sustainability of structural measures or the landforms they protect. None of the individual measures was eliminated at this phase because incremental analysis is needed to evaluate the most cost-effective and efficient mix of the measures included in the alternatives. Ecological modeling proposed for the TSP phase will quantify the ecological benefits of the measures, so that the most efficient array of measures in each alternative can be identified.

5.5 EVALUATION ARRAY OF ALTERNATIVE PLANS CARRIED FORWARD

The initial screening discussed above resulted in the identification of the evaluation array of alternatives to be carried to the next screening. Table 5-14, Table 5-15, and Table 5-16 list the Initial Array of alternative plans and summarized the reasons for eliminating alternative plans or carrying alternative plans forward to the Evaluation Array of Alternative Plans. Alternative plans determined to be the most viable plans to carry forward to the Evaluation Plans Array based on the four criteria in Section 5.3 are indicated by shading. The Evaluation Array of Alternative Plans comprises 10 alternatives (three from Sabine region, four from Galveston region, and three from Brazoria region) to be evaluated in more detail in the Section 6.0.

Table 5-11. Qualitative Analysis of Environmental Impacts Sabine Region

Alternative Number	Description	Environmental Impacts (Qualitative Analysis)			Impact Description
		Construction Impacts to Wetlands and Sensitive Habitats	System-wide Hydrologic Impacts	Endangered Species Impacts	
S5	Sabine Inland Barrier CSRM Focus(Neches Gate/Sabine Levees/HFP)	Medium	Medium	Low	Construction of navigation gate and barrier across Neches River would impact small area of river bottom and navigation channel, but construction of south Orange County and Sabine River west bank surge barriers would impact moderate amount of wetlands. Neches River gate has potential to adversely affect tidal circulation, sediment transport, aquatic organism access and erosion in lower Neches River watershed. No impacts on endangered species are anticipated.
S6	Sabine Inland Barrier CSRM Focus (Neches &Sabine Gates/Sabine Levees/HFP)	Medium	Medium	Low	Construction of Neches and Sabine River gates would impact small area of river bottom, but construction of south Orange County surge barrier, Sabine River surge barrier, and barrier extension into Calcasieu Parish would impact moderate amount of wetlands. Neches River gate has potential to adversely affect tidal circulation, sediment transport, aquatic organism access and erosion in lower Neches River watershed. Sabine River gate could have small effect on normal tidal circulation, while preventing storm surge impacts on about 5,500 acres of cypress-tupelo swamp in Sabine Island WMA. No impacts on endangered species are anticipated.
S4	Sabine Inland Barrier CSRM Focus (Sabine & Neches Levees/HFP)	Medium	Low	Low	Construction of surge barriers along Neches River south bank, high terrace of Neches River north bank, south Orange County and Sabine River south bank would impact moderate amount of wetlands. No impacts on endangered species are anticipated.
S9	Sabine Inland Barrier (Neches Gate/Sabine Levees/HFP) and ER	Medium	Medium	Low	Construction of Neches River gate would impact small area of river bottom, but construction of south Orange County and Sabine River west bank surge barriers would impact moderate amount of wetlands. Neches River gate has potential to adversely affect tidal circulation, sediment transport, aquatic organism access and erosion in lower Neches River watershed. Beach and dune restoration, beach ridge restoration, GIWW shoreline protection from Neches River to High Island, marsh restoration at Keith Lake and Texas Point, and Salt Bayou hydrologic restoration are all ER measures; impacts of construction are outweighed by overall benefit. No impacts on endangered species are anticipated.
S2	Sabine Inland Barrier All-Inclusive CSRM (Neches Gate/Sabine Levees/HFP) and ER (without Salt Bayou measures)	Medium	Medium	Low	Construction of navigation gate and barrier across Neches River would impact small area of river bottom and navigation channel, but construction of Orange County and Sabine River west bank levees would impact moderate amount of wetlands. Neches River gate has potential to adversely affect tidal circulation, sediment transport, aquatic organism access and erosion in lower Neches River watershed. Beach and dune restoration, beach ridge restoration, all GIWW shoreline protection, regional marsh restoration, and Salt Bayou hydrologic restoration are all ER measures; impacts of construction are outweighed by overall benefits. No impacts on endangered species are anticipated.
S3	Sabine Inland Barrier All-Inclusive CSRM (Neches &Sabine Gates/Sabine Levees/HFP) and ER	Medium	Medium	Low	Construction of Neches and Sabine River gates would impact small area of river bottom, but construction of south Orange County surge barrier, Sabine River surge barrier, and barrier extension into Calcasieu Parish would impact moderate amount of wetlands. Neches River gate has potential to adversely affect tidal circulation, sediment transport, aquatic organism access and erosion in lower Neches River watershed. Sabine River gate could have small effect on normal tidal circulation, while preventing storm surge impacts on about 5,500 acres of cypress-tupelo swamp in Sabine Island WMA. Beach and dune restoration, beach ridge restoration, GIWW shoreline protection, regional marsh restoration, and Salt Bayou hydrologic restoration are all ER measures; impacts of construction are outweighed by overall benefits. No impacts on endangered species are anticipated.
S1	Sabine Inland Barrier All-Inclusive CSRM (Sabine & Neches Levees/HFP) and ER	Medium	Low	Low	Construction of surge barriers along Neches River south bank, high terrace of Neches River north bank, and Sabine River south bank would impact moderate amount of wetlands. Beach and dune restoration, beach ridge restoration, all GIWW shoreline protection, regional marsh restoration, and Salt Bayou hydrologic restoration are all ER measures; impacts of construction are outweighed by overall benefits. No impacts on endangered species are anticipated.

Table 5-11, continued

Alternative Number	Description	Environmental Impacts (Qualitative Analysis)			Impact Description
		Construction Impacts to Wetlands and Sensitive Habitats	System-wide Hydrologic Impacts	Endangered Species Impacts	
S10	Sabine GIWW Shoreline Protection	Low	Low	Low	Construction impacts would likely be limited to submerged edge of GIWW, footprint of breakwaters or other ER erosion control structures. Structures are expected to slow shoreline erosion and not expected to have effect on larger system. No endangered species impacts are anticipated.
S7	Sabine ER (without Neches River marsh restoration)	Low	Low	Low	Beach and dune restoration, beach ridge restoration, GIWW shoreline protection from Neches River to High Island, marsh restoration at Keith Lake and Texas Point, and Salt Bayou hydrologic restoration are all ER measures; impacts of construction are outweighed by overall benefits. No impacts on endangered species are anticipated.
S8	Sabine ER (with surge barrier on upper Sabine River)	Low	Low	Low	Sabine Island Swamp surge barrier and gate would prevent storm surge impacts to about 5,500 acres of cypress-tupelo swamp in Sabine Island Wildlife Management Area. Beach and dune restoration, beach ridge restoration, GIWW shoreline protection, regional marsh restoration, and Salt Bayou hydrologic restoration are all ER measures; impacts of construction are outweighed by overall benefits. No impacts on endangered species are anticipated.
S11	Sabine Nonstructural Alternative	Low	Low	Low	Conservation of natural landscapes would have beneficial long-term environmental effects.

Table 5-12. Qualitative Analysis of Environmental Impacts Galveston Region

Alternative Number	Description	Environmental Impacts (Qualitative Analysis)			Impact Description
		Construction Impacts to Wetlands and Sensitive Habitats	System-wide Hydrologic Impacts	Endangered Species Impacts	
G5	South Galveston Bay Inland Barriers CSRM Focus	Low	Med	Low	With exception of Chocolate Bayou, construction right-of-way would be located primarily in developed areas, so few wetlands or sensitive habitats would be affected. Surge gate and barrier at Hartman Bridge has potential to adversely affect tidal circulation, sediment transport, aquatic organism access, and erosion in lower San Jacinto and Buffalo Bayou watersheds. Construction would not jeopardize continued existence of endangered species, but construction would impact small areas of piping plover critical habitat. It is assumed that impacts could be mitigated.
G2	Galveston Coastal Barrier CSRM Focus	Medium	High	Medium	Construction right-of-way would be located on existing highways; minor wetlands impacts would be expected along expanded right-of-way. Gate structures would be located in natural passes and navigation channels; impacts to natural bottom and oyster reef would be expected. 65-mile long barrier and gates have potential to adversely affect tidal circulation, salinity, sediment transport, aquatic organism access, erosion and oyster reefs in greater Galveston Bay and lower San Jacinto and Buffalo Bayou watersheds. Construction would not jeopardize continued existence of endangered species, but construction would impact small areas of piping plover critical habitat. It is assumed that impacts could be mitigated.
G4	Galveston Inland Barriers Comprehensive CSRM and ER	Low	Med	Low	With exception of Chocolate Bayou, construction right-of-way would be located primarily in developed areas, so few wetlands or sensitive habitats would be affected. Surge gate and barrier at Hartman Bridge has potential to adversely affect tidal circulation, sediment transport, aquatic organism access and erosion in lower San Jacinto and Buffalo Bayou watersheds. Beach and dune restoration would temporarily impact piping plover critical habitat, but would stabilize habitat over the long-term. Beach and dune restoration, GIWW shoreline protection, marsh restoration, and East Bay shoreline protection are all ER measures; impacts of construction are outweighed by overall benefits.
G6	South Galveston Bay Local Protection CSRM Focus	Low	Low	Low	With exception of Chocolate Bayou, construction right-of-way would be located primarily in developed areas, so few wetlands or sensitive habitats would be affected. Texas City HFP is existing project that would be upgraded; no wetland impacts anticipated. Construction of levees around Chocolate Bayou facilities would impact small amount of wetlands. Local systems would have no effect on Galveston Bay hydrology and there would be no endangered species impacts.
G1	Galveston Coastal Barrier All-Inclusive CSRM and ER (without GIWW Protection)	Low	High	Medium	Coastal barrier construction right-of-way would be located on existing highways; minor wetlands impacts would be expected along the expanded right-of-way. 65-mile long barrier and gates have potential to adversely affect tidal circulation, salinity, sediment transport, aquatic organism access, erosion and oyster reefs in greater Galveston Bay and lower San Jacinto and Buffalo Bayou watersheds. Beach and dune restoration would temporarily impact piping plover critical habitat, but would stabilize habitat over long-term. Beach and dune restoration, marsh restoration, and East Bay shoreline protection are all ER measures; impacts of construction are outweighed by overall benefits. Construction would not jeopardize continued existence of endangered species, but construction would impact small areas of piping plover critical habitat. It is assumed that impacts could be mitigated.
G3	Galveston Coastal Barrier All-Inclusive CSRM and ER	Low	High	Medium	Coastal barrier construction right-of-way would be located on existing highways; minor wetlands impacts would be expected along expanded right-of-way. 65-mile long barrier and gates have potential to adversely affect tidal circulation, salinity, sediment transport, aquatic organism access, erosion and oyster reefs in greater Galveston Bay and lower San Jacinto and Buffalo Bayou watersheds. Beach and dune restoration would temporarily impact piping plover critical habitat, but would stabilize habitat over long-term. Beach and dune restoration, marsh restoration, and East Bay shoreline protection are all ER measures; impacts of construction are outweighed by overall benefits. Construction would not jeopardize the continued existence of endangered species, but construction would impact small areas of piping plover critical habitat. It is assumed that impacts could be mitigated.

Table 5-12, continued

Alternative Number	Description	Environmental Impacts (Qualitative Analysis)			Impact Description
		Construction Impacts to Wetlands and Sensitive Habitats	System-wide Hydrologic Impacts	Endangered Species Impacts	
G8	Galveston Bay GIWW Shoreline Protection	Low	Low	Low	Construction impacts would likely be limited to submerged edge of GIWW, footprint of erosion protection (e.g. breakwaters) or other living shoreline erosion control structures. Structures are expected to slow shoreline erosion and not expected to have effect on larger system. No endangered species impacts are anticipated.
G7	Galveston Bay ER	Low	Low	Low	Beach and dune restoration would temporarily impact piping plover critical habitat, but would stabilize habitat over the long-term. Beach and dune restoration, marsh restoration, and East Bay shoreline protection are all ER measures; impacts of construction are outweighed by overall benefits.
G9	Galveston Bay Nonstructural Alternative	Low	Low	Low	Conservation of natural landscapes would have beneficial long-term environmental effects.

Table 5-13. Qualitative Analysis of Environmental Impacts Galveston Region

Alternative Number	Description	Environmental Impacts (Qualitative Analysis)			Impact Description
		Construction Impacts to Wetlands and Sensitive Habitats	System-wide Hydrologic Impacts	Endangered Species Impacts	
B2	Brazoria Coastal Barrier CSRM Focus (revised)	Low	Low	Low	Reconstruction of existing Freeport HFP would not impact wetlands or sensitive habitats. Alterations to lower Brazos River system are existing conditions and no changes would results from reconstruction of HFP. No endangered species impacts are anticipated.
B1	Brazoria Coastal Barrier All-Inclusive CSRM and ER	Low	Low	Low	Reconstruction of existing Freeport HFP would not impact wetlands or sensitive habitats. Alterations to lower Brazos River system are existing conditions and no changes would results from reconstruction of HFP. Beach and dune restoration would temporarily impact piping plover critical habitat, but would stabilize habitat over long-term. Beach and dune restoration, groin construction, and GIWW shoreline protection are all ER measures; impacts of construction are outweighed by overall benefits.
B4	Brazoria GIWW Shoreline Protection	Low	Low	Low	Construction impacts would likely be limited to submerged edge of GIWW, footprint of breakwaters or other living shoreline erosion control structures. Structures are expected to slow shoreline erosion and not expected to have effect on larger system. No endangered species impacts are anticipated.
B3	Brazoria ER	Low	Low	Low	Beach and dune restoration would temporarily impact piping plover critical habitat, but would stabilize habitat over long-term. Beach and dune restoration, groin construction, and GIWW shoreline protection are all ER measures; impacts of construction are outweighed by overall benefits.
B5	Brazoria Nonstructural Alternative	Low	Low	Low	Conservation of natural landscapes would have beneficial long-term environmental effects.

Table 5-14. Summary of Screening of Sabine Region Alternatives for Evaluation Array*

Alternative Number	Alt Name / Description	Reason Eliminated or Carried Forward to Evaluation Array
S5	Sabine Inland Barrier CSRM Focus(Neches Gate/Sabine Levees/HFP)	Carried Forward to Evaluation Array because of highest net excess benefits
S6	Sabine Inland Barrier CSRM Focus (Neches &Sabine Gates/Sabine Levees/HFP)	Eliminated because of lower net excess benefits than S5. Sabine gate has complex interstate issues and not known if GLO can fund project that would be in LA. Sabine gate is carried forward in S8 as a separate measure to allow in to be further studied.
S4	Sabine Inland Barrier CSRM Focus (Sabine & Neches Levees/HFP)	Eliminated because of lower net excess benefits than S5. Longer lines of defense at higher cost.
S9	Sabine Inland Barrier (Neches Gate/Sabine Levees/HFP) and ER	Eliminated because of lower net excess benefits than S5 due to the costs of the ER measures. CSRM measures same as S5. Considered redundant as ER measures carried forward in S8.
S2	Sabine Inland Barrier All-Inclusive CSRM (Neches Gate/Sabine Levees/HFP) and ER (without Salt Bayou measures)	Eliminated because implementation costs are high. Considered redundant as ER measures carried forward in S8.
S3	Sabine Inland Barrier All-Inclusive CSRM (Neches &Sabine Gates/Sabine Levees/HFP) and ER	Eliminated for same reasons as S6 (Sabine Gate in LA) and S2 (ER measures carried forward in S8).
S1	Sabine Inland Barrier All-Inclusive CSRM (Sabine & Neches Levees/HFP) and ER	Eliminated because of lower net excess benefits. Long lines of defense at higher costs. ER measures carried forward under S8.
S10	Sabine GIWW Shoreline Protection	Eliminated because of lack of significant economic benefits. GIWW shoreline protection carried forward as part of S8.
S7	Sabine ER (without Neches River marsh restoration)	Eliminated because of lack of significant economic benefits. ER measures are also in S8 and will be evaluated further under S8.
S8	Sabine ER (with surge barrier on upper Sabine River)	Carried forward as ER Alternative Plan. Carrying forward one ER plan with all ER measures rolled into it allows PDT to refine ER benefits during next study phase. Based on refined benefits, PDT can perform incremental analysis and ER plan can then be reformulated to maximize ER benefits.
S11	Sabine Nonstructural Alternative	Carried forward to develop during next phase of study. Assumed some level of buyouts and Lone Star-type of Conservation plan will be part of recommended plan.

* Listed in order of Economic Benefits

Table 5-15. Summary of Screening of Galveston Region Alternatives for Evaluation Array*

Alternative Number	Alt Name / Description	Reason Eliminated or Carried Forward to Evaluation Array
G5	South Galveston Bay Inland Barriers CSRM Focus	Carried Forward to Evaluation Array because of high net excess benefits.
G2	Galveston Coastal Barrier CSRM Focus	Carried Forward to Evaluation Array because of high net excess benefits.
G4	Galveston Inland Barriers Comprehensive CSRM and ER	Eliminated due to lower net excess benefits than G5 or G2. High Implementation Costs associated with the ER measures. Surge reduction measures same as G5. ER measures carried forward under Alternative G7.
G6	South Galveston Bay Local Protection CSRM Focus	Eliminated due to not provide any benefits for Harris or Chambers Counties and does not reduce risk for the Houston Ship Channel and associated industry.
G1	Galveston Coastal Barrier All-Inclusive CSRM and ER (without GIWW Protection)	Eliminated due to extremely high implementation costs due to the addition of all ER measures. The surge reduction measures are the same as G2. ER measures are carried forward under Alternative G7.
G3	Galveston Coastal Barrier All-Inclusive CSRM and ER	Eliminated for same reasons as G1. GIWW measures are also carried forward under G7.
G8	Galveston Bay GIWW Shoreline Protection	Eliminated due to lack of significant economic benefits. GIWW shoreline protection carried forward as part of G7.
G7	Galveston Bay ER	Carried forward as ER Alternative Plan. Carrying forward one ER plan with all ER measures rolled into it allows PDT to refine ER benefits during next study phase. Based on refined benefits, PDT can perform incremental analysis and ER plan can then be reformulated to maximize ER benefits.
G9	Galveston Bay Nonstructural Alternative	Carried forward to develop during next phase of study. Assumed some level of buyouts and Lone Star-type of Conservation plan will be part of recommended plan.

* Listed in order of Economic Benefits

Table 5-16. Summary of Brazoria Region Alternatives Eliminated or Carried Forward to Evaluation Array*

Alternative Number	Alt Name / Description	Reason Eliminated or Carried Forward to Evaluation Array
B2	Brazoria Coastal Barrier CSRM Focus (revised)	Carried Forward because of highest economic benefit of all Brazoria alternatives.
B1	Brazoria Coastal Barrier All-Inclusive CSRM and ER	Eliminated due to high implementation costs associated with ER measures. ER measures are carried forward as part of alternative B3.
B4	Brazoria GIWW Shoreline Protection	Eliminated due to lack of significant economic benefits. GIWW shoreline protection carried forward as part of B3.
B3	Brazoria ER	Carried forward as ER Alternative Plan. Carrying forward one ER plan with all ER measures rolled into it allows PDT to refine ER benefits during next study phase. Based on refined benefits, PDT can perform incremental analysis and ER plan can then be reformulated to maximize ER benefits.
B5	Brazoria Nonstructural Alternative	Carried forward to develop during next phase of study. Assumed some level of buyouts and Lone Star-type of Conservation plan will be part of recommended plan.

* Listed in order of Economic Benefits

6 EVALUATION ARRAY OF ALTERNATIVE PLANS

6.1 EVALUATION ARRAY OF ALTERNATIVES

The Evaluation Array of Alternatives was identified from the screening of the Initial Array of Alternatives. Table 6-1 described this evaluation array.

Table 6-1. Evaluation Array of Alternatives

Alternative Number	Alternative Name	Description
S5	Sabine Inland Barrier CSRM Focus(Neches Gate/Sabine Levees/HFP)	Neches River Navigation Gate, Sabine Levees, Port Arthur HFP
S8	Sabine ER (with surge barrier on upper Sabine River)	Beach and dune restoration, restore beach ridge, nearshore breakwaters, GIWW shoreline protection, marsh restoration on Neches River and at Keith Lake and Texas Point, Salt Bayou hydrologic restoration, Sabine River levees and gate
S11	Sabine Nonstructural Alternative	Buyouts and Lone Star-type conservation plan
G2	Galveston Coastal Barrier CSRM Focus	Coastal barrier and gates, and buyouts/relocations within a 500 ft buffer
G5	South Galveston Bay Inland Barriers CSRM Focus	Surge barrier and gates near Hartman Bridge, Tx City HFP, Galveston Ring Levee, Chocolate Bayou ring levee, Raise Hwy 146 and buyouts/relocations within a 500 ft buffer
G7	Galveston Bay ER	Beach and dune restoration, GIWW shoreline protection, marsh restoration, East Bay shoreline protection, closing Rollover Pass
G9	Galveston Bay Nonstructural Alternative	Buyouts and Lone Star-like conservation plan
B2	Brazoria Coastal Barrier CSRM Focus (revised)	Freeport HFP
B3	Brazoria ER	Beach and dune restoration, groin, and GIWW shoreline protection
B5	Brazoria Nonstructural Alternative	Buyouts and Lone Star-like conservation plan

6.2 EVALUATION SCREENING OF ALTERNATIVES

The Evaluation Screening of Alternatives was used as the decision point for this analysis to determine whether the data collected and utilized for this analysis is sufficient to make the determination of which alternative (S5-Gate/ S8-No-Gate) to carry forward for detailed analysis. In order to make this comparison between these two alternatives, it was decided that the S8 Alternative was configured to provide the same level of protection as that provided by the S5 Alternative. This level of protection would be assumed to provide roughly the same amount of benefits, as evidenced by the inundation patterns of the two alternatives compared to inundation for the without-project condition shown in the figures below. Therefore, since the benefits are roughly the same, the primary determining factor becomes cost, allowing the alternative with the lowest cost to be the alternative to be carried forward into more detailed evaluation. If the two

alternative costs were not significantly different, both alternatives would require additional detailed evaluation before either could be ruled out.

6.2.1 Development of Alternative Alignments

The Gate Alternative consists of a protection system utilizing the existing Port Arthur Hurricane Flood Protection (HFP) levee with construction of a navigation gate across the Neches River and new levees along the west bank of the Sabine River. Figure 6-1 shows the Gate Alternative alignment as previously developed for the initial screening analysis. The No-Gate Alternative consists of a protection system utilizing the existing Port Arthur Hurricane Flood Protection (HFP) levee with extension of the levees along the west bank of the Neches River, as well as new levees along the east bank of the Neches River and the west bank of the Sabine River. Figure 6-2 shows the No-Gate Alternative alignment also from the previously developed initial screening.

The levee alignments for both of the alternatives in this analysis were based on alignments from the Orange County Flood Protection Planning Study (Orange Report), which was completed in 2012. Refinement of the alignments was made in some areas to increase potential benefits, reduce costs and reduce potential environmental impacts, and to protect critical infrastructure. Additional effort was taken to avoid disruptions to major pipeline corridors and to identify opportunities for potential buyouts. The alignment for the closure gate at the mouth of the Neches River also originated from the Orange County Study. This alignment was refined to minimize impacts on the environment and navigation and to identify specific location for a pumping station that would be used to reduce the risk of inland flows impacting gate operation. This pumping station would need to have the ability to pump discharge from the inland Neches River into Sabine Lake, when the gate structure was closed.

The area that would be protected by the Gate Alternative is roughly 290 square miles in size (186,500 acres). The western boundary of the protected area is approximately 20 miles long, stretching from Interstate Highway 10 (IH 10) at the northern end to the southern end of the existing Port Arthur HFPS near the intersection of the Gulf Intracoastal Waterway (GIWW) and the Sabine Neches Waterway. The eastern boundary extends roughly 11 miles from IH 10 at its northern extent to the mouth of the Sabine River at the northeastern corner of Sabine Lake to the south. At its maximum width, the area is approximately 22 miles wide along the IH 10 corridor. This area encompasses the lower 18 and lower 11 river miles of the Neches and Sabine Rivers, respectively.

The area that would be protected by the No-Gate Alternative is the same general location, with the exception of the Neches River bottomland and some flood prone uplands that would be open to hurricane storm surge flooding without the surge gate at the mouth of the Neches River. West of the Neches River, the area protected by the proposed levee/floodwall system would be approximately 62 square miles (63,000 acres) in size. East of the Neches River and West of the Sabine River, the area protected would be approximately 100 square miles (66,000 acres) in size.

Figure 6-1. Gate Alternative

Figure 6-2. No-Gate Alternative

Together, the protected areas total approximately 162 square miles (129,000 acres). The layout of the levee/floodwall system has been placed on the upland margins to the greatest extent possible, and therefore wetland areas protected from storm surge impacts are much smaller than the Gate Alternative, covering roughly 7,000 acres.

6.2.2 Hydraulic and Hydrology (H&H) Analysis

For the H&H analysis to compare these two alternatives, inundation for the 100-year event was developed. Figure 6-3, Figure 6-4, and Figure 6-5 show the inundation pattern of the 100-year event for the without-project, and for the No-Gate Alterative and the Gate Alternative. Note that the levee and gate alignments were slightly refined from the original alternative figures.

A joint probability analysis of riverine discharge and storm surge on the Neches River was conducted to assist with preliminary screening of the Neches gate alternative. The analysis calculates the probability of discharge with respect to extreme water level.

The nearest gage measuring river discharge is a USGS gage at the Neches River Saltwater Barrier. The nearest gage measuring water level is a NOAA gage at the mouth of the Neches River. Data gathered from the NOAA and USGS gages was utilized in performing a joint probability analysis of discharge and water level. First, the peak over threshold approach was used to determine extreme water level and discharge events. Frank and empirical Copula bivariate distribution functions were then fit to the data to calculate the distribution. Figure 6-6 plots the probability distribution calculated with the Frank (top) and empirical (bottom) Copula functions. The colors and contours show probability in return period.

In summary, the analysis leads to the following general conclusions:

- The 100-year return period the Neches River discharge could reach a maximum level of 40,000 cubic feet per second (cfs) for events that could occur during gate closure.
- There would be some storage volume in the Neches River basin behind the gate. This storage volume reduces the amount of Neches River flow the pump would need to discharge.
- Coincident analysis and historical data indicate that a flow between 20,000 cfs and 30,000 cfs would be expected during an event that requires gate closure.
- During Hurricane Rita (2005), the flow in the Neches River varied between 15,000 cfs and 22,000 cfs during the time when gate closure would be necessary due to high water levels.
- Based on the joint probability analysis, basin storage volume, and historical data a pump with a minimum discharge capacity of approximately 20,000 cfs is recommended.
- If the gate remains the preferred alternative, more detailed analysis of joint probability of water level and discharge should be conducted to inform operations and design.

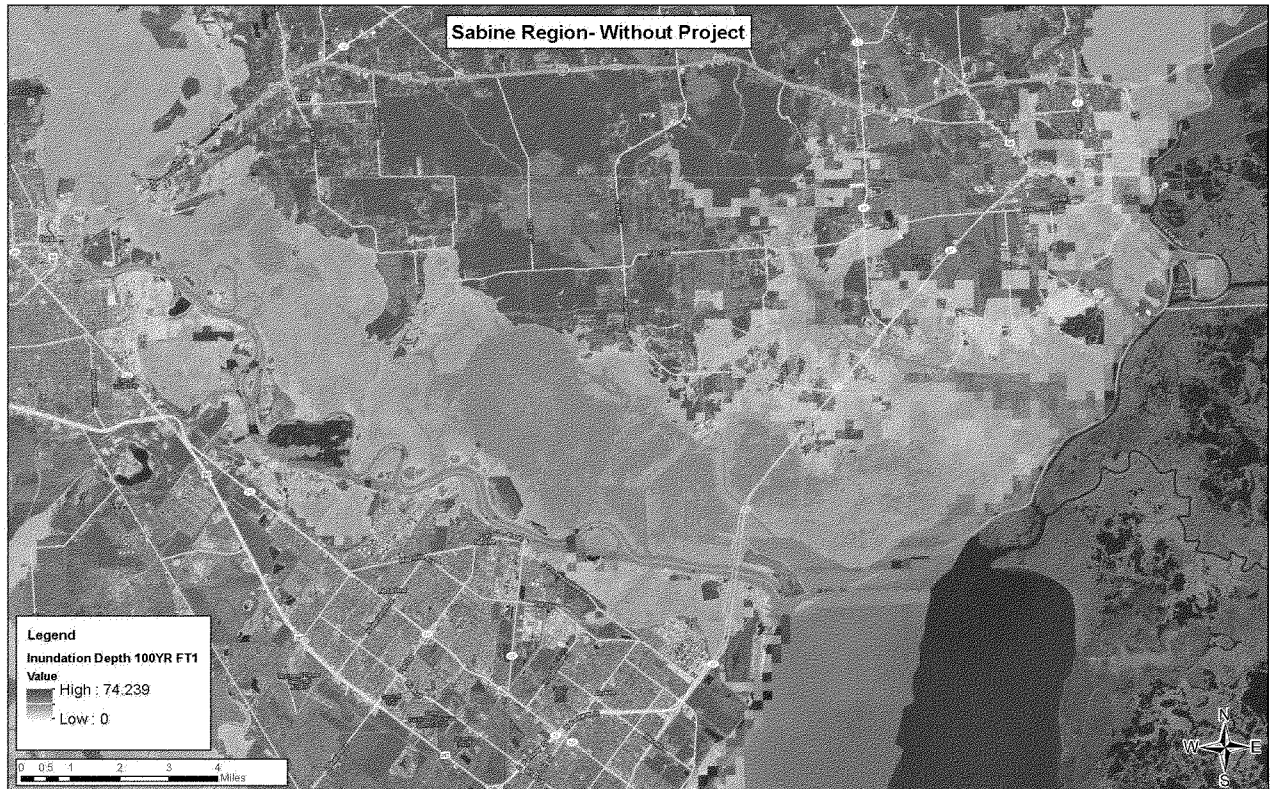


Figure 6-3. Sabine Region 100-Year Flood Inundation – Without-Project Condition

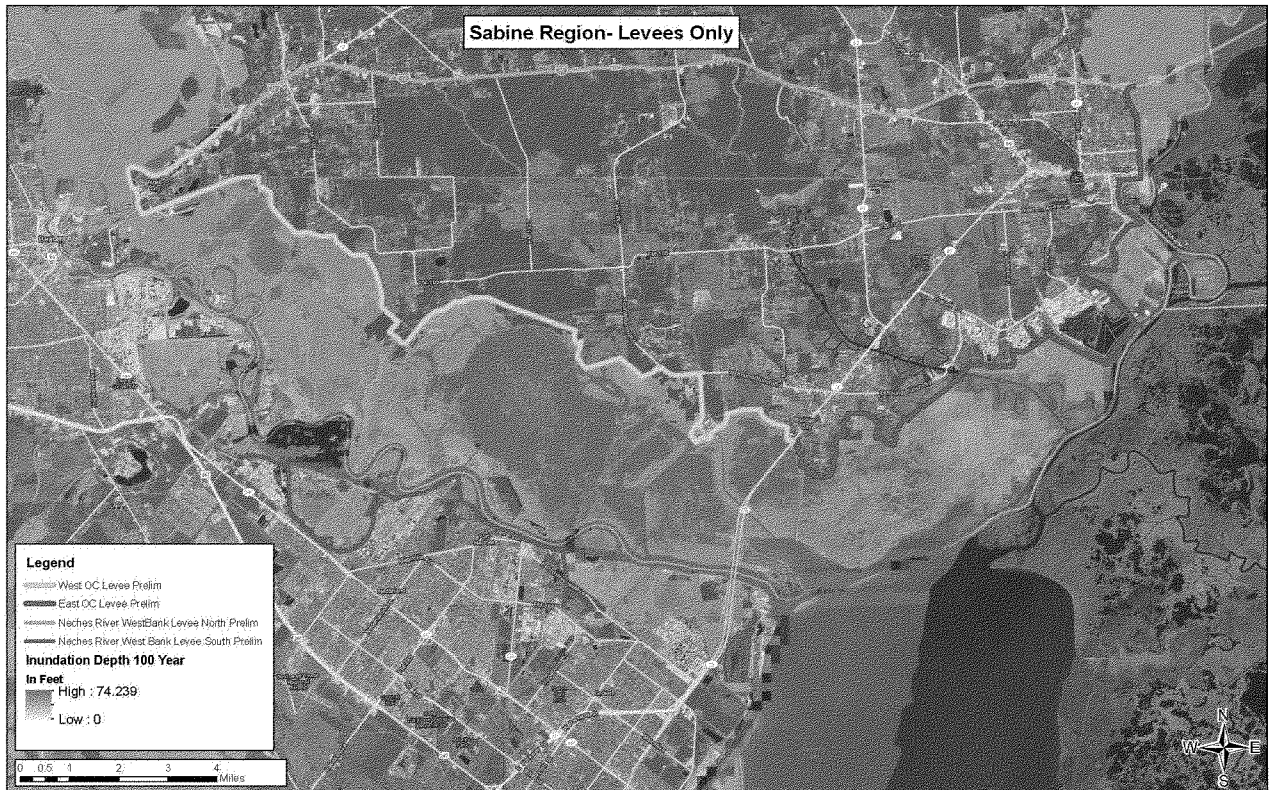


Figure 6-4. Sabine Region – No-Gate Alternative

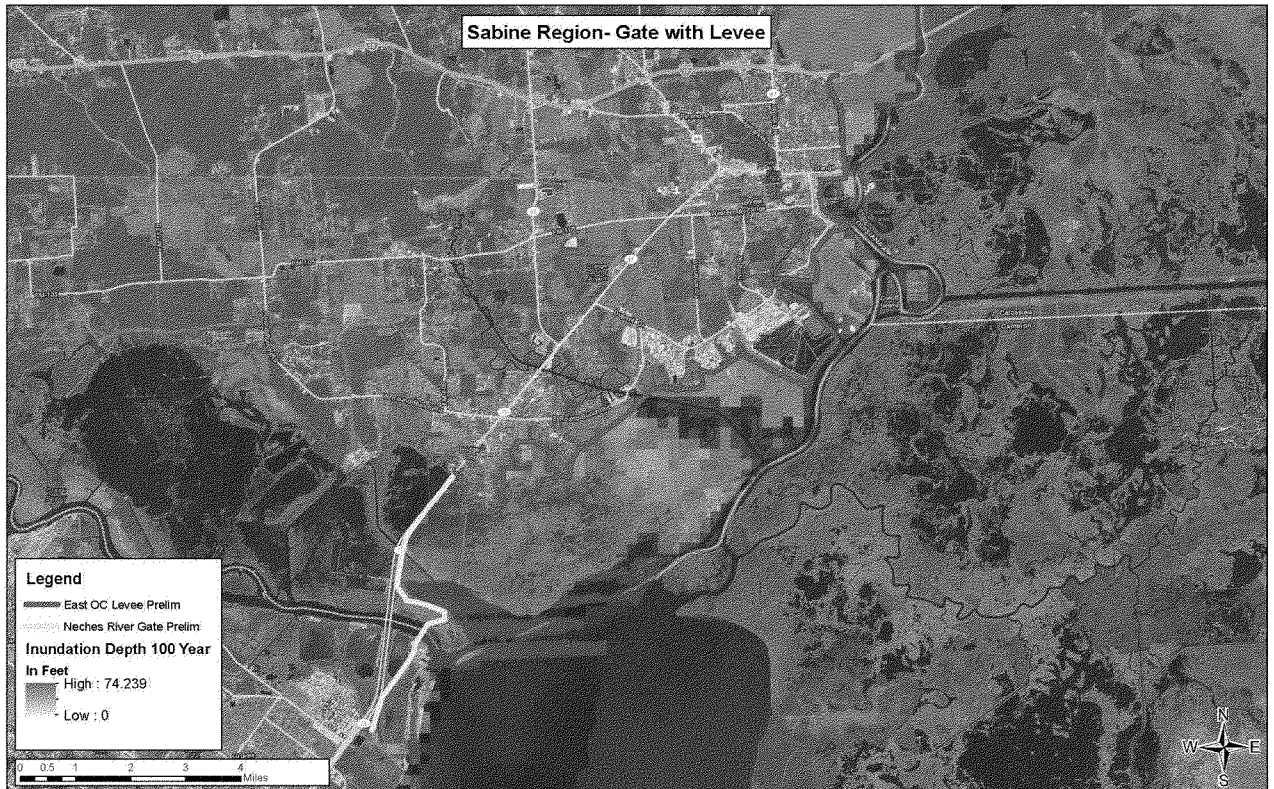


Figure 6-5. Sabine Region – Gate Alternative

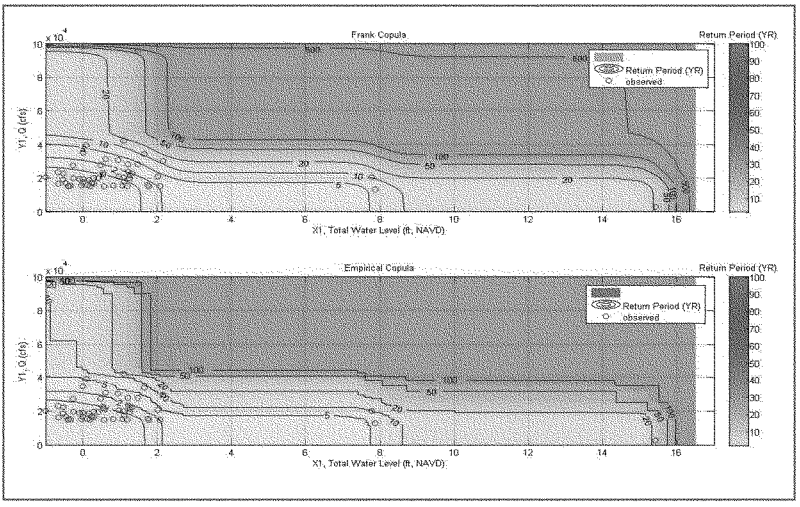


Figure 6-6. Joint probability of discharge (Q) and water level.

6.2.3 Geotechnical and Structures Analysis

A Geotechnical and Structural analysis was performed and consisted of a preliminary assessment of the proposed alignment in conjunction with H&H and Environmental analysis. The alignment was then reviewed to delineate the different reaches of floodwall and levee. The preliminary floodwall section designs were based on the Industrial Canal floodwall sections from the reconstruction of the New Orleans system. The levee sections were considered to be 15 feet in height with a 15 feet crown width and 1V:4H side slopes. The overall lengths of floodwall and levee were provided to cost. Drainage and closure structures were not separated out. The gate and pump station locations were also provided to the PDT.

6.2.4 Environmental Impacts

The construction of a flood protection system in the vicinity of Orange and north Jefferson Counties would have a high potential of impacting tidally influenced marshes and forested wetlands, cultural resources, and hazardous, toxic, or radioactive waste (HTRW) sites. The region is highly industrialized with numerous, large petrochemical refineries and other industries. Natural habitats in the area affected by the Neches River Gate and No-Gate Alternatives include the lower reaches of the Sabine and Neches Rivers, fringing marshes, bottomland hardwoods and swamps, and adjacent upland areas.

6.2.5 Wetlands and Hydrology

Wetland areas protected by the Gate Alternative from storm surge impacts cover roughly 30,000 acres. These areas include extensive tidal (fresh, intermediate, brackish, and saline) marsh along the Neches and Sabine River bottoms, as well as cypress-tupelo swamp and bottomland

hardwoods. The forested wetlands occupy an intricate network of sloughs and sandy ridges formed within the rivers' relict meander belts. They tend to be located in slightly higher elevations intermediate between the marshes and the Pleistocene terrace uplands and are found scattered throughout the affected area. A large navigable surge gate in the Neches River could potentially block some of the normal tidal flow into the system, depending upon how much of the gate is constructed within the river banks. It has been assumed that the impacts on flow could be minimized by the gate design, but residual impacts could remain. Smaller-scale navigable surge gates on Cow and Adams Bayous could have similar impacts. If reduction of the tidal prism is sizable, the smaller tidal prism could reduce daily flooding of marshes and swamps, potentially leading to changes in marsh and swamp extent. The smaller cross-section could also reduce fish and shellfish larvae access to the marsh nursery areas. Although these effects cannot be quantified for this preliminary screening, they would be systemic and have the potential for significant impacts to wetlands and nursery habitat in the Neches River system.

Habitats types protected by the No-Gate Alternative are the same as those protected by the Gate Alternative. The No-Gate Alternative would leave the Neches River floodplain open to the effects of storm surge flooding. These effects can be both positive and negative. The existing floodplain has developed under the influence of the existing tidal regime, which includes periodic flooding during storm surge events. These periodic floods bring sediments to renourish marshes. The river also provides access for estuarine organisms to reach nursery areas in the extensive marsh systems along the river bottoms. On the other hand, storm surges also scour marsh and increase salinities in areas not accustomed to higher salinity. The effects of the salinity stress varies, depending upon how long the area takes to drain high salinity surge waters after the storm, and the extent of rainfall events to help flush the system after the storm.

Direct construction impacts of both alternatives have been estimated with a GIS analysis. The classification of wetlands in the area was provided by USGS and is illustrated in Figure 6-7 and Figure 6-8. The levee/floodwall alignments were buffered to cover a total of 650 feet. This is conservatively large because it is much wider than necessary for the floodwall segments. The wetland impacts for each alternative are shown in Table 6-1 below. Overall, the No-Gate Alternative has much higher direct construction impacts than the Gate Alternative, with the exception of the brackish marsh class, for which impacts are roughly equal. However, these impacts do not include the potential indirect impacts on wetlands and nursery habitat in the Neches River system that might be caused by the large gate's obstruction of a portion of the normal tidal flow.

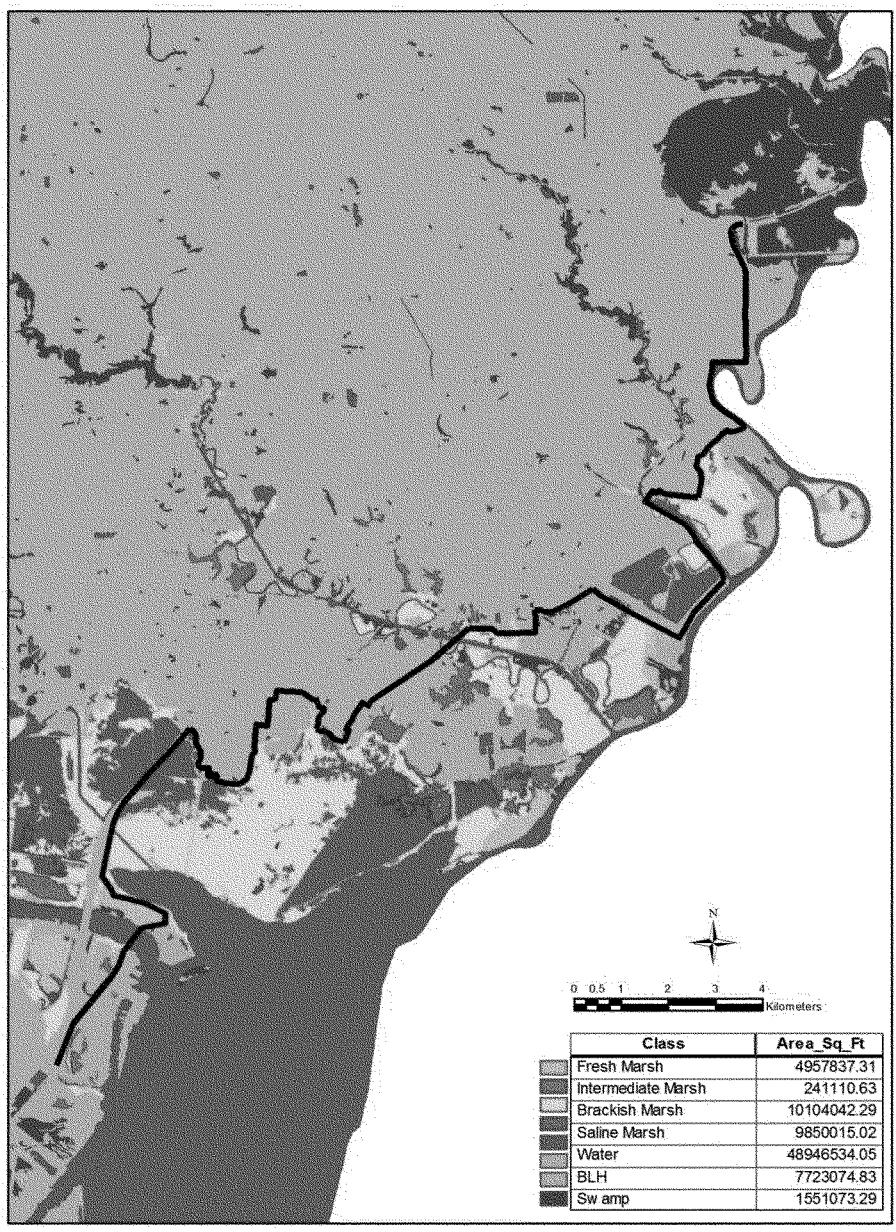


Figure 6-7. Impact of Wetlands with Gate Alternative

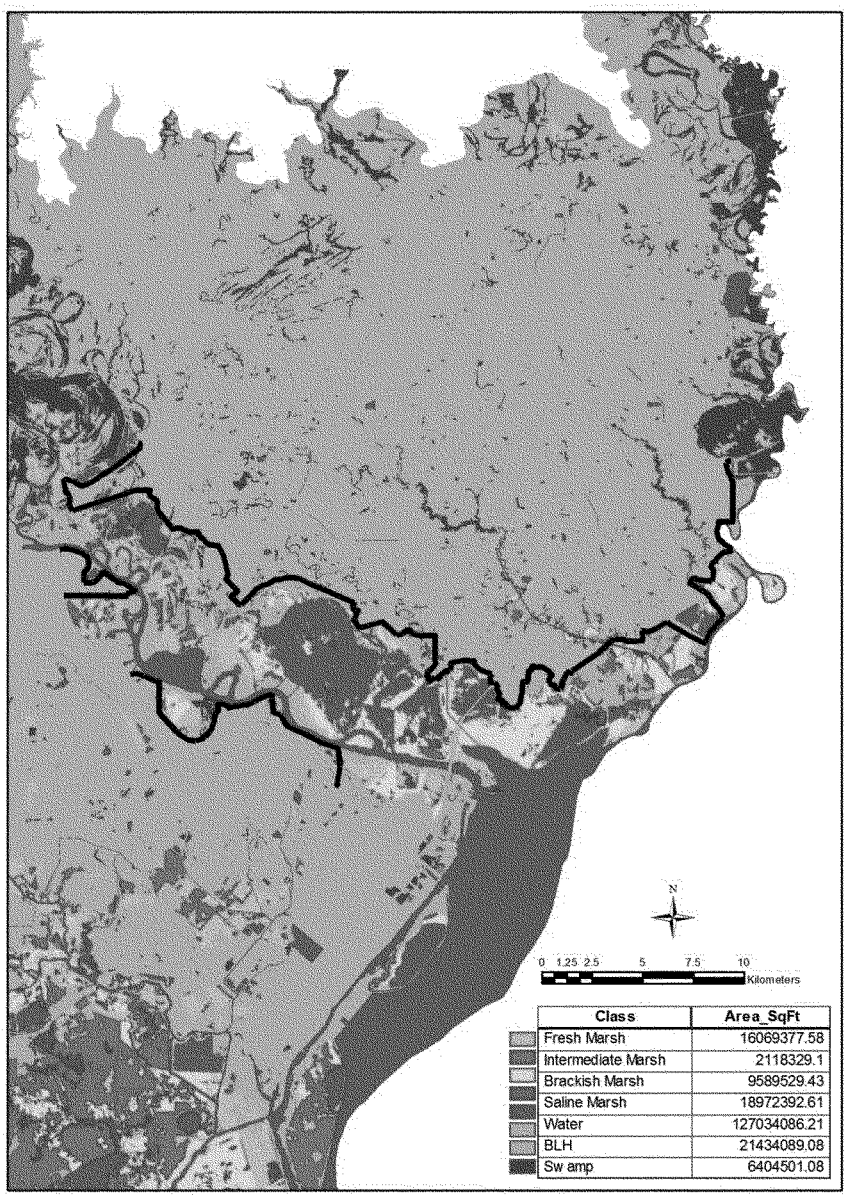


Figure 6-8. Impact of Wetlands with No-Gate Alternative

Table 6-2. Wetland Impacts Comparison of Potential Construction Impact Areas Neches River Gate and No-Gate Alternatives

Wetland Class	Gate (ac)	No-Gate (ac)
Fresh Marsh	114	369
Intermediate Marsh	6	49
Brackish Marsh	232	220
Saline Marsh	226	436
Bottomland Hardwood	177	492
Swamp	36	147
Total Emergent Vegetation	791	1713
Water	1124	2916
Total	1915	4629

The Orange County report's estimate of total wetlands that would be impacted by each alternative is very close to the USACE-USGS estimate, and therefore it is reasonable to use that report's mitigation estimates for this preliminary analysis. The Orange County report assumed that mitigation would be in-kind to the greatest extent possible and that mitigation would be performed through purchase of credits in mitigation banks. No impacts on endangered species or designated critical habitat are expected with either alternative. The estimated costs described below are included in the costs per linear foot that were used by Cost Estimating to prepare estimates for each alternative, and therefore there is no line item cost for environmental mitigation in cost comparison presented below.

Mitigation estimates in the Orange County report account for only the direct constructions impacts of these alternatives. The total mitigation cost estimated for the Gate Alternative is $69 million, while mitigation costs for the No-Gate Alternative are estimated to be $157 million. Mitigation costs for direct construction impacts appear to be much higher for the No-Gate Alternative. However, these costs do not include an estimate of mitigation for indirect impacts on the Neches River system. Potential impacts on the hydrology of the Neches River system from a large surge gate in the Neches River, and associated effects on tidally influenced wetlands and estuarine organism access were not described in the Orange County report and mitigation costs are not included in the for the Gate Alternative. Therefore, it is not possible to determine with this preliminary analysis which alternative would require the most mitigation. In either case, however, costs for mitigation are likely to be dwarfed by construction costs, and so are not likely to affect plan selection.

6.2.6 HTRW

Because of the highly industrial nature of the project area, new levee alignments have the potential to disturb HTRW sites in the project vicinity. The Orange County analysis obtained information from a one-mile radius of the new levee segments in each alternative from Banks Environmental Data, and thus over counts by a large margin the number of sites that would actually be affected by construction. The regulatory data search identified locations of HTRW sites that are regulated

by CERCLA and RCRA, as well as sites with potential environmental health and safety concerns. The number of sites that could be impacted by each alternative is roughly equal, and therefore the costs to avoid or remediate affected sites are also assumed to be roughly equal. A total of 429 sites were identified within one mile of the Gate Alternative and a total of 452 sites were identified within one mile of the No-Gate Alternative.

The Orange County HTRW analysis did not include a reevaluation of the existing Port Arthur HFPS, and therefore no analysis of potential HTRW sites adjacent to these levees and floodwalls was included in that report. USACE assumes that potential sites exist as the HFPS system passes through and adjacent to a large refinery south of Port Arthur and by other industrial facilities as well. No database search was conducted for this analysis because reevaluation of the existing HFPS is part of both alternatives and any cost associated with avoidance or remediation would be the same in both cost estimates.

Cultural Resources - A preliminary assessment of the cultural resources was conducted using a desktop review of the databases maintained by the Texas Historical Commission. The assessment looked at a 700-foot corridor for both the No-Gate and Gate Alternatives. The No-Gate Alternative overlaps with eleven archaeological sites, one National Register District, four cemeteries, and two historic markers. Ten of the archaeological sites are prehistoric and the final site has both prehistoric and historic components. None of the archeological sites has been evaluated for NRHP eligibility. The Navy Park Historic District in Orange, Texas, is the only historic property currently listed that overlaps with the project area. This is a residential neighborhood with approximately 203 contributing elements. The cemeteries include the Hollywood Community, Adcock, Sullivan, and one unknown cemetery. Both the Adcock and Sullivan cemeteries date to the early Twentieth Century and it is unknown if they are in current use. The Hollywood Community cemetery is primarily an African-American cemetery and dates to the late Nineteenth Century through the present. The two historic markers were placed in 1969 and 1986 and are likely not eligible for inclusion in the NRHP. The Gate Alternative overlaps with nine archaeological sites, the Navy Park Historic District, the Hollywood Community cemetery, and one historic marker. The nine archeological sites are also unevaluated for NRHP eligibility; however one of the sites is reported to have prehistoric human interments. The historic marker in this alternative is the same marker as above constructed in 1986. A total of 37 archeological investigations overlap with the two alternatives, however these only cover a small percentage of the total project area. Intensive historic properties investigations will likely be required in all areas with a moderate to high probability for cultural resources to occur. The cultural resource records search has determined that each alternative is likely to affect roughly the same number of archaeological sites, and therefore National Register assessment and data recovery costs would be roughly the same for each alternative.

6.2.7 Real Estate Analysis

The Real Estate (RE) analysis of the two alternatives was formulated using data from the August 2012 Final Draft of the Orange Report. RE costs were included in the cost per linear foot for the construction of the levee for both options. The only additional RE cost estimate developed was for the Neches River Crossing (NRX) segment for the Gate Option. Two elements were taken under consideration to calculate the RE cost for the NRX segment for the Gate Option; Right of

Way (ROW) acquisition and condemnation costs. When determining the ROW for the NRX, it was assumed that the width of the ROW will vary from 60 feet to 700 feet. The cost for ROW acquisition was developed by multiplying the acreage of the proposed alignment segments by the cost per acre of the ROW type provided by the Orange Report. It is assumed that 10 percent of the proposed acquisitions will be contested; therefore, condemnation actions are anticipated. Condemnation costs were calculated by taking 10 percent of the total number of affected tracts multiplied by the average cost of the condemnation process, or $70,000. The condemnation cost was provided by the Orange Report. Based upon this analysis, the RE cost estimate for the NRX segment of the Gate Option is $2,600,000.

6.2.8 Economic Analysis

A qualitative and semi-quantitative assessment for any potential disparities between the potential benefits associated with either the Gate or No-Gate alternatives was conducted utilizing ArcMap, HAZUS-MH, and parcel data from the Orange and Jefferson Counties Appraisal Districts. Inundation rasters were created from ADCIRC data points for the 100- and 500-year events in order to identify areas that could be impacted by either of these events. For this exercise, the 100-year event was used to identify a without-project damage area, which is depicted in Figure 6-3. The "dollar exposure" for this area's development was pulled from HAZUS-MH for those census blocks that intersect the 100-year inundation grid. This development is listed in Table 6-3 below by county.

Table 6-3. 100-Year HAZUS-MH Development by County (1,000s)

	Res.	Comm.	Ind.	Ag.	Rel.	Govt.	Edu.	Total
Jefferson	$166,119	$18,992	$4,024	$424	$4,828	$0	$2,450	$196,837
Orange	$154,723	$21,145	$7,766	$694	$3,640	$245	$3,546	$191,759
Total	$320,842	$40,137	$11,790	$1,118	$8,468	$245	$5,996	$388,596

The levee alignments, based on the Orange Report alignment done in 2012, were refined in some areas to increase potential benefits, reduce costs and potential environmental impacts, and to protect critical infrastructure. Additional effort was taken to avoid disruptions to major pipeline corridors and to identify opportunities for potential buyouts. The alignment for the closure gate at the mouth of the Neches River also originated from the Orange Report. This alignment was also refined to minimize impacts to the environment and navigation and to identify a potential location for a pumping station. This pumping station would need to have the ability to pump discharge from the inland Neches River into Sabine Lake.

Potential benefits for the Gate and No-Gate Alternatives were identified by trimming the 100-year inundation raster behind those areas that would be protected by each alternative. Since the decision is whether the surge gate should be ruled out from further consideration, the No-Gate Alternative was configured to provide the same level of protection as what would be provided by the Gate alternative. "Benefits" would therefore be that development removed from behind the protected areas for both alternatives. These benefits are depicted graphically for each alternative in Figure 6-4 and Figure 6-5. These reductions in monetary exposure (i.e., "Benefits") are depicted in Table

6-4 below. The assumption is that the two alternatives provide roughly the same amount of benefits.

Table 6-4. 100-Year HAZUS-MH "Benefits" by County
(1,000s)

Orange	Res.	Comm.	Ind.	Ag.	Rel.	Govt.	Edu.	Total
Without Project	$154,723	$21,145	$7,766	$694	$3,640	$245	$3,546	$191,759
Gate	$92,407	$12,236	$7,148	$694	$1,312	$245	$3,546	$117,588
No-Gate	$92,817	$14,504	$6,322	$694	$3,640	$245	$3,546	$121,768
Jefferson	**Res.**	**Comm.**	**Ind.**	**Ag.**	**Rel.**	**Govt.**	**Edu.**	**Total**
Without Project	$166,119	$18,992	$4,024	$424	$4,828	$0	$2,450	$196,837
Gate	$918	$0	$0	$0	$0	$0	$0	$918
No-Gate	$918	$0	$0	$0	$0	$0	$0	$918

For Orange County, relatively small differences exist between the Gate and No-Gate Alternative in the monetary benefits. Graphically, the protected areas for both are essentially identical. The monetary benefits for Jefferson County are identical between the two alternatives. Graphically, the No-Gate Alternative does not cut off surge going up the Neches. Because of this, the Gate Alternative showed the potential to offer greater protection since more census blocks could be impacted by the No-Gate Alternative. A closer examination however showed no additional development being unprotected by this alternative.

From this analysis, the assumption holds that the two alternatives offer roughly the same level of protection. This is supported by the inundation patterns of the two alternatives compared to inundation for the without project condition and from this qualitative/semi-quantitative assessment based on reductions in monetary exposure. The primary factor then determining the decision between the Gate and No-Gate Alternatives becomes cost.

6.2.9 Cost Estimates

Cost estimates were prepared for both alternatives in the Sabine Region:

- Gate Alternative, and
- No-Gate Alternative

These cost estimates are not representative of the overall total costs but rather are just screening level costs. The order of magnitude for these two alternatives is comparable. Both plans contain an earthen levee along the Sabine River. The Gate Option contains earthen levee, floodwalls, a Sector gate across the Neches River, and a 20,000 CFS Pump Station. The No-Gate Alternative contains earthen levee, and floodwalls. Quantities and design features were developed by the Galveston District (SWG) Engineering Branch.

For purpose of this estimate the cost for the earthen levee construction was developed by averaging the levee cost per linear foot from the Orange County Report. In doing so, these cost per linear

foot capture the cost for the construction of the levee and any incidental costs associated with the levee construction such as real estate, mitigation, pipeline relocation, culverts, road closures, etc. The cost for the floodwall was developed from the cost provided by New Orleans District. The Neches gate cost was derived by extrapolating from the gate costs in the Ike Dike Report, and the cost for the new pump station was derived from the Orange Report. No contingencies were added to the cost for this effort.

For the Engineering and Design, a flat 15 percent was applied to the construction cost. In addition, for the Construction Management, a flat 7.5 percent was added to the construction cost. See Table 6-5 below for the estimated cost summary of each alternative.

Table 6-5. Estimated Total Cost (For Each Alternative)

	Cost ($)	
Item	**Gate Alternative**	**No-Gate Alternative**
Levees & Floodwalls	762,856,000	1,550,187,000
Gate	1,296,000,000	0
Pump Station	233,182,000	0
RE Cost	2,600,000	*
Engineering & Design	342,306,000	255,405,000
Const Management	171,153,000	127,703,000
TOTAL COST	2,798,097,000	1,933,295,000

*RE costs included in the cost per linear foot of the flood wall.

6.2.10 Port of Beaumont: Evaluation of Storm Surge Impacts on Functionality and Operations of Port

A preliminary investigation was conducted by USACE to evaluate the vulnerability of the Beaumont area to storm surge, and what, if any, level of protection the proposed Neches River gate would provide to the Port and its functionality.

The representative from the Port of Beaumont stated that surge in the Port did occur during Hurricane Ike but caused only minor damage to docks and electrical systems. The Port of Beaumont was fully operable two to three days after Hurricane Ike passed. Hurricane Rita caused almost no surge or damage at the Port. Damages from Rita in the Beaumont area were almost entirely due to wind. The local floodplain administrator provided additional information on surge related damages in the Beaumont area. Ike flood damages were focused in two areas. The first area was along Pine Street in Beaumont, which experienced significant flooding. Most of the properties damaged at this location have since been bought out. The other location that was damaged by surge was the Exxon Mobil facility area located just south of the Port of Beaumont. FEMA Region VI provided damage claim amounts for the Ports of Orange and Beaumont during Hurricanes Ike and Rita. For Ike, 87 percent of damage claims were Category A (debris removal) with minimal damages to infrastructure or facilities. Damages claimed during Rita only amounted to $109,000. The Sabine Neches Navigation District reported considerable damages along Taylors Bayou caused by Hurricane Ike. They have since constructed a large diversion culvert to route water around the area and prevent flood damages on Taylors Bayou. The Water Utilities

Department noted the salt water barrier intake on the Neches River was damaged during Ike, but the cost of repair was minimal.

In summary, surge events have historically caused minimal damages to the Port and City of Beaumont. Drainage features have been constructed to alleviate flooding along Taylors Bayou, and buyouts have been performed in Beaumont to remove structures from flood prone areas. The only area that has experienced damages and not been protected or removed from flood prone areas is the Exxon facility area (which would be protected under either alternative currently being considered). During surge events water is almost entirely contained within the undeveloped Neches floodplain in the vicinity of Beaumont. Historically the Port and associated Neches River navigable waterway have been fully functional two to three days after a major storm surge event.

6.2.11 Conclusion of Gate/No-Gate Screening

Analysis for both alternatives was developed to offer roughly the same level of economic protection in order to use the costs of both to compare the Gate and No-Gate Alternatives. The cost of the Gate Alternative is approximately $865 million more expensive than the No-Gate Alternative. This cost difference is significant and further refinement and detailed analyses would not be expected to reduce this difference. Therefore, it is recommended that the Gate Alternative be dropped from further consideration in the study.

6.3 SCOPING OF STUDY UNDER 3X3X3 GUIDELINES

Recent USACE planning modernization has resulted the 3x3x3 guidelines under which this study was being developed. Therefore, a scope was developed for completion of the study that would evaluate the final array of structural and non-structural alternatives in the six-county study area and that would be completed in three years for $3 million.

One practical option available to the PDT was to develop only programmatic information, identification of projects for future studies, within the 3-year window. However, this programmatic information would not recommend a project for authorization that would reduce storm surge damages and was not supported by the non-Federal sponsor. Additionally, after coordination with the VT, it was determined that the level of effort and associated risk for the large and complex regional study was too high and other options should be developed for consideration.

A key to minimizing the study budget across all study alternatives is limiting data collection costs. Therefore, the availability of technical data has guided the PDT's approach in sequencing feasibility assessments for the upper Texas coast. The PDT would rely on technical information and assessments obtained following recent hurricanes. For example, hurricane surge data was collected at coastal levees throughout the study region after Hurricanes Rita (2006) and Ike (2008). Comprehensive storm surge modeling along the Texas coast was completed by FEMA in 2012 using modern probabilistic techniques. USACE Risk Management Center (RMC) and ERDC are conducting Potential Failure Mode Analysis (PFMA) and I-wall assessments, respectively, of existing coastal levee infrastructure in the Brazoria County region, including recommendations for improving level of performance, reliability, and resiliency. The PDT would maximize use of technical data developed by local stakeholders. In the Sabine region, Orange County and the Texas

Water Development Board have developed a planning report proposing enhanced storm surge protection infrastructure. In the Brazoria region, Velasco Drainage District has completed a storm surge assessment and collected extensive geotechnical data to support levee assessment and improvements. In the Galveston region, planning efforts have begun at multiple research agencies, including Texas A&M University at Galveston and the SSPEED Center. Additionally, the Gulf Coast Community Protection and Recovery District (GCCPRD) has begun an effort to collect existing technical data within the study area using a $3.9 million grant from GLO. Order of magnitude economic benefit and cost data exist for projects throughout the entire six-county study region.

Despite extensive data available, the VT has determined that there remain substantial data gaps, which introduce high to moderate risk in study completion for large-scale, complex engineering projects over an extensive geographic area. Therefore, the level of risk associated with the engineering and environmental decisions for the full scope to be made for completion of this $3 million study is considerable and was considered to be unacceptable by the VT.

The USACE Galveston District (SWG) developed an option for completing the study in a manner that was low to moderate risk and requested an exemption from the 3x3x3 guidelines to complete this study. The recommendation was to pursue a $4.4 million programmatic assessment of the six-county study area and focused evaluation on two sub-regions, Sabine and Brazoria, within the study area as the first interim study for CSRM project implementation. This first interim feasibility study would be followed by future studies recommending CSRM projects in the Galveston region, as well as ER opportunities throughout the entire six-county region. Future feasibilities will leverage studies, data, and models currently under development by others in the Galveston region. The exemption request was approved by USACE Headquarters and the recommended focus of the study in the Sabine and Brazoria regions continued into the final array of alternative plans.

6.4 IDENTIFICATION OF FINAL ARRAY OF ALTERNATIVES

From the combination of the evaluation screening of alternatives and exemption request approval, the gate structures in the Sabine region, all alternatives in the Galveston Region, and the ER alternatives in the entire study area were dropped from further consideration. The final array of alternatives was identified and is presented in Table 6-6. These alternatives will be evaluated in detail in the Final Screening of Alternatives to determine the TSP.

Table 6-6. Final Array of Alternatives

Alternative Number	Alternative Name	Description
S8	Sabine ER (with surge barrier on upper Sabine River)	Beach and dune restoration, restore beach ridge, nearshore breakwaters, GIWW shoreline protection, marsh restoration on Neches River and at Keith Lake and Texas Point, Salt Bayou hydrologic restoration, Sabine River levees and gate
S11	Sabine Nonstructural Alternative	Buyouts and Lone Star-type conservation plan
B2	Brazoria Coastal Barrier CSRM Focus (revised)	Freeport HFP
B5	Brazoria Nonstructural Alternative	Buyouts and Lone Star-like conservation plan

7 COMPARISON OF FINAL ARRAY OF ALTERNATIVE PLANS AND DECISION CRITERIA

7.1 FINAL ARRAY OF ALTERNATIVES

The screening of the Evaluation Array along with the recommended study scope from the exemption resulted in the modification of a Final Array of Alternative Plans with this array not including ER measures because those are to be included in future interim feasibility studies, along with the Galveston region.

In accordance with the exemption request approval, the Sabine and Brazoria CSRM measures have been carried forward into detailed feasibility analysis. A navigable surge gate structure on the Neches River in the Sabine region was screened out primarily because levees performed better economically. The Lone Star-like conservation plan non-structural alternative was also screened out, as it was not implementable by USACE. The remaining alternatives became the final array of alternatives. The final array of alternatives is presented in Table 7-1. These alternatives were evaluated in detail in the final evaluation to determine the Tentatively Selected Plan (TSP).

The Final Array of Alternatives are generally listed in Table 7-1. This list is considered a project area for the remainder of the discussion of the evaluation and comparison of the final array. The "Optimization Alternatives" embedded in the project areas listed in Table 7-1 are the actual final array evaluated and compared to determine the TSP. In the final evaluation, it became necessary to redefine the names for the Final Array of Alternatives. For example, the S5 Alternative was split into two individual alternatives: 1) Orange-Jefferson CSRM; and 2) Port Arthur and Vicinity CSRM. The project areas are listed by their name in Table 5-4.

Table 7-1. Final Array of Alternatives

Alternative Number	Description
No Action	No Action or Future Without Project (FWOP)
S5	Orange-Jefferson CSRM
S5	Port Arthur and Vicinity CSRM
B2	Freeport and Vicinity CSRM
S11 & B5	Brazoria and Sabine Nonstructural

The Optimization Alternatives are defined in Table 7-2. The Optimization Alternatives were defined by Alternative Reaches discussed in the updated FWOP described in Section 3.1.2 of the main report. The Alternative Reaches are included in the table for reference. The No Action Alternative is not listed in the table since it is the FWOP condition for each of the project areas. Brazoria and Sabine Nonstructural are also not listed because Alternative Reaches were not required for the nonstructural evaluation.

Table 7-2. Relationship with Project Area, Alternative Reaches and Optimization Alternatives

Project Area	Alternative Reaches	Optimization Alternatives
Orange-Jefferson CSRM	Orange 1	11-, 12-, 13-, and 14-foot New Levee
	Orange 2	11-, 12-, 13-, and 14-foot New Levee
	Orange 3	11-, 12-, 13-, and 14-foot New Levee
	Jefferson Main	11-, 12-, 13-, and 14-foot New Levee
	Beaumont A	11-, 12-, 13-, and 14-foot New Levee
	Beaumont B	11-, 12-, 13-, and 14-foot New Levee
	Beaumont C	11-, 12-, 13-, and 14-foot New Levee
Port Arthur and Vicinity CSRM	8- to10-foot I-Wall	No Fail, 1-foot Raise, 2-foot Raise
	Closure Structure	No Fail, 1-foot Raise, 2-foot Raise
	I-Wall Near Valero	No Fail, 1-foot Raise, 2-foot Raise
	I-Wall Near Tank Farm	No Fail, 1-foot Raise, 2-foot Raise
Freeport and Vicinity CSRM	DOW Barge Canal	Levee Rehabilitation; Gate Structure
	Oyster Creek Levee	No Fail, 1-foot Raise, 2-foot Raise
	East Storm Levee	No Fail, 1-foot Raise, 2-foot Raise
	South Storm Levee	1-foot Raise, 2-foot Raise
	Freeport Dock Floodwall	Partial Fail, No Fail, 1-foot Raise
	Old River Levee at DOW Thumb	No Fail, 1-foot Raise, 2-foot Raise
	Tide Gate I-Wall	No Fail, 1-foot Raise, 2-foot Raise

7.1.1 Final Screening Criteria

In order to select a plan from the final array, screening criteria were developed that align with the objectives of the study (See Table 4-1, Section 4.2.3 of the main report) and listed below.

- Objective 1: Reduce economic damages to business, residents and infrastructure for the Sabine and Brazoria region for the 50-year period of analysis.
- Objective 2: Reduce risk to human life from storm surge impacts for the Sabine and Brazoria region for the 50-year period of analysis.
- Objective 3: Maintain and/or restore coastal habitat that contributes to storm surge attenuation where feasibility for the 50-year period of analysis.
- Objective 4: Enhance energy security and reduce economic impacts of petrochemical supply-related interruption for the Sabine and Brazoria region for the 50-year period of analysis.
- Objective 5: Reduce risk to critical infrastructure (e.g. medical centers, ship channels, schools, transportation) for the Sabine and Brazoria region for the 50-year period of analysis.
- Objective 6: Identify opportunities to enhance functionality of existing hurricane protection system including evaluation of impacts due to sea level rise for the 50-year period of analysis.

The planning objectives were aligned with the four accounts: NED, EQ, RED, and OSE. The Optimization Alternatives were evaluated in detail, then compared against each other to identify

which plan contributes most to the objectives. These screening criteria are different than the screening process used in the Initial and Evaluation Array of Alternatives. The Optimization Alternatives were evaluated first for the NED objectives (Objectives 1, 4 and 6) using the HEC-FDA model. The EADs presented in this report use storm surge levels without considering sea level rise scenarios for the 20-, 50- and 100-year sea level rise scenarios. Alternative Reaches were defined in the FWOP; this condition is the baseline to show reductions in EAD and to identify which plan reasonably maximizes net economic benefits (i.e., the NED plan). The compilation of each NED plan from the project areas are considered for the TSP. The screening criteria for RED and OSE objectives are qualitative (Objectives 4 and 2, respectively). For RED, critical infrastructure impacts are discussed qualitatively with focus on the effect of transportation disruptions after storms and the number of critical facilities and evacuation routes for which risk is reduced. For OSE, alternative performance is measured based on the number of people for which risk is reduced. This is discussed qualitatively for the final array. Another means to measure reduction in life-safety risk is to utilize a quantitative model. The HEC-FIA model has not been used to evaluate the final array. The final array evaluation results are described first in terms of economic performance (i.e., the net benefits are displayed for each Optimization Alternative). The net benefits were developed by comparing the Optimization Alternatives to the FWOP EADs. The qualitative discussion of life-safety, critical infrastructure, and consideration of RSLC is provided in Section 7.1.8.

7.1.2 Final Array Evaluation Results

The following sections present the results of the evaluation of the final array. This section focuses on a description of the Optimization Alternatives and the economic evaluation results. Additional description of the Optimization Alternatives is provided in Appendix D, Section 1.9, and the detailed economic evaluation results is provided in Appendix C, Economics. Project Area

The regions were further refined in the study within the Sabine and Brazoria regions located in Orange, Jefferson and Brazoria counties into project areas. These project areas were defined for the final array to show more detail on the FWOP conditions storm surge flood risk. The project areas generally align with the 0.2% Annual Chance Exceedance (ACE) (500-year floodplain) and locations of structures analyzed in the study. Figure 7-1 and 7-2 show the project areas. The Orange-Jefferson CSRM and Port Arthur and Vicinity CSRM projects areas are in the same general vicinity. In Figure 7-1, the highlighted areas shown in red are located on Orange County side and structure in yellow on the Jefferson County side. The Orange-Jefferson CSRM focus on inundation of structure on the Orange and Jefferson County side, while the Port Arthur and vicinity focus on the Jefferson County side.

7.1.3 FWOP Conditions Updates for the Final Array of Alternatives

The conditions described here focus on summarizing the technical engineering and economic evaluations that drive the flood risk analysis for this study. Flood risk is described in terms of life-safety risk, economic damages, and impacts on infrastructure with national significance. These items are important in comparison of plans evaluated to address the storm surge problems and meet the study objectives.

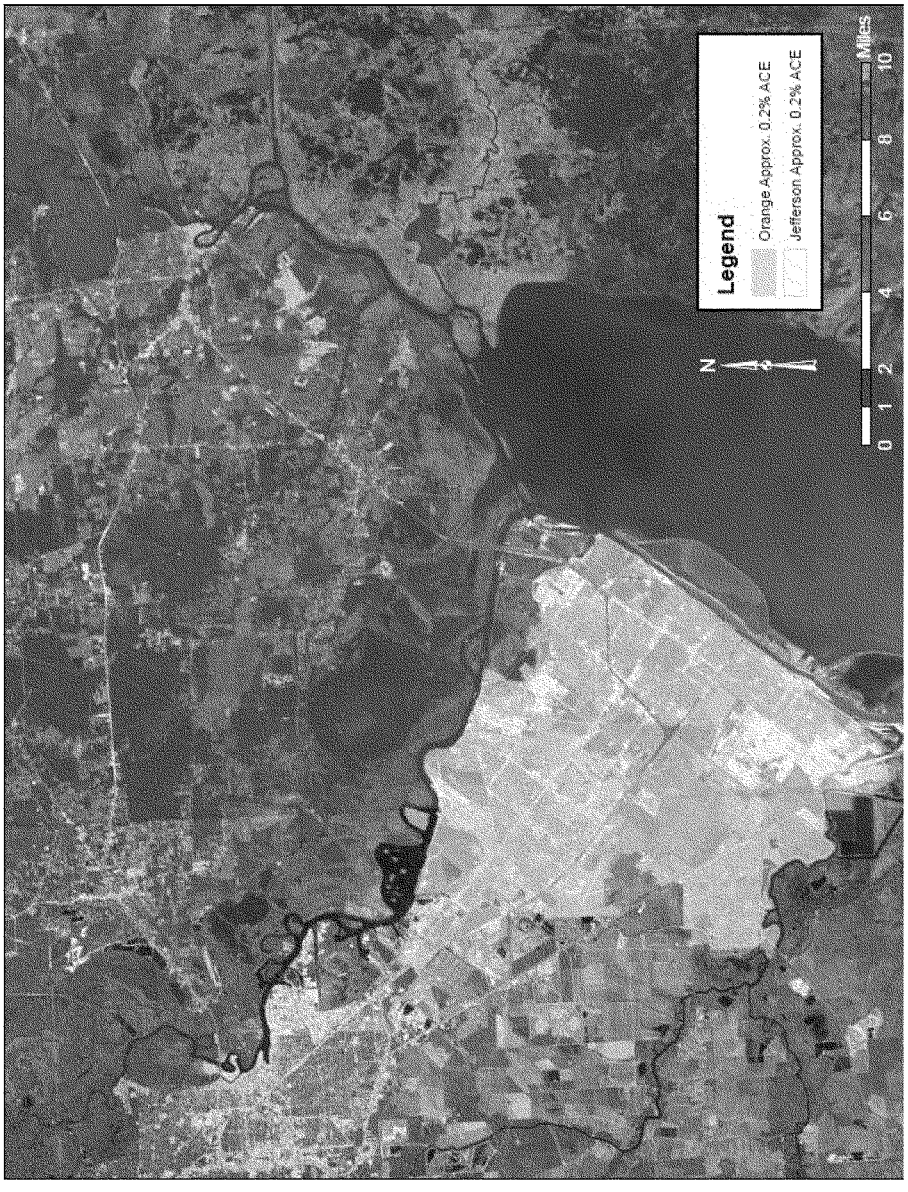


Figure 7-1. Orange-Jefferson CSRM and Port Arthur and Vicinity CSRM Project Areas

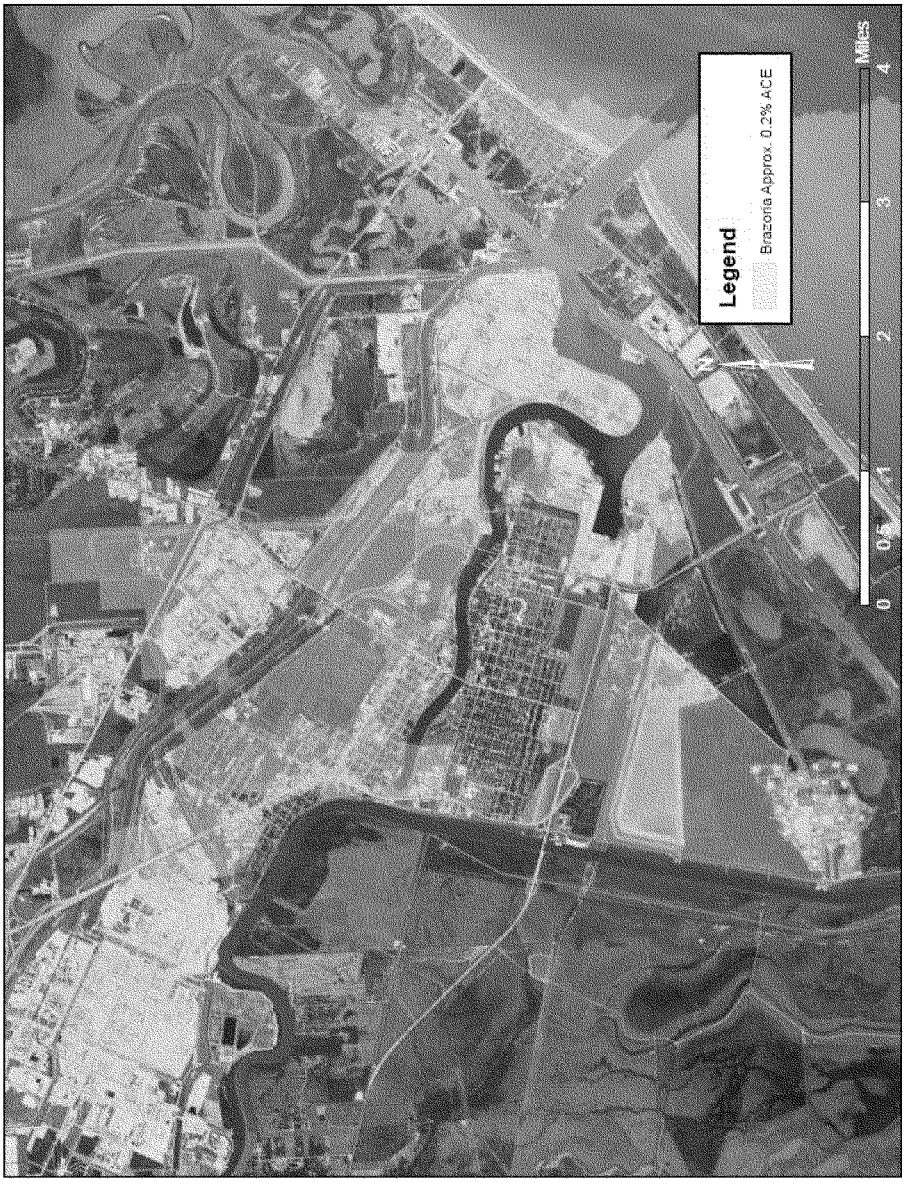


Figure 7-2. Freeport and Vicinity CSRM Project Areas

In order to define the conditions for life-safety, economic damages and infrastructure under the FWOP, a description of the existing HFPPs is required. This includes a description of the existing facilities in place and the known vulnerabilities in those systems. The following is a brief description of the existing projects in place, including two Federal projects (Freeport HFPP and Port Arthur HFPP). Other projects in the vicinity are noted, but were not originally built by USACE. Additional detail of the existing projects is included in the engineering appendix (Appendix D).

As noted in Section 1.9 of the main report, the Port Arthur and the Freeport HFPPs were constructed by USACE. The local sponsors responsible for operation and maintenance are the Jefferson Country Drainage District No. 7, and the Velasco Drainage District (VDD), respectively. There is no existing USACE HFPP in the Orange-Jefferson CSRM project area. The following describes the existing projects in place for each project area.

7.1.4 Existing Hurricane Flood Protection Facilities

Orange-Jefferson CSRM
A known existing flood protection facility located in the Orange-Jefferson CSRM project area is a wall surrounding the Exxon Mobil industrial facilities as indicated in Figure 7-3. This facility was constructed by local industry around the Exxon Mobil plant.

Port Arthur and Vicinity CSRM
The system protects the Port Arthur region from coastal storm surge events coming from the Gulf of Mexico. It also protects from flooding from the Sabine River. The levee system consists of 27.8 miles of earthen embankment and 6.6 miles of floodwall. This includes 3.5 miles of coastal cantilever I-wall (Texas Coastal I-Wall study). There is also a wave barrier on Pleasure Island. The system was designed and constructed for a 1% ACE.

The Port Arthur and Vicinity CSRM project area has an existing USACE HFPP that has a preliminary Levee Safety Action Classification (LSAC) that has resulted in the RMC initiating a Semi-Quantitative Risk Assessment (SQRA) to better define the systems risk. This classification was primarily driven by three main risk factors (probability of load, probability of failure, and nature of the consequences). The following lists the major engineering concerns for the Port Arthur and Vicinity CSRM:

- Potential failure due to I-wall stability (locations of concern shown in Figure 7-4); and
- Currently the system would suffer a catastrophic failure during a future hydraulic loading roughly equivalent to 0.6% ACE (150-year event).

The existing system at Port Arthur is considered "minimally acceptable" under the USACE' P.L. 84-99 program. A Periodic Inspection was completed for the Port Arthur system in 2012. The sponsor was provided a list of items to correct. The sponsor is in the process of correcting these items. The potential failure issues addressed in this study are not considered an O&M responsibility. The existing Port Arthur HFPP is certifiable for FEMA accreditation under CFR 65.10 so the local sponsor has no current plans to address the risk drivers for the engineering

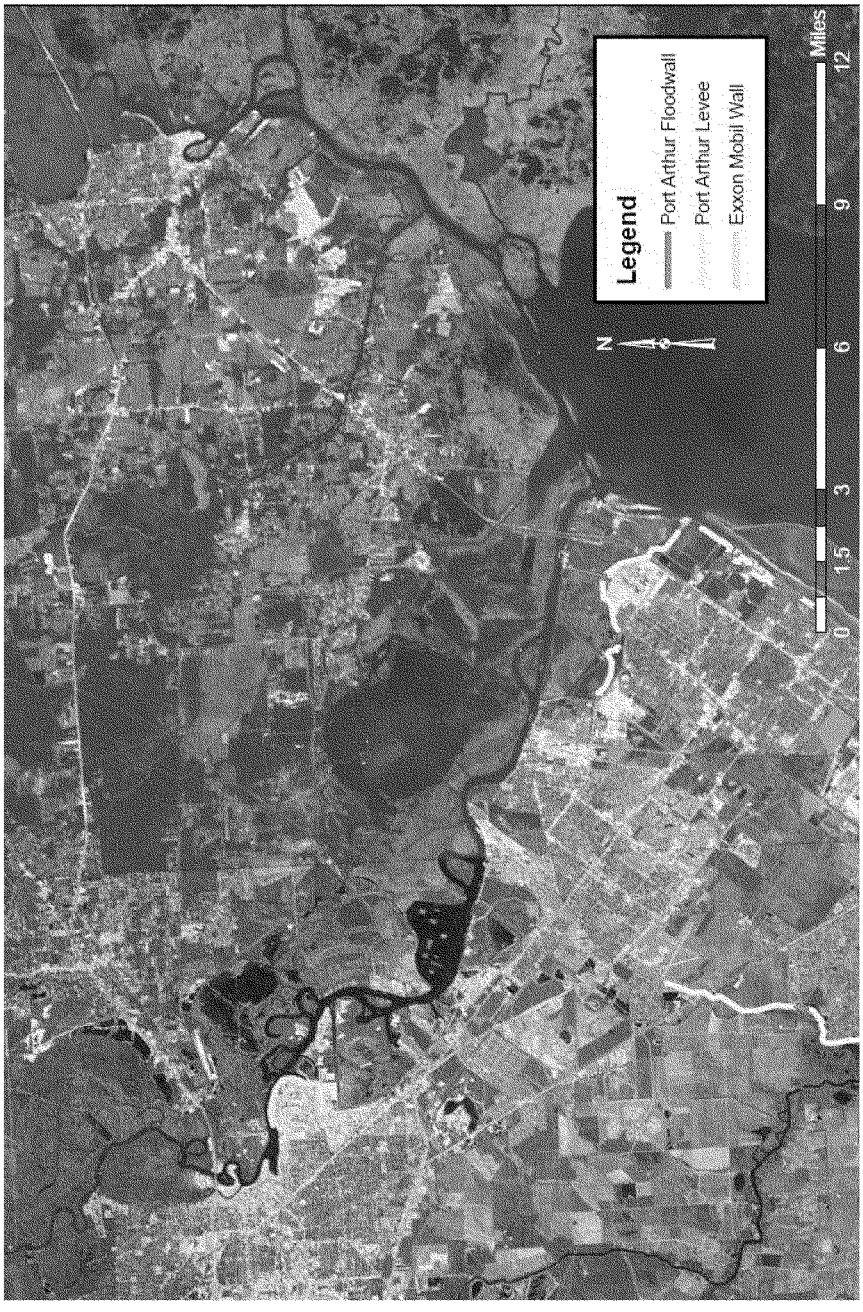


Figure 7-3. Existing Floodwall in the Orange-Jefferson CSRM Project Areas

Figure 7-4. Port Arthur and Vicinity CSRM Failure Locations

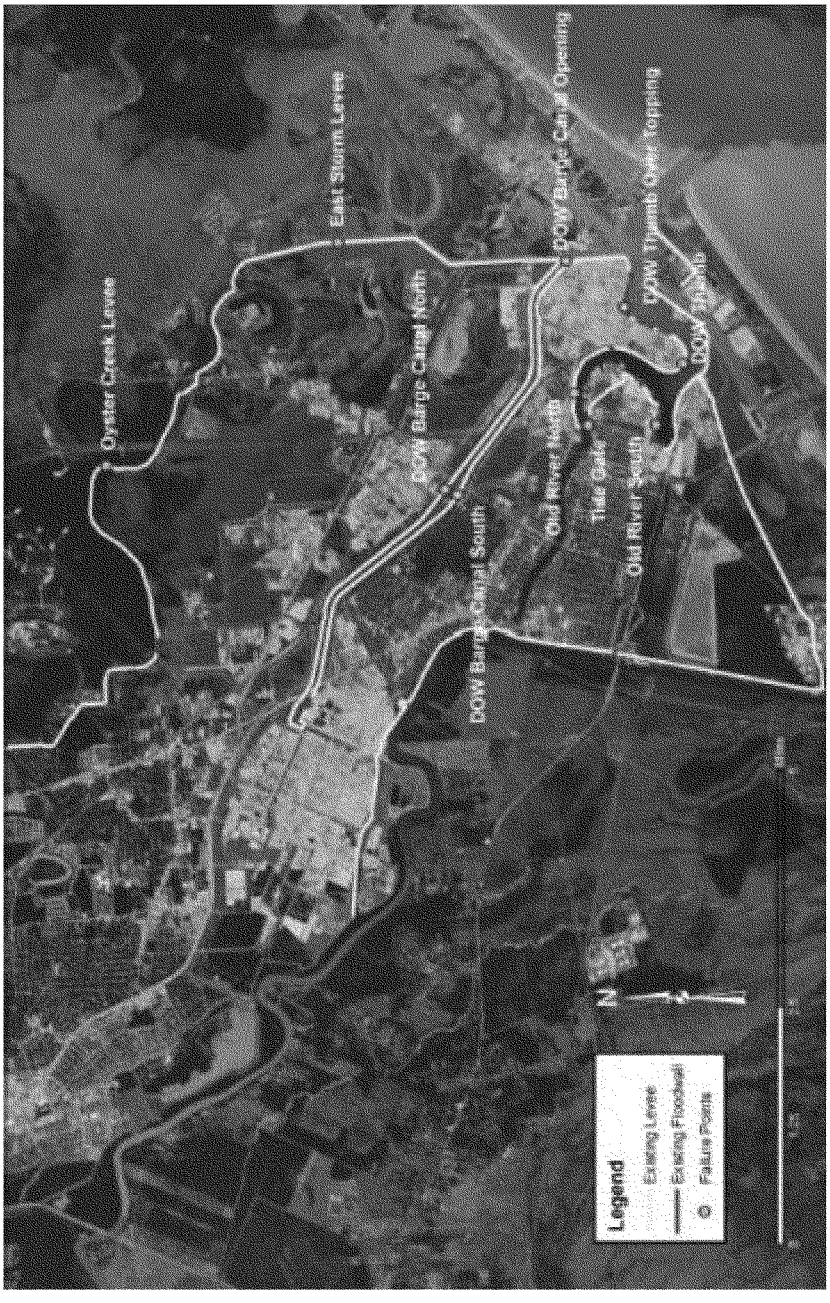


Figure 7-5. Existing HFPP in Freeport and Vicinity CSRM

concerns in the FWOP condition. It is assumed in the FWOP condition, no other actions to reduce the risk will take place by others.

Freeport and Vicinity CSRM
The existing HFPP at Freeport consists of approximately 43 miles of levees and wave barriers, seven pump stations and multiple gates, culverts and related appurtenances. Additionally, in the line of protection includes multiple structures that also serve as control structures and docks for the Dow Chemical Co., BASF, Conoco Philips, Exxon and Port Freeport.

The Freeport and vicinity system has a preliminarily LSAC that has resulted in the RMC conducting an SQRA to define the systems risk. This classification was driven by numerous factors. The primary structural factors that would have federal interest are seepage/slope stability of "sandy" levees, I-wall stability, and a "low" level of protection (i.e., high probability of overtopping).

- Steady state seepage analysis for the levees and foundation areas that have a high sand content show high potential for levee failure at top of levee loading;
- Potential failure of the I-wall at the tide gate due to stability; and
- System capacity corresponds to around a 0.7% ACE (130-year event) with significant consequences.

Currently the system is "unacceptable" in the PL 84-99 program and not certifiable for FEMA accreditation under CFR 65.10; therefore, the local sponsor has a System-Wide Improvement Framework (SWIF) plan in place to address the deferred maintenance issues and issues impeding CFR 65.10 accreditation. The sponsor has no current plans to address the structural risk drivers for the LSAC rating due to the performance concerns coming at a more significant hydraulic loading event than the requirements under CFR 65.10. The future without project conditions would result in no action being undertaken to reduce the risk that the system would suffer a catastrophic failure during a future hydraulic loading roughly equivalent to a 0.7% ACE event.

7.1.5 Economic Evaluation

Structure files for the project areas were developed to determine the potential flood damages to properties based on estimated storm surge events. Estimated Annual Damages (EAD) under the FWOP conditions were calculated using the risk and uncertainty within HEC-FDA version 1.2.5, through integration of frequency-damage data. Based on the characteristics of the floodplain, the project areas were split into damage reaches. The damage reach determinations were based on hydraulic, geotechnical, social and environmental considerations as appropriate, and defined within the respective project area sections below. The EADs for the FWOP conditions are presented for each alternative reach along with the engineering inputs and assumptions into the model. Tables displaying structure and content values by reach, and additional detail regarding development of the structure file is provided in Appendix C.

The effort for estimating EAD estimates for each damage reach used a different methodology than what was employed for the initial screening of alternatives. The initial screening used HEC-FIA with 1% annual chance exceedance (ACE) depth grids in conjunction with HAZUS-MH data to

determine without and with-project economic damages. The analysis for evaluating the final array incorporated a risk-based analysis in compliance with ER-1105-2-101.

Still water levels were used to determine the overall economic efficiency of the final array alternatives since low-probability wave run-up and/or overtopping do not incorporate a reliable means of determining high-level overall economic efficiency. Design considerations for wave run-up and overtopping will be analyzed later and applied to specific locations where it is applicable. This includes along the levee/floodwall system, and necessary interior drainage analysis on the final feasibility-level design of the recommended plan.

Fragility curves were developed for use in the HEC-FDA model for specific locations along the Port Arthur and Freeport systems in order to account for the anticipated system performance at those locations and were used to scope the reconstruction and resiliency features for the existing system. These curves were developed by the SWG Geotechnical and Structural Engineering section using existing information. Existing data used included performance history based on previous hydraulic loadings for the system, draft findings of the Freeport SQRA, draft findings of the Texas Coastal I-wall study, USACE work on erosion for Herbert Hover Dike, Interagency Performance Evaluation Task Force (IPET) report, Engineering Technical Letter (ETL) 1110-2-575 criteria, along with influence from the LSAC screenings and the HEC Risk Analysis for Flood Damage Reduction Projects and RMC Internal Erosion Workshop. The curves were focused on anticipated structural performance of the I-walls along with erosion from overtopping of embankments and at wall embankment tie-in locations and reflect uncertainty in storm duration, size, landfall location, and wind driven wave height. Additional detail of the fragility curve development for the economic evaluation for the FWOP condition and the with-project conditions discussed in the subsequent sections are included in Appendix D, Geotechnical Section.

Orange-Jefferson CSRM

To estimate EADs, the system was set up with three major components based on their location. This was primarily due to initial configurations of new levees based on alignments from the Orange County Flood Protection Planning Study (Orange Report), completed in 2012. The following lists the major features.

- Orange 1, Orange 2, and Orange 3;
- Jefferson Main;
- Beaumont A, Beaumont B, and Beaumont C.

The Orange component runs along the north side of the Neches River and was divided into three sections: Orange 1 on the western end that primarily protects Rose City, Orange 2 that begins just east of Rose City and ends roughly halfway between Rose City and Bridge City, and Orange 3, which encompasses the remainder of the Orange County component. Figure 7-6 presents the Orange-Jefferson damage reaches. The "with-project" levee and floodwall alignments are included in this figure although this discussion is only supposed to present the reaches.

Fragility curves for use within the HEC-FDA model were not required since there was no existing HFPP in this project area. The FWOP condition EADs for the Orange-Jefferson CSRM were

based on Hydrology and Hydraulic (H&H) and structure file inputs, and described in detail in Appendix C.

For the Orange 1, Orange 2, and Orange 3 alternative reaches, significant damages start at approximately the 1% ACE; the depth of flooding at the 1% ACE is approximately eight feet. In the Jefferson Main alternative reach, significant damages start between the 2% and 1% ACE; the depth of flooding between the 2% and 1% ACE is approximately 6.5 feet and 7.5 feet. For the Beaumont A, Beaumont B and Beaumont C the significant damages start at the 1% ACE; the depth of flooding is approximately 7.5 feet.

The total number of structures in the Orange-Jefferson CSRM is 27,125 (Orange County) and 26,605 (Jefferson Country). The total structure and content values of inventoried structures (2015 price and levels of development) for the Orange-Jefferson CSRM, in Orange County is $6,147,511,000 ($3,170,490,000 structure value, and $2,977,021,000 in content value). Total structure and content values of inventoried structures (2015 price and levels of development) for the Orange-Jefferson CSRM, in Jefferson County is $8,120,438,000 ($3,998,788,000 structure value, and $4,121,650,000 in content value).

Table 7-3 estimates the FWOP EADs for the damage reaches in the Orange-Jefferson CSRM. Damage categories are defined as the following; *Comm.* (commercial), Ind. (industrial), *MFR* (multi-family residential), *MR* (mobile residences), *Public* (public), *POV* (personal occupancy vehicles), and *SFR* (single-family residential).

Port Arthur and Vicinity CSRM

The draft findings of the SQRA for the Freeport system were applied to the plan formulation for the Port Arthur because one has not yet been done for this system. For the Port Arthur HFPP, the detailed description of the needs is similar to what will be presented in the Freeport HFPP section. However, the Port Arthur system is different because there are no known deferred maintenance issues for the Port Arthur system at this time.

The FWOP conditions for the Port Arthur and Vicinity CSRM began with defining reaches for the system. These were based on the failure locations identified by the levee safety program in the absence of a SQRA. Figure 7-7 displays the Port Arthur HFPP failure locations. These locations were included in the plan formulation where improvements would positively impact the system's capacity for protection. The following lists the reaches at Port Arthur.

- 8-foot to 10-foot I-Wall
- Closure Structure
- I-Wall Near Valero
- Tank Farm

The FWOP condition EADs for the Port Arthur and Vicinity CSRM were based on fragility curves, Hydrology and Hydraulic (H&H) and structure file inputs, and described in detail in Appendix C.

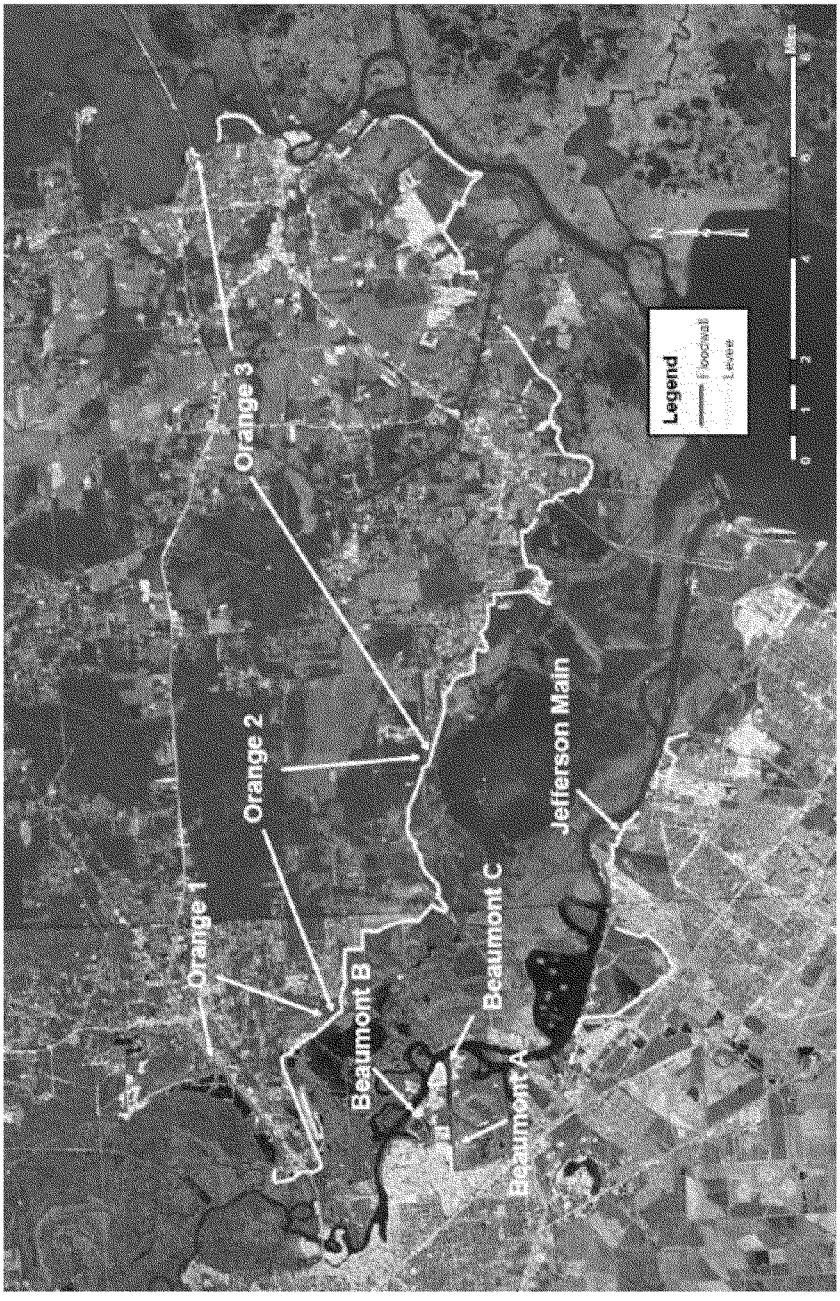


Figure 7-6. Orange-Jefferson Alternative Reaches

Table 7-3. Expected Annual Damages Future Without-Project Condition for Orange-Jefferson CSRM (2015 price level)

	Damage Categories						
Reach	**Commercial**	**Industrial**	**MFR**	**MR**	**Public**	**POV**	**SFR**	**Total**
Orange Jefferson CSRM								
Orange 1	$73,000	$0	$0	$7,000	$10,000	$33,000	$190,000	$312,000
Orange 2	$0	$0	$0	$4,000	$0	$10,000	$54,000	$68,000
Orange 3	$21,833,000	$0	$93,000	$98,000	$409,000	$969,000	$6,585,000	$29,987,000
Beaumont A	$0	$6,937,000	$0	$0	$0	$0	$0	$6,937,000
Beaumont B	$0	$23,000	$0	$0	$0	$0	$0	$23,000
Beaumont C	$0	$262,000	$0	$0	$0	$0	$0	$262,000
Jefferson Main	$4,600,000	$929,000	$4,834,000	$0	$1,824,000	$536,000	$15,509,000	$28,231,000

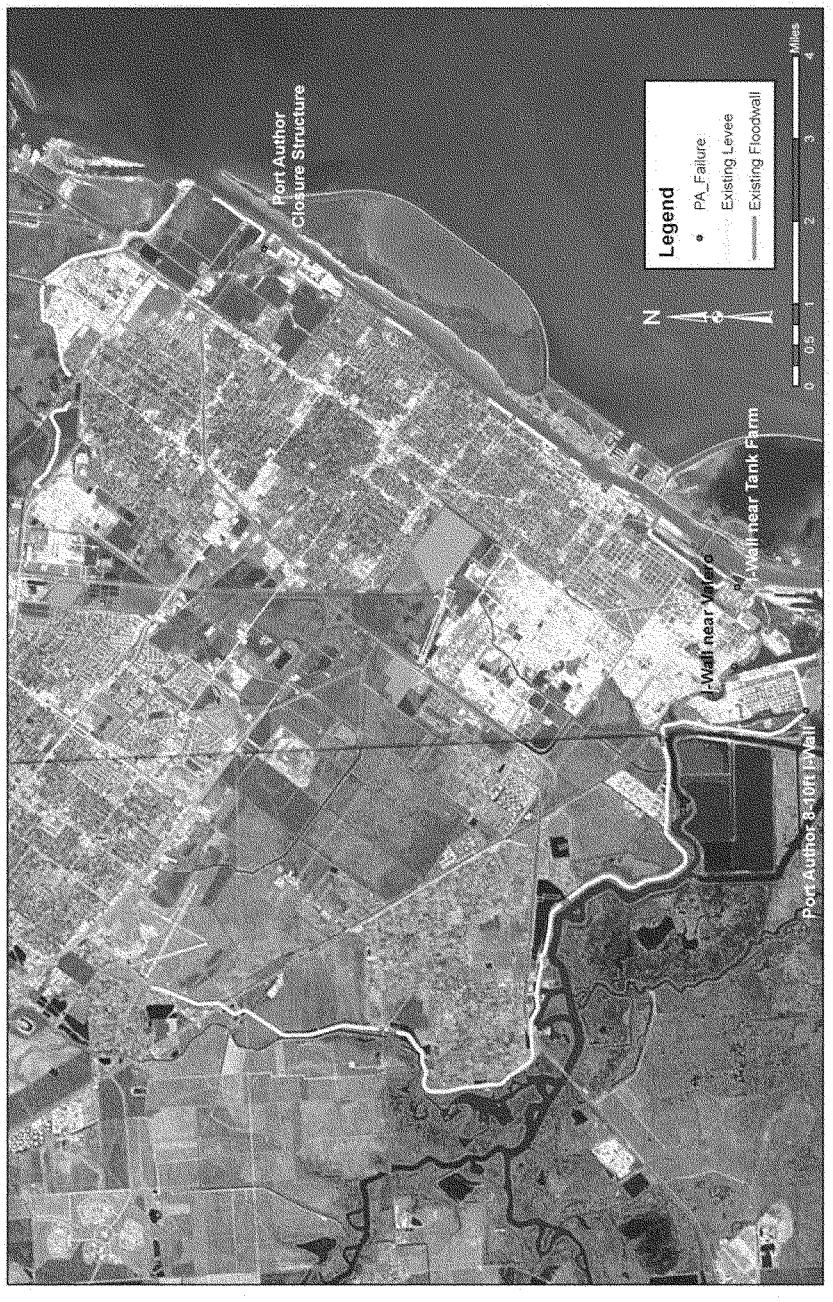


Figure 7-7. Port Arthur and Vicinity Failure Locations

The estimated start of damages for the Port Arthur and Vicinity alternative reaches is approximately 15 feet, which correlates to an estimated high probability of failure of the existing HFPP based on the fragility curves. Flooding depths approximate the stage on the exterior side of the existing HFPP, which goes up to approximately 14 feet for the 0.1% ACE.

There are 43,968 structures included in the structure file for the Port Arthur and Vicinity CSRM. The total structure and content values of inventoried structures (2015 price and levels of development) for the Port Arthur and Vicinity CSRM is $19,195,051,000 ($7,869,963,000 structure value, and $11,625,088,000 in content value).

Table 7-4 estimates the FWOP EADs for the damage reaches in the Port Arthur and Vicinity CSRM. Damage categories are defined as the following; *Comm.* (commercial), Ind. (industrial), *MFR* (multi-family residential), *MR* (mobile residences), *Public* (public), *POV* (personal occupancy vehicles), and *SFR* (single-family residential).

Freeport and Vicinity CSRM

The draft findings of the SQRA for the Freeport system show vulnerabilities primarily associated with steady state seepage issues, and floodwall and levee overtopping. Other performance issues identified during the SQRA were the result of deferred local sponsor maintenance, or alterations that local industrial stakeholders have constructed over time. Floodwall performance issues, at locations where the originally constructed floodwall is still in place and has been operated and maintained in an acceptable manner, are being evaluated to include stability and resiliency. Levee reaches that are non-uniform in height or otherwise susceptible to concentrated overtopping erosion during an event are being evaluated for raising or armoring to reduce the likelihood of breach.

The formulation of alternatives for the Freeport and Vicinity CSRM began with defining reaches for the system. These were based on the failure locations identified in the SQRA (Figure 7-8). These locations were then narrowed during formulation to those locations where improvements would positively impact the system's capacity for protection and to reduce any redundancies. For example, improvements to the Dow Barge Canal would negate any failures at the Dow Turning Basin.

The following is the resulting list of reaches at the Freeport and Vicinity CSRM.

- Dow Barge Canal
- East Storm Levee
- Freeport Dock
- Old River at Dow Thumb
- Oyster Creek Levee
- South Storm Levee
- Tide Gate I-Wall

The FWOP condition EADs for the Freeport and Vicinity CSRM were based on fragility curves, Hydrology and Hydraulic (H&H) and structure file inputs, and described in detail in Appendix C.

Table 7-4. Expected Annual Damages Future Without-Project Conditions for Port Arthur and Vicinity CSRM (2015 price level)

	Damage Categories							
Reach	**Commercial**	**Industrial**	**MFR**	**MR**	**Public**	**POV**	**SFR**	**Total**
Port Arthur and Vicinity CSRM								
Port Arthur 8ft-10ft I-Wall	$19,302,000	$560,000	$83,000	$0	$368,000	$275,000	$2,824,000	$23,413,000
Port Arthur Closure Structure	$3,128,000	$86,000	$13,000	$0	$59,000	$44,000	$453,000	$3,784,000
Port Arthur I-Wall Near Valero	$50,798,000	$1,587,000	$228,000	$0	$975,000	$726,000	$7,553,000	$61,867,000
Port Arthur Tank Farm	$31,139,000	$1,012,000	$143,000	$0	$599,000	$446,000	$4,670,000	$38,009,000

Figure 7-8. Freeport and Vicinity CSRM Failure Locations

The estimated start of damages for the Freeport and Vicinity alternative reaches is approximately 15 feet, which correlates to estimated high probability of failure of the existing HFPP based on the fragility curves. Flooding depths approximate the stage on the exterior side of the existing HFPP, which goes up to approximately 19 feet for the 0.1% ACE.

There are 23,326 structures included in the structure file for the Freeport and Vicinity CSRM. The total structure and content values of inventoried structures (2015 price and levels of development) is approximately $16,700,000,000. Estimates could be higher based on additional structures in the lower reaches outside the Dow Barge Canal structure file inventory.

Table 7-5 estimates the FWOP EADs for the damage reaches in the Freeport and Vicinity CSRM. Damage categories are defined as the following; *Comm.* (commercial), Ind. (industrial), *MFR* (multi-family residential), *MR* (mobile residences), *Public* (public), *POV* (personal occupancy vehicles), and *SFR* (single-family residential).

7.1.6 Life Safety

The population at risk broken down by project area is included in Table 7-6. These populations at risk were developed based on the 2010 census blocks that intersect the damageable properties in the project areas. This population reflects the residential population that could be exposed to flood risk. This does not include transportation routes for population evacuating or those at work in commercial or industrial areas.

Broad warnings as storm systems develop are coordinated through various agencies such as the National Weather Service, which provides reports to the essential print and electronic media outlets. The National Weather Service generally releases tropical storm watches 48 hours in advance of any anticipated onset of tropical storm force winds. Since outside preparedness activities become difficult once winds reach tropical storm force, warnings are issued 36 hours in advance of any anticipated onset of tropical storm force winds. The Texas Department of Public Safety's Division of Emergency Management coordinates the state emergency management program as well as implementing the Texas Emergency Tracking Network (ETN), part of a comprehensive data-management system that provides real-time information before, during, and after a disaster. Orange and Jefferson Counties are members of the Southeast Texas Altering Network, which can alert users of emergencies, plant operations, traffic, and weather information or other outreach from emergency management. Orange and Jefferson Counties, as well as Brazoria County, have emergency management departments that engage their respective cities including specific evacuation plans and processes.

7.1.7 Critical Infrastructure

The following is a description of the existing critical infrastructure in each project area. Critical infrastructure listed here includes industrial and manufacturing facilities, as well as public facilities. This is a qualitative discussion of the future without project condition focused on the impacts associated with potential storm surge flooding. The inventory of critical infrastructure was developed from information derived from the Homeland Security Infrastructure Program (HSIP), which is an infrastructure geospatial data inventory. The critical infrastructure is

Table 7-5. Expected Annual Damages Future Without-Project Conditions for Freeport and Vicinity CSRM (2015 price level)

	Damage Categories							
Reach	**Commercial**	**Industrial**	**MFR**	**MR**	**Public**	**POV**	**SFR**	**Total**
Freeport and Vicinity CSRM								
Dow Barge Canal	$3,070,000	$145,903,000	$884,000	$2,000	$4,815,000	$3,088,000	$8,897,000	$166,660,000
East Storm Levee	$346,000	$247,000	$99,000	$0	$233,000	$191,000	$587,000	$1,701,000
Freeport Dock	$768,000	$583,000	$217,000	$0	$549,000	$456,000	$1,387,000	$3,960,000
Old River at Dow Thumb	$489,000	$367,000	$139,000	$0	$349,000	$290,000	$882,000	$2,517,000
South Storm Levee	$52,000	$37,000	$15,000	$0	$35,000	$28,000	$87,000	$254,000
Tide Gate I-Wall	$541,000	$406,000	$154,000	$0	$387,000	$321,000	$977,000	$2,785,000
Oyster Creek	$744,000	$553,000	$211,000	$0	$526,000	$436,000	$1,329,000	$3,800,000

Table 7-6. Population at Risk by Project Area

Population at Risk	
Orange-Jefferson CSRM	
Orange 1	17,014
Orange 2	13,952
Orange 3	60,044
Beaumont A	2,078
Beaumont B	2,078
Beaumont C	2,078
Jefferson Main	116,762
Port Arthur and Vicinity CSRM	116,762
Freeport and Vicinity CSRM	16,559

reported for the project areas by type (school, chemical manufacturing, etc.). A North American Industry Classification System (NAICS) code is included in the full listing of the inventory included in Appendix C, Economic Analysis. The project areas are discussed by county; Orange-Jefferson CSRM includes Orange and Jefferson County; Port Arthur and Vicinity CSRM includes Jefferson County; Freeport includes Brazoria County.

Orange – Jefferson CSRM (Orange and Jefferson County)
Public Facilities – Orange County

- 20 schools
- 14 law enforcement
- 2 hospitals/6 nursing homes
- 11 fire stations

Industrial and Manufacturing – Orange County

- 20 chemical manufacturing
- 5 electric generation
- 0 petroleum refining
- 1 airport

Public Facilities – Jefferson County

- 42 schools
- 19 law enforcement
- 13 hospitals/7 nursing homes
- 26 fire stations

Industrial and Manufacturing – Jefferson County

- 54 chemical manufacturing
- 1 electric generation
- 3 petroleum refining
- 1 airport

Some of the significant industrial and manufacturing facilities located in Orange-Jefferson CSRM include Exxon Mobil, DuPont, Honeywell, Firestone, Petrochemical, Chevron, Phillips, Laxness, Solvay Solexis, and Entergy. A detailed description of each critical facility is not provided here; however, to explain one in some detail, Exxon Mobil is located near downtown Beaumont, Texas on the Neches River. The refinery processes 345,000 barrels of crude oil per day and produces 2.5 billion gallons of gasoline annually (Exxon Mobil, 2015).

Port Arthur and Vicinity CSRM (Jefferson County)
Public Facilities – Jefferson County

- 42 schools
- 19 law enforcement
- 13 hospitals/7 nursing homes
- 26 fire stations

Industrial and Manufacturing – Jefferson County
- 54 chemical manufacturing
- 1 electric generation
- 3 petroleum refining
- 1 airport

Significant industrial and manufacturing facilities located in the Port Arthur and Vicinity CSRM include Valero, Premcor, Total, Motiva Enterprises, and Huntsman Petrochemical. Jack Brooks Regional Airport is also in the project area. A detailed description of each critical facility is not provided here; however, to explain one in some detail, Motiva is the largest petroleum refinery in the United States, with a capacity of approximately 600,000 barrels of crude oil (Beaumont Enterprise, 2014).

Freeport and Vicinity CSRM (Brazoria County)
Public Facilities – Brazoria County
- 6 schools
- 3 law enforcement
- 0 hospitals/0 nursing homes
- 2 fire stations

Industrial and Manufacturing – Brazoria County
- 24 chemical manufacturing
- 0 electric generation
- 0 petroleum refining

Significant industrial and manufacturing facilities located in the Freeport and Vicinity CSRM include Petroleum Reserve, Dow Chemical, Freeport LNG, Huntsman Gulf Chemicals, Phillips 66 Liquefied Petroleum Gas (LPG) Terminal, SI Group and NALCO. A detailed description of each critical facility is not provided here; however, to explain one in some detail, Dow Chemical is the largest integrated chemical manufacturing complex in the western hemisphere. The Freeport site produces 44 percent of Dow's products sold in the U.S. and 20 percent of the company's products sold globally (Dow, 2015).

In summary, the critical infrastructure located in the project areas could be impacted during a flood. Of note, if the refineries were closed down due to flood events, there could be significant impacts on gas supplies and multiplier effects to the economy, e.g., increase in transportation costs. Local roadways and major thoroughfares in the project areas were not evaluated in detail for the FWOP condition. Although it is included in the objectives for this study, they are considered ancillary benefits, so they are only covered in this context in the report.

7.1.8 Relative Sea Level Change

USACE expectations of climate change and relative seas level change, and their impact is an important component of the FWOP condition. The planning horizon of 50 years is used in this

study; however, RSLC is estimated beyond that to 100 years. Some key expectations for RSLC in a feasibility study include:

- At minimum 20-, 50-, and 100-year planning horizons should be considered in the analysis.
- Reinforces the concept that a thorough physical understanding of the project area and purpose is required to effectively assess the projects sensitivity to RSLC.
- Sea level changes should be incorporated into models at the mean and extreme events.
- Identification of thresholds by the project delivery team and tipping points within the impacted project area will inform both the selection of anticipatory, adaptive, and reactive options selected and the decision/timing strategies.

Tables 7-7 through 7-9 present the estimated RSLC in the project areas for the 20-, 50- and 100-year project life for the Low, Intermediate and High scenarios. Additional information on how the estimates were developed are included in Appendix D. The Sabine Pass, TX row corresponds to the sea level rise estimates for the Orange-Jefferson CSRM and Port Arthur and Vicinity CSRM; and the Freeport, TX row corresponds to the Freeport and Vicinity CSRM project areas.

Table 7-7. Estimated RSLC over the First 20 Years of the Project Life (2030-2050)

Tidal Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	0.37	0.54	1.08
Freeport, TX	4.35 mm/yr	0.29	0.46	1.00

Table 7-8. Estimated RSLC over the First 50 Years of the Project Life (2030-2080)

Tidal Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	0.93	1.49	3.26
Freeport, TX	4.35 mm/yr	0.72	1.27	3.05

Table 7-9. Estimated RSLC over the First 100 Years of the Project Life (2030-2130)

Tidal Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	1.86	3.42	8.38
Freeport, TX	4.35 mm/yr	1.43	2.99	7.95

The EAD tables presented for the FWOP condition for the final array did not include estimates for the 20-50- and 100-year sea level rise scenarios. The TSP from the final array was measured against sea level rise scenarios to show performance against the various scenarios.

7.2 FINAL ARRAY EVALUATION RESULTS

7.2.1 Orange-Jefferson CSRM

The following section describes the proposed Orange-Jefferson CSRM Optimization Alternatives. The plans in this project area include a combination of new levees and floodwalls at varying

heights to address the storm surge flood risk. The Optimization Alternatives run along the north side of the Neches River and the west bank of the Sabine River. Figure 7-9 shows the location of the Optimization Alternatives listed below.

- Orange 1 consists of approximately 27,000 linear feet (LF) of levee and 16,500 LF of floodwall (total of 8.2 miles); levee heights evaluated include 11-foot, 12-foot, 13-foot and 14-foot;
- Orange 2 consists of approximately 34,600 LF of levee (6.6 miles); levee heights evaluated include 11-foot, 12-foot, 13-foot and 14-foot;
- Orange 3 consists of a combination of 113,600 LF of levee and 29,800 LF of floodwall (total of 27 miles); levee heights evaluated include 11-foot, 12-foot, 13-foot and 14-foot;
- Jefferson Main runs along the south side of the Neches River and consists of approximately 41,700 LF of levee and 16,200 LF of floodwall (11 miles); levee heights evaluated include 11-foot, 12-foot, 13-foot and 14-foot;
- Beaumont A is combination of 3,100 LF of levee and 200 LF of floodwall (0.6 mile); levee heights evaluated include 11-foot, 12-foot, 13-foot and 14-foot;
- Beaumont B is 2,500 LF of levee (0.5 mile); levee heights evaluated include 11-foot, 12-foot, 13-foot and 14-foot; and
- Beaumont C is 6,800 LF of levee (1.3 mile); levee heights evaluated include 11-foot, 12-foot, 13-foot and 14-foot.

Economic Evaluation

The economic evaluation of the alternatives for the Orange-Jefferson CSRM damage reaches are presented in Tables 7-10 through 7-12. Fish and wildlife mitigation costs were included in the economic evaluation. The approved WVA was used to quantify habitat impacts for a conservatively wide footprint of the alignment's construction right-of-way. Estimated mitigation costs (first costs and monitoring/adaptive management costs) were developed based upon conceptual mitigation plans. The same mitigation cost was applied to all height alternatives in each segment as the impacts and mitigation would be similar for all heights and the cost variation among them would be small. When compared to other cost elements, estimated fish and wildlife mitigations costs were not large enough to affect plan selection.

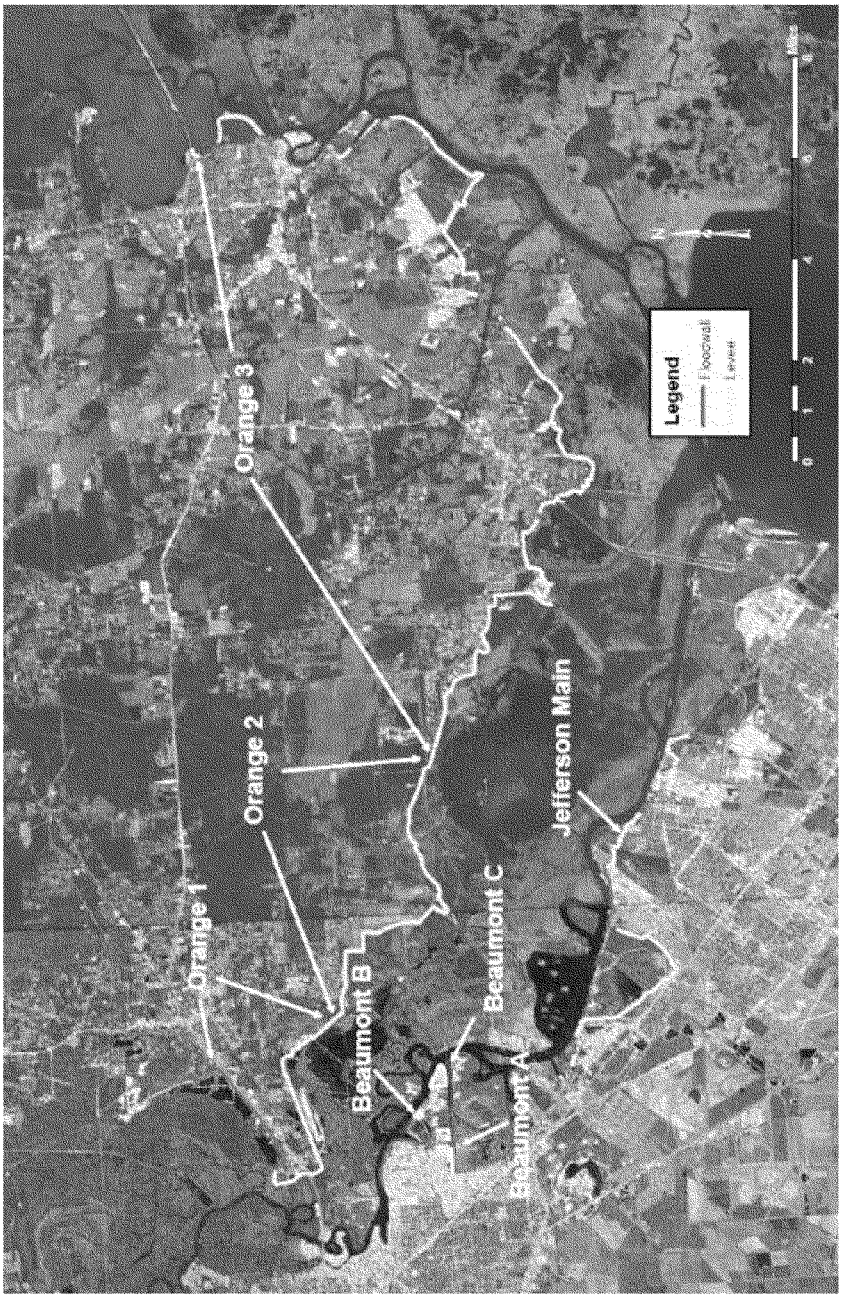


Figure 7-9. Location of Optimization Alternatives in the Orange-Jefferson CSRM Project Area

Table 7-10. Economic Performance of New Levees at Orange and Jefferson Counties

(FY 2015 Price Level/3.375% interest rate)

	Orange 1				Orange 2				Orange 3			
	11 - Foot	12 - Foot	13 - Foot	14 - Foot	11 - Foot	12 - Foot	13 - Foot	14 - Foot	11 - Foot	12 - Foot	13 - Foot	14 - Foot
INVESTMENT												
Estimated First Cost	$46,617,000	$60,935,000	$75,252,000	$89,570,000	$41,088,000	$49,305,000	$57,523,000	$65,740,000	$246,811,000	$288,284,000	$329,762,000	$371,237,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36	36	36	36	36	36	36
Interest During Construction	$2,377,000	$3,108,000	$3,838,000	$4,568,000	$2,095,000	$2,515,000	$2,934,000	$3,353,000	$12,587,000	$14,702,000	$16,818,000	$18,933,000
Investment Cost	$48,995,000	$64,043,000	$79,090,000	$94,138,000	$43,183,000	$51,820,000	$60,456,000	$69,093,000	$259,398,000	$302,986,000	$346,580,000	$390,169,000
Interest	$1,654,000	$2,161,000	$2,669,000	$3,177,000	$1,457,000	$1,749,000	$2,040,000	$2,332,000	$8,755,000	$10,226,000	$11,697,000	$13,168,000
Amortization	$388,000	$508,000	$627,000	$746,000	$342,000	$411,000	$479,000	$548,000	$2,056,000	$2,402,000	$2,747,000	$3,093,000
OMRR&R ($/year)*									$4,084,000	$4,084,000	$4,084,000	$4,084,000
TOTAL ANNUAL COSTS	**$2,042,000**	**$2,669,000**	**$3,296,000**	**$3,923,000**	**$1,800,000**	**$2,160,000**	**$2,520,000**	**$2,880,000**	**$14,895,000**	**$16,711,000**	**$18,528,000**	**$20,345,000**
Without Project EAD	$312,000	$312,000	$312,000	$312,000	$68,000	$68,000	$68,000	$68,000	$29,987,000	$29,987,000	$29,987,000	$29,987,000
Residual EAD	$39,000	$23,000	$12,000	$6,000	$26,000	$20,000	$16,000	$11,000	$5,242,000	$3,044,000	$1,654,000	$832,000
Storm Reduction Benefits	$273,000	$289,000	$300,000	$306,000	$42,000	$48,000	$52,000	$57,000	$24,745,000	$26,943,000	$28,333,000	$29,155,000
TOTAL BENEFITS	**$273,000**	**$289,000**	**$300,000**	**$306,000**	**$42,000**	**$48,000**	**$52,000**	**$57,000**	$24,745,000	$26,943,000	$28,333,000	$29,155,000
NET BENEFITS	**($1,769,000)**	**($2,380,000)**	**($2,996,000)**	**($3,617,000)**	**($1,757,000)**	**($2,112,000)**	**($2,467,000)**	**($2,822,000)**	**$9,851,000**	**$10,232,000**	**$9,804,000**	**$8,810,000**
BENEFIT-COST RATIO	**0.13**	**0.11**	**0.09**	**0.08**	**0.02**	**0.02**	**0.02**	**0.02**	**1.66**	**1.61**	**1.53**	**1.43**

*For Mitigation

Note: Tables may not add up exactly due to rounding.

Table 7-11. Economic Performance of New Levees at Orange and Jefferson Counties

(FY 2015 Price Level/3.375% interest rate)

	Beaumont A				Beaumont B				Beaumont C		
	11 - Foot	12 - Foot	13 - Foot	14 - Foot	11 - Foot	12 - Foot	13 - Foot	14 - Foot	11 - Foot	12 - Foot	13 - Foot
INVESTMENT											
Estimated First Cost	$62,661,000	$70,202,000	$77,743,000	$85,284,000	$1,695,000	$2,295,000	$2,895,000	$3,494,000	$15,793,000	$16,078,000	$19,007,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36	36	36	36	36	36
Interest During Construction	$3,196,000	$3,580,000	$3,965,000	$4,349,000	$86,000	$117,000	$148,000	$178,000	$805,000	$820,000	$969,000
Investment Cost	$65,857,000	$73,782,000	$81,708,000	$89,634,000	$1,782,000	$2,412,000	$3,042,000	$3,673,000	$16,599,000	$16,898,000	$19,977,000
Interest	$2,223,000	$2,490,000	$2,758,000	$3,025,000	$60,000	$81,000	$103,000	$124,000	$560,000	$570,000	$674,000
Amortization	$522,000	$585,000	$648,000	$711,000	$14,000	$19,000	$24,000	$29,000	$132,000	$134,000	$158,000
TOTAL ANNUAL COSTS	**$2,745,000**	**$3,075,000**	**$3,405,000**	**$3,736,000**	**$74,000**	**$101,000**	**$127,000**	**$153,000**	**$692,000**	**$704,000**	**$833,000**
Without Project EAD	$6,937,000	$6,937,000	$6,937,000	$6,937,000	$23,000	$23,000	$23,000	$23,000	$262,000	$262,000	$262,000
Residual EAD	$1,449,000	$870,000	$494,000	$259,000	$7,000	$4,000	$3,000	$1,000	$12,000	$7,000	$4,000
Storm Reduction Benefits	$5,488,000	$6,067,000	$6,442,000	$6,677,000	$17,000	$19,000	$21,000	$22,000	$249,000	$255,000	$258,000
TOTAL BENEFITS	**$5,488,000**	**$6,067,000**	**$6,442,000**	**$6,677,000**	**$17,000**	**$19,000**	**$21,000**	**$22,000**	**$249,000**	**$255,000**	**$258,000**
NET BENEFITS	**$2,743,000**	**$2,992,000**	**$3,037,000**	**$2,942,000**	**($58,000)**	**($82,000)**	**($106,000)**	**($131,000)**	**($442,000)**	**($449,000)**	**($574,000)**
BENEFIT-COST RATIO	**2.00**	**1.97**	**1.89**	**1.79**	**0.23**	**0.19**	**0.17**	**0.14**	**0.36**	**0.36**	**0.31**

Note: Tables may not add up exactly due to rounding.

Table 7-12 Economic Performance of New Levees at Orange and Jefferson Counties

(FY 2015 Price Level/3.375% interest rate)

	Jefferson Main			
	11 - Foot	**12 - Foot**	**13 - Foot**	**14 - Foot**
INVESTMENT				
Estimated First Cost	$65,726,000	$87,674,000	$104,747,000	$121,814,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50
Construction Period (months)	36	36	36	36
Interest During Construction	$3,352,000	$4,471,000	$5,342,000	$6,212,000
Investment Cost	$69,078,000	$92,145,000	$110,089,000	$128,027,000
Interest	$2,331,000	$3,110,000	$3,715,000	$4,321,000
Amortization	$548,000	$730,000	$873,000	$1,015,000
OMRR&R ($/year)*	$371,000	$371,000	$371,000	$371,000
TOTAL ANNUAL COSTS	**$3,250,000**	**$4,212,000**	**$4,960,000**	**$5,707,000**
Without Project EAD	$28,231,000	$28,231,000	$28,231,000	$28,231,000
Residual EAD	$2,520,000	$1,440,000	$776,000	$401,000
Flood Reduction Benefits	$25,711,000	$26,791,000	$27,456,000	$27,831,000
TOTAL BENEFITS	**$25,711,000**	**$26,791,000**	**$27,456,000**	**$27,831,000**
NET BENEFITS	**$22,461,000**	**$22,580,000**	**$22,496,000**	**$22,123,000**
BENEFIT-COST RATIO	**7.91**	**6.36**	**5.54**	**4.88**

* For Mitigation

Note: Tables may not add up exactly due to rounding.

7.2.2 Port Arthur and Vicinity

The following section describes the proposed Port Arthur and Vicinity CSRM Optimization Alternatives. The plans include modifications to the existing HFPP at Port Arthur. Figure 7-10 shows the location of the Optimization Alternatives listed below.

- 8- to 10-foot I-Wall
  - No fail: 3,500 LF of 15-foot-wide 6-inch scour pad
  - 1-foot raise: 7,500 LF of 15-foot-wide 6-inch scour pad. This option would include adding capacity to the system in this reach by addressing low areas of the levee system, raising 2,000 LF of levee 1 foot and providing overtopping erosion protection.
  - 2-foot raise: 7,500 LF of 15-foot-wide 6-inch scour pad. Additional 60,000 LF of levee raising 2 feet along with raising the highway 87 and highway 73 levee crossings. Floodwalls at two pump stations would be added along with 1,000 LF of floodwall reconstruction at the Taylors Bayou closure. This option would also require the replacement of one gravity drainage structure and one vehicle closure structure.

- *Closure Structure*
  - No fail: Construction of two 300 LF of 100-foot-wide 6-inch scour pads, one on each side of the structure to provide erosion protection to reduce the likely hood of a brittle failure if the systems' capacity is exceeded.
  - 1-foot raise: This includes replacement of the closure structure gate that is 12 feet height by 30 feet width. It also includes 2,300 LF of 100-foot-wide 6-inch scour pad, one on each side of the structure to provide erosion protection to reduce the likelihood of a brittle failure if the systems' capacity is exceeded. This option also included raising 12,000 LF of levee 1 foot.
  - 2-foot raise: Replace two closure structures gate structures are 12 feet height by 30 feet width including two 300 LF of 100-foot-wide 6-inch scour pad at each closure structure. This plan includes raising 12,000 LF of levee 1 foot and adding floodwalls at two pump stations, 500 LF total (7 feet tall) along with reinforcing pump station walls at four existing pump stations.

- I-Wall Near Valero
  - No fail: Construction of 5,000 LF of 15-foot-wide 6-inch scour pad to provide additional structural integrity and erosion protection to reduce the likelihood of failure.
  - 1-foot raise: Construction of 5,000 LF of 15-foot-wide 6-inch scour pad with a 1-foot rise will provide additional system capacity, increase structural integrity of the I-wall and provide erosion protection to reduce the likelihood of system overtopping. Additionally, 3,000 LF of levee will need to be raised 1 foot.
  - 2-foot raise: This option will require significant reconstruction of the HFPP in the evaluated area including 5,000 LF of flood wall (15 feet tall), 10 closure structures 15 feet height and 20 foot width, 3,000 LF of levee raised 2 feet along with the work

Figure 7-10. Optimization Alternatives - Port Arthur and Vicinity CSRM Project Area

- specified in the I-wall near Tank Farm (2-foot raise) and 8-10 foot I-Wall (2-foot raise) required work.

- *I-Wall Near Tank Farm*
  - No fail: Construction of 1,800 LF of 15-foot-wide 6-inch scour pad to provide additional structural integrity and erosion protection to reduce the likely hood of a brittle failure if the systems' capacity is exceeded.
  - 1-foot raise: Construction of 1,800 LF of 15-foot-wide 6-inch scour pad and batter piling and wailer system with 1-foot rise will provide additional system capacity, increase structural integrity of the I-wall and provide erosion protection to reduce the likely hood of a brittle failure if the system's capacity is exceeded. Additionally, 7,000 LF of levee will need to be raised 1 foot.
  - 2-foot raise: Construction of 2,000 LF of floodwall (15 feet tall) along with 9,000 LF of levee raised 2 feet. There would be construction of a floodwall at 1 pump station (200 LF at 7 feet tall) and raise an additional 10,400 LF of levee 2 feet and reconstruct 12,000 LF 15 feet tall floodwall. There would be rebuilding four existing pump stations at 1,100 cubic feet per second (cfs).

Economic Evaluation
The economic evaluation of the alternatives for the Port Arthur and Vicinity CSRM damage reaches are presented in Table 7-13. Environmental impacts and associated mitigation costs were not needed in the comparison.

7.2.3 Freeport and Vicinity CSRM

The following section describes the proposed Freeport and Vicinity CSRM Optimization Alternatives. The plans include modifications to the existing HFPP at Freeport. Figure 7-11 shows the location of the Optimization Alternatives listed below.

- *Dow Barge Canal Protection*

The Dow Barge Canal levees are approximately eight miles long and represent a significant risk to the HFPP performance at and above the design event. This risk is primarily from seepage and instability caused by seepage through the "sandy" levee and foundation material. Significant risk also exists with numerous pipeline penetrations, I-wall instability, and non-uniform levee heights. The study team utilized a closure structure and pump station constructed at the junction of the North Barge Canal and East Storm Levee. This structure will allow barge traffic to pass during routine operations and will have a pumping capacity of 2,000,000 gallons per minute (gpm). The structure length will be approximately 500 feet long, two sector gates totaling approximately 80 feet width for vessel traffic. Additional tidal circulation will be provided by two sluice gates approximately 15 feet wide each. The final configuration of this structure will match the proposed level of protection for the system.

Table 7-13. Economic Performance of Port Arthur and Vicinity CSRM

(FY 2015 Price Level/3.375% interest rate)

	8ft-10ft I-Wall			Closure Structure			I-Wall Near Valero			Tank Farm		
	No Fail	1 Foot Raise	2 Foot Raise	No Fail	1 Foot Raise	2 Foot Raise	No Fail	1 Foot Raise	2 Foot Raise	No Fail	1 Foot Raise	2 Foot Raise
INVESTMENT												
Estimated First Cost	$3,330,000	$8,915,000	$66,744,000	$3,804,000	$10,654,000	$22,822,000	$7,655,000	$8,948,000	$312,523,000	$2,756,000	$4,627,000	$188,878,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36	36	36	36	36	36	36
Interest During Construction	$170,000	$455,000	$3,404,000	$194,000	$543,000	$1,164,000	$390,000	$456,000	$15,938,000	$141,000	$236,000	$9,633,000
Investment Cost	$3,500,000	$9,370,000	$70,148,000	$3,998,000	$11,197,000	$23,986,000	$8,045,000	$9,404,000	$328,461,000	$2,897,000	$4,863,000	$198,511,000
Interest	$118,000	$316,000	$2,367,000	$135,000	$378,000	$810,000	$272,000	$317,000	$11,086,000	$98,000	$164,000	$6,700,000
Amortization	$28,000	$74,000	$556,000	$32,000	$89,000	$190,000	$64,000	$75,000	$2,604,000	$23,000	$39,000	$1,574,000
TOTAL ANNUAL COSTS	**$146,000**	**$391,000**	**$2,924,000**	**$167,000**	**$467,000**	**$1,000,000**	**$335,000**	**$392,000**	**$13,689,000**	**$121,000**	**$203,000**	**$8,273,000**
Without Project EAD	$23,413,000	$23,413,000	$23,413,000	$3,784,000	$3,784,000	$3,784,000	$61,867,000	$61,867,000	$61,867,000	$38,009,000	$38,009,000	$38,009,000
Residual EAD	$9,962,000	$5,730,000	$3,274,000	$995,000	$408,000	$156,000	$16,379,000	$10,813,000	$7,101,000	$25,130,000	$16,874,000	$10,893,000
Flood Reduction Benefits	$13,451,000	$17,683,000	$20,138,000	$2,788,000	$3,375,000	$3,628,000	$45,488,000	$51,054,000	$54,766,000	$12,879,000	$21,135,000	$27,116,000
TOTAL BENEFITS	**$13,451,000**	**$17,683,000**	**$20,138,000**	**$2,788,000**	**$3,375,000**	**$3,628,000**	**$45,488,000**	**$51,054,000**	**$54,766,000**	**$12,879,000**	**$21,135,000**	**$27,116,000**
NET BENEFITS	**$13,305,000**	**$17,292,000**	**$17,215,000**	**$2,622,000**	**$2,908,000**	**$2,628,000**	**$45,153,000**	**$50,662,000**	**$41,076,000**	**$12,758,000**	**$20,932,000**	**$18,843,000**
BENEFIT-COST RATIO	**92.13**	**45.23**	**6.89**	**16.69**	**7.23**	**3.63**	**135.79**	**130.24**	**4.00**	**106.44**	**104.11**	**3.28**

Note: Tables may not add up exactly due to rounding.

Figure 7-11. Location of Optimization Alternatives in the Freeport and Vicinity CSRM Project Area

- *Oyster Creek Levee*

Oyster Creek Levee was constructed at varying elevations to account for the changes in flood elevation as noted in the hydraulic modeling. Updated hydraulic modeling showed a height deficiency over 3,500 LF.

- No fail: The Oyster Creek levee will be raised 2 feet over 3,500 LF in order to correct the noted height deficiency. The construction procedure will include stripping topsoil, removal of a 12 feet wide asphalt road, placement of fill, replacement of a 12 feet wide road and turfing.
- 1-Foot Raise: Construction will include 3,500 LF of 3 feet levee raise and 10,000 LF of 1-foot levee raise for a total distance of 13,500 LF. The construction procedure will include stripping topsoil, removal of a 12-foot-wide asphalt road, placement of fill, replacement of a 12-foot-wide road and turfing.
- 2-Foot Raise: Construction will include 3,500 LF of a 4-foot levee raise and 1,000 LF of floodwall reconstruction along with raising Highway 523 at the levee crossing. Additionally, 33,000 LF of levee raised 2 feet, reconstruction of one pump station 1,100 cfs, and replacement of six gravity structures would be required.

- *East Storm Levee*

East Storm Levee is a large earth embankment that faces the Gulf of Mexico and has direct wave and surge impacts from the Gulf. The proposed construction procedure will include stripping topsoil, removal of a two-lane asphalt road, placement of fill, replacement of a two-lane road and turfing.

- No Fail: Construction of 13,115 LF of High Performance Turf Reinforcing Mat (HPTRM)
- 1-foot raise: Construction includes 13,115 LF of levee raised 1 foot with HPTRM
- 2-foot raise: Construction includes 19,115 LF of levee raised 2 foot with HPTRM, and a floodwall at one pump station 800 LF total (5 feet tall). Reinforcing pump station walls and raising Highway 332 at the levee crossing would be required.

- *South Storm Levee*

The south storm levee is a frontal levee that has potential for direct wave impact from the Gulf of Mexico during storm loading. When this levee was originally constructed, the area south of the levee was very low in elevation. Over the last 40 years, USACE constructed dredge disposal areas for the deep draft navigation channel to in this low area. Continued use of the disposal areas has increased the elevation of the low area to a point that it is now higher than the South Storm Levee.

- 1-foot: Construction would include earth placement on top of the existing earth embankment for a 1-foot raise.
- 2-foot: Construction would include earth placement on top of the existing earth embankment for a 2-foot raise.

- *Freeport Dock Floodwall*

The Freeport Dock floodwall is a 3-foot floodwall that was added to the dock face at the Port Freeport docks after Hurricane Ike under PL 84-99. This floodwall has drop in panels that are removable to allow for "roll on, roll off" cargo loading. During evaluation of the HFPP for CFR 65.10, the local sponsor noted that the wall/panels were structurally deficient. This deficiency was confirmed during the Freeport SQRA.

- Partial Fail: Construction includes replacing the drop in panels and anchor system.
- No Fail: Construction of 3,000 LF of floodwall to meet all USACE requirements for a wall/drop in panel system located at a port facility.
- 1-Foot Raise: Construction would require complete reconstruction of the dock and flood wall assembly.

- *Old River Levee at Dow Thumb*

This reach of levee is an earth embankment that would be susceptible to erosion during an overtopping event. Updated modeling shows an area of this reach that has significant risk to large wave attack and overtopping from wave propagation along the adjacent deep draft navigation channel.

- No Fail: Construction of 14,500 LF of HPTRM and 4,000 LF of 15-foot-wide 6-inch scour pad to provide erosion protection to reduce the likelihood of failure.
- 1-Foot Raise: Construction of 4,000 LF of 15-foot-wide 6-inch scour pad along with 3,000 LF of levee raised 1 foot and 14,500 LF of HPTRM to "level up" the low spots and provide erosion protection to reduce the likely hood of a brittle failure if the system's capacity is exceeded.
- 2-Foot Raise: Due to extremely low Factors of Safety (FOS) for global stability raising the levee over existing heights by adding additional earth fill is not an option; therefore, under this scenario, the existing embankment would be removed and 12,000 LF of 10 feet tall floodwall would be constructed. In areas that do not have stability issues 6,500 LF of levee would be raised 2 feet, one drainage structure would be replaced and the saltwater intake at DOW A801 would be replaced.

- *Tide Gate I-Wall*

The I-wall located at the Tide Gate was constructed as part of the original HFPP construction when the earth embankment section could not reach design elevation. The very soft foundation materials that were present in the old river channel would not support the additional weight of the embankment section. The proposed construction will be to reconstruct the I-wall as a pile founded T-wall. The overall length of the T-wall is approximately 362 feet.

- No Fail: Construction of 362 LF of floodwall 10 feet tall.
- 1-Foot Raise: Construction of 700 LF of floodwall (11 feet tall) along with 2,000 LF of levee raised 1 foot.
- 2-Foot Raise: Construction of 700 LF of floodwall (12 feet tall) and 3,500 LF of levee raised 2 feet along with adding a floodwall at one pump station (200 LF at 7 feet tall). The

tide gate structure adjacent to the I-wall will require significant modification or complete reconstruction to accommodate a 2-foot raise.

Economic Evaluation
The economic evaluation of the alternatives for the Freeport Arthur and Vicinity CSRM damage reaches are presented in Table 7-14.

7.2.4 Sabine and Brazoria Nonstructural Buyouts

Surveys of aerial imagery for the three counties were performed to look for the potential for nonstructural buyouts. Buyouts would be ancillary to the implementation of new levees/floodwalls in Orange and Jefferson Counties and to the enhancement of features in the Port Arthur and Freeport CSRM project areas. Buyout opportunities in Brazoria are virtually non-existent and very limited in both Orange and Jefferson Counties. Several structures in Jefferson have the potential for being bought out; however, these structures are commercial and buying out these structures is very unlikely to be the economic viable. Figure 11 of Appendix C shows the potential for buyouts in Orange County. There are approximately 20 residential structures that could be potentially economically viable and are currently being evaluated. While some of the parcels appeared to have no structures located on them, inspection of County appraisal records in many cases showed improvements on a lot of these parcels. Visual inspections of aerial photos and further inspection of the appraisal records showed that many of these were agricultural improvements and would therefore not be subject to any permanent evacuation analysis. A quantitative analysis was conducted to determine the viability of any proposed nonstructural buyout. The analysis showed the nonstructural buyouts had negative net benefits and any potential buyouts were screened from the analysis. The economic evaluation results are included in Table 13 of the Economic Appendix.

7.3 COMPARISON OF ALTERNATIVE PLANS

This section provides a summary of the results of the Final Array of Alternatives evaluation and a comparison of plans. The screening criteria are applied to select a TSP. Table 7-15 presents the final array plans and a summary of the contributions to the planning objectives. Plans were evaluated first to identify an NED plan.

Objectives 1, 4 and 6 are described first since they were the objectives related to NED. The following is a summary and comparison of the plans for these objectives. For Objective 1, the net benefits were calculated for each Optimization Alternative. The plan the reasonably maximizes net benefits is the NED plan. Objective 4 is embedded within the NED and RED accounts. Specifically for NED, the values of the critical infrastructure were included in the economic analysis, and measured when the economic evaluation of the Optimization Alternatives was performed and an NED plan was identified.

Table 7-14. Economic Performance of Freeport and Vicinity

(FY 2015 Price Level/3.375% interest rate)

	Dow Barge Canal	Oyster Creek Levee			East Storm Levee			Freeport Dock		
	No Fail - Closure Structure	No Fail	1 Foot Raise	2 Foot Raise	No Fail	1 Foot Raise	2 Foot Raise	Partial Fail	No Fail	1 Foot Raise
INVESTMENT										
Estimated First Cost	$130,000,000	$1,663,000	$4,869,000	$54,244,000	$3,415,000	$6,530,000	$26,402,000	$1,500,000	$2,850,000	$150,000,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36	36	36	36	36
Interest During Construction	$6,630,000	$85,000	$248,000	$2,766,000	$174,000	$333,000	$1,346,000	$76,000	$145,000	$7,650,000
Investment Cost	$136,630,000	$1,748,000	$5,117,000	$57,010,000	$3,590,000	$6,863,000	$27,748,000	$1,576,000	$2,995,000	$157,650,000
Interest	$4,611,000	$59,000	$173,000	$1,924,000	$121,000	$232,000	$937,000	$53,000	$101,000	$5,321,000
Amortization	$1,083,000	$14,000	$41,000	$452,000	$28,000	$54,000	$220,000	$12,000	$24,000	$1,250,000
TOTAL ANNUAL COSTS	**$5,694,000**	**$73,000**	**$213,000**	**$2,376,000**	**$150,000**	**$286,000**	**$1,156,000**	**$66,000**	**$125,000**	**$6,570,000**
Without Project EAD	$166,660,000	$3,800,000	$3,800,000	$3,800,000	$1,701,000	$1,701,000	$1,701,000	$3,960,000	$3,960,000	$3,960,000
Residual EAD	$47,052,000	$1,717,000	$1,272,000	$933,000	$782,000	$581,000	$425,000	$3,771,000	$1,742,000	$1,333,000
Storm Reduction Benefits	$119,608,000	$2,083,000	$2,527,000	$2,866,000	$919,000	$1,121,000	$1,276,000	$189,000	$2,218,000	$2,627,000
TOTAL BENEFITS	**$119,608,000**	**$2,083,000**	**$2,527,000**	**$2,866,000**	**$919,000**	**$1,121,000**	**$1,276,000**	**$189,000**	**$2,218,000**	**$2,627,000**
NET BENEFITS	**$113,914,000**	**$2,010,000**	**$2,314,000**	**$490,000**	**$769,000**	**$835,000**	**$120,000**	**$123,000**	**$2,093,000**	**($3,944,000)**
BENEFIT-COST RATIO	**21.01**	**28.53**	**11.86**	**1.21**	**6.13**	**3.92**	**1.10**	**2.86**	**17.74**	**0.40**

Economic Performance of Freeport and Vicinity CSRM (cont'd)
(FY 2015 Price Level/3.375% interest rate)

	Old River at Dow			South Storm Levee		Tide Gate		
	No Fail	**1 Foot Raise**	**2 Foot Raise**	**1 Foot Raise**	**2 Foot Raise**	**No Fail**	**1 Foot Raise**	**2 Foot Raise**
INVESTMENT								
Estimated First Cost	$7,581,000	$8,294,000	$92,088,000	$3,325,000	$6,650,000	$1,720,000	$3,800,000	$35,644,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36	36	36
Interest During Construction	$387,000	$423,000	$4,696,000	$170,000	$339,000	$88,000	$194,000	$1,818,000
Investment Cost	$7,968,000	$8,717,000	$96,784,000	$3,495,000	$6,989,000	$1,808,000	$3,994,000	$37,462,000
Interest	$269,000	$294,000	$3,266,000	$118,000	$236,000	$61,000	$135,000	$1,264,000
Amortization	$63,000	$69,000	$767,000	$28,000	$55,000	$14,000	$32,000	$297,000
TOTAL ANNUAL COSTS	**$332,000**	**$363,000**	**$4,034,000**	**$146,000**	**$291,000**	**$75,000**	**$166,000**	**$1,561,000**
Without Project EAD	$2,517,000	$2,517,000	$2,517,000	$254,000	$254,000	$2,785,000	$2,785,000	$2,785,000
Residual EAD	$1,215,000	$913,000	$679,000	$182,000	$127,000	$1,184,000	$897,000	$675,000
Storm Reduction Benefits	$1,302,000	$1,604,000	$1,838,000	$72,000	$127,000	$1,601,000	$1,888,000	$2,110,000
TOTAL BENEFITS	**$1,302,000**	**$1,604,000**	**$1,838,000**	**$72,000**	**$127,000**	**$1,601,000**	**$1,888,000**	**$2,110,000**
NET BENEFITS	**$969,000**	**$1,241,000**	**($2,196,000)**	**($74,000)**	**($164,000)**	**$1,526,000**	**$1,721,000**	**$549,000**
BENEFIT-COST RATIO	**3.92**	**4.42**	**0.46**	**0.49**	**0.44**	**21.35**	**11.37**	**1.35**

Note: Tables may not add up exactly due to rounding.

Table 7-15. Comparison of Final Array of Alternative by Planning Objectives

	NED			OSE		RED
	Objective 1		Objective 6	Objective 2		Objective 4 and 5
	Net Benefits	Screening Status	Sea Level Rise	Population at Risk		Critical Infrastructure Impacts
Orange-Jefferson CSRM						
Orange 1			Surplus/Deficit Range (Approx. Feet NAVD)	PAR FWOP/Expected Impact		Number of Facilities by County
11-foot Raise	($1,769,000)	Screened Out		17,014	Expected Positive Impact	Reduces likelihood of secondary impacts on: • 20 schools • 14 law enforcement • 2 hospitals/6 nursing homes • 11 fire stations • 20 chemical manufacturing • 5 electric generation • 0 petroleum refining
12-foot Raise	($2,380,000)	Screened Out				
13-foot Raise	($2,996,000)	Screened Out				
14-foot Raise	($3,617,000)	Screened Out				
Orange 2						
11-foot Raise	($1,757,000)	Screened Out		13,952	Expected Positive Impact	
12-foot Raise	($2,112,000)	Screened Out				
13-foot Raise	($2,467,000)	Screened Out				
14-foot Raise	($2,822,000)	Screened Out				
Orange 3						
11-foot Raise	$9,851,000	$9,851,000	-1.3 – 4.8 feet deficit	60,044	Expected Positive Impact	
12-foot Raise	$10,232,000	$10,232,000	-0.5 – 3.8 feet deficit			
13-foot Raise	$9,804,000	Screened Out	0.5 surplus - 2.8 feet deficit			
14-foot Raise	$8,810,000	Screened Out				
Beaumont A						
11-foot Raise	$2,743,000	Screened Out	-1.3 – 4.8 feet deficit	2,078	Expected Positive Impact	Reduces likelihood of secondary impacts on: • 42 schools • 19 law enforcement • 13 hospitals/7 nursing homes • 26 fire stations • 54 chemical manufacturing • 1 electric generation • 0 petroleum refining • 1 airport
12-foot Raise	$2,992,000	$2,992,000	-0.5 – 3.8 feet deficit			
13-foot Raise	$3,037,000	$3,037,000	0.5 surplus - 2.8 feet deficit			
14-foot Raise	$2,942,000	Screened Out				
Beaumont B						
11-foot Raise	($58,000)	Screened Out		2,078	Expected Positive Impact	
12-foot Raise	($82,000)	Screened Out				
13-foot Raise	($106,000)	Screened Out				
14-foot Raise	($131,000)	Screened Out				
Beaumont C						
11-foot Raise	($442,000)	Screened Out		2,078	Expected Positive Impact	
12-foot Raise	($449,000)	Screened Out				
13-foot Raise	($574,000)	Screened Out				
Jefferson Main						
11-foot Raise	$22,461,000	$22,461,000	-1.3 – 4.8 feet deficit	116,762	Expected Positive Impact	
12-foot Raise	$22,580,000	$22,580,000	-0.5 – 3.8 feet deficit			
13-foot Raise	$22,496,000	Screened Out	0.5 surplus - 2.8 feet deficit			
14-foot Raise	$22,123,000	Screened Out				
Port Arthur and Vicinity CSRM*						
8-10ft I-Wall						
No Fail	$13,305,000	Screened Out		116,762	Expected Positive Impact	Reduces likelihood of secondary impacts on: • 42 schools • 19 law enforcement • 13 hospitals/7 nursing homes • 26 fire stations • 54 chemical manufacturing • 1 electric generation • 0 petroleum refining
1-foot Raise	$17,292,000	$17,292,000				
2-foot Raise	$17,215,000	Screened Out				
Closure Structure						
No Fail	$2,622,000	Screened Out				
1-foot Raise	$2,908,000	$2,908,000				
2-foot Raise	$2,628,000	Screened Out				
I-Wall Near Valero						
No Fail	$45,153,000	Screened Out				
1-foot Raise	$50,662,000	$50,662,000				
2-foot Raise	$41,076,000	Screened Out				
I-Wall Near Tank Farm						

	NED			OSE		RED
	Objective 1		Objective 6	Objective 2		Objective 4 and 5
	Net Benefits	Screening Status	Sea Level Rise	Population at Risk		Critical Infrastructure Impacts
No Fail	$12,758,000	Screened Out				• 1 airport
1-foot Raise	$20,932,000	$20,932,000				
2-foot Raise	$18,843,000	Screened Out				
Freeport and Vicinity CSRM*						
Dow Barge Canal						
No Fail	$113,914,000	$113,914,000				
Oyster Creek Levee						
No Fail	$2,010,000	Screened Out				
1-foot Raise	$2,314,000	$2,314,000				
2-foot Raise	$490,000	Screened Out				
East Storm Levee						Reduces likelihood of secondary impacts on:
No Fail	$769,000	Screened Out				
1-foot Raise	$835,000	$835,000				
2-foot Raise	$120,000	Screened Out				
Freeport Dock						• 6 schools • 3 law enforcement • 0 hospitals/0 nursing homes • 2 fire stations • 24 chemical manufacturing • 0 electric generation • 0 petroleum refining
Partial Fail	$123,000	Screened Out				
No Fail	$2,093,000	$2,093,000		16,559	Expected Positive Impact	
1-foot Raise	($3,944,000)	Screened Out				
Old River at Dow Thumb						
No Fail	$969,000	Screened Out				
1-foot Raise	$1,241,000	$1,241,000				
2-foot Raise	($2,196,000)	Screened Out				
South Storm Levee						
1-foot Raise	($74,000)	Screened Out				
2-foot Raise	($164,000)	Screened Out				
Tide Gates						
No Fail	$1,526,000	Screened Out				
1-foot Raise	$1,721,000	$1,721,000				
2-foot Raise	$549,000	Screened Out				
Sabine Nonstructural Buyout	Need Result	Screened Out				
Brazoria Nonstructural Buyout	Need Result	Screened Out				

*The comparison shows the economic analysis performs well with the RSLC scenario for the 50-year period for Port Arthur and Vicinity and the Freeport and Vicinity CSRM; therefore, the surplus is not reported in this table

In the Orange-Jefferson CSRM project area, Optimization Alternatives within the Orange 1, Orange 2, Beaumont B and Beaumont C Alternative Reaches did not have positive net benefits; therefore, the new levees considered at the various heights for those reaches were screened from further consideration. In the Port Arthur and Vicinity CSRM project area, all alternative reaches had positive net benefits. In the Freeport and Vicinity CSRM project area, all Alternative Reaches had positive net benefits except the South Storm Levee. The raises considered for that reach was screened from further consideration. The nonstructural buyouts for the Sabine and Brazoria Regions were not economically viable and screened from further consideration. The plans that reasonably maximized NED from each project area are highlighted green in Table 7-15 and listed below:

The NED plan for the Orange-Jefferson CSRM is:

- Orange 3 New Levee (11-foot)
- Jefferson Main New Levee (11-foot)
- Beaumont A New Levee (12-foot)

The NED plan for the Port Arthur Vicinity CSRM is:

- 8-10 ft I-Wall Raise (1-foot)
- Closure Structure Raise (1-foot)
- I-Wall Raise Near Valero (1-foot)
- I-Wall Raise Near Tank Farm (1-foot)

The NED plan for the Freeport and Vicinity CSRM is:

- DOW Barge Canal Gate Structure
- Oyster Creek Levee Raise (1-foot)
- East Storm Levee Raise (1-foot)
- Freeport Dock Floodwall Raise (1-foot)
- Old River Levee Raise at Dow Thumb (1-foot)
- Tide Gate I-Wall Raise (1-foot)

Regarding Objective 6, the EADs presented in this report use storm surge levels without considering sea level rise scenarios for the 20-, 50- and 100-year sea level change scenarios; however, a performance of the NED plans against RSLC is provided. Table 7-16 shows the performance of the NED plans against the 50-year RSLC estimated for the project areas. This table was developed by averaging levee heights specified by engineering criteria for the 50-year RSLC and comparing them to the elevation of the index points used in the HEC-FDA model for the NED Plans. The column highlighted yellow is the height of the NED plans in the economic analysis. The comparison shows the NED Plans perform well with the RSLC scenario for the 50-year period, except for areas in the "Sabine Region." The rows highlighted in light blue show the Orange-Jefferson CSRM (NED plan) is deficient in height at the 50-year project life.

Table 7-16. Average Recommended Relative Sea Level Change (RSLC), Feet NAVD

Location	Without RSLC	Low RSLC	Int.* RSLC	High RSLC	Height in Economic analysis**	Surplus/ Deficit (Without)	Surplus/ Deficit (Low)	Surplus /Deficit (Int.)	Surplus/ Deficit (High)
Dow Barge Canal	15.85	16.58	17.15	18.93	26.00	10.15	9.43	8.85	7.08
Sabine Floodwall	12.50	13.43	13.98	15.77	11.00	-1.50	-2.43	-2.98	-4.77
Sabine Levee	12.33	13.24	13.83	15.59	11.00	-1.33	-2.24	-2.83	-4.59
Freeport Levee	16.42	17.13	17.66	19.45	20.75	4.33	3.63	3.09	1.30
Oyster Creek	16.41	16.41	16.41	16.41	19.00	2.59	2.59	2.59	2.59
Port Arthur Floodwall	13.25	16.10	16.72	18.25	19.00	5.75	2.90	2.28	0.75
Port Arthur Levee	12.94	13.86	14.43	16.20	18.00	5.06	4.14	3.58	1.80

*Note Int. – Intermediate

** Note heights listed are different under the recommended plan, due to final refinements under feasibility design

Table 7-15 summarizes the range in RSLC deficits for the Orange-Jefferson CSRM project area. As the height of the plan decreases, the range in the deficit increases among the Optimization Alternatives. The locations listed in Table 7-15 correspond to locations included in the H&H analysis.

The expectation for each project area would be all plans would positively impact life-safety risk and reduce the likelihood of secondary impacts to critical infrastructure to meet Objectives 2 and 4. This is shown in Table 7-15 as an expected positive impact. Additional qualitative discussion of Objectives 2 and 4 is provided in the next section. Objective 3 was removed from consideration in this planning study from an ER implementation standpoint. Opportunities to meet these objectives could be pursued under different study authorizations. The ER objective is achieved in this study through avoiding, minimizing, and mitigating impacts on existing habitats.

7.4 IDENTIFYING A TENTATIVELY SELECTIVE PLAN (TSP)

The decision criteria for selecting a TSP at this point in the study was based on building a plan for each project area that reasonably maximized net benefits (Objective 1 for the study) from the Final Array of Alternatives. The current TSP is the NED plan for each project area and only considers economics as the decision criteria. The TSP includes the following features:

Orange-Jefferson CSRM

- Orange 3 New Levee (11-foot)
- Beaumont A New Levee (12-foot)
- Jefferson Main New Levee (11-foot)

Port Arthur and Vicinity CSRM

- 8-10 ft I-Wall Raise (1-foot)
- Closure Structure Raise (1-foot)

- I-Wall Raise Near Valero (1-foot)
- I-Wall Raise Near Tank Farm (1-foot)

Freeport and Vicinity CSRM

- Dow Barge Canal Gate Structure
- Oyster Creek Levee Raise (1-foot)
- East Storm Levee Raise (1-foot)
- Freeport Dock Floodwall Raise (1-foot)
- Old River Levee Raise at Dow Thumb (1-foot)
- Tide Gate I-Wall Raise (1-foot

7.5 SELECTION OF THE RECOMMENDED PLAN

Note: This section describes the selection process that led to the identification of the TSP. The information contained herein was presented in the Sept 11, 2015 DIFR-EIS that was released for public review. Changes to the TSP have occurred since the public review are briefly described at the end of this section. The changes to the TSP resulted in the Recommended Plan presented in the last section and in the Main Report.

USACE guidance requires selection of the TSP as the Recommended Plan unless there are other Federal, state, local, or international concerns that make another alternative viable to recommend at full cost sharing. In addition, there is an opportunity for the local sponsor to request implementation of a locally preferred plan (LPP) in which they would fully fund the cost above the NED plan if it were higher, or the plan would be reduced in cost if they preferred a smaller plan. Any plan other than the NED Plan would require a waiver from the Assistant Secretary of the Army for Civil Works. It is unlikely there will be a locally preferred plan for this study. However, it may make sense to recommend a plan that provides a higher level of performance because it fulfills other, non-economic objectives of the study, including considerations of life-safety, critical infrastructure, and RSLC.

This draft report will undergo public, policy, Agency Technical Review (ATR), Independent External Peer Review (IEPR), and the Study Team will address all comments from these reviews. Based particularly on input from public and agency reviews concerning public safety and infrastructure concerns, it may be appropriate for USACE to consider recommending a more robust plan for the Orange-Jefferson CSRM after the Agency Decision Milestone (ADM) is conducted. The ADM is the decision point where a Senior Leader Panel confirms the TSP and makes the decision on the Recommended Plan to carry forward for detailed feasibility-level design based on policy, public, ATR and IEPR reviews of the draft report.

The decision to select a plan other than the TSP is not based on quantitative economic analysis alone, but rather takes into consideration other factors that could justify higher project cost and more robust construction than could be otherwise justified. The following discussion identifies other compelling factors that might support a plan larger than the TSP for the Orange-Jefferson

CSRM for consideration by the Senior Leader Panel. If approved, a TSP providing greater protection for the Orange-Jefferson CSRM would be further refined in the next study phase.

For example, Table 7-17 is a summary of comparable Optimization of Alternatives in terms of net benefits, percent change in net benefits, annual costs, and total project cost differences within the Orange-Jefferson CSRM project area. An increase in one foot above the Optimization Alternatives would cost about $72 million more but would only provide about $545,000 more in net annual benefits. Based on economics alone, even though the 11-foot levee is incrementally justified, it doesn't make sense to recommend a plan that costs that much more for such minimal benefits.

However, based on the qualitative evaluation performed, each alternative reach is expected to have a positive impact on life-safety, because reductions in economic damages are generally considered highly correlated to reductions in risk in terms of life-safety. For the Orange-Jefferson CSRM project area, the population at risk is estimated as follows:

- Orange 3 Alternative Reach – 60,044 residents
- Beaumont A Alternative Reach – 2,078 residents
- Jefferson Main Alternative Reach – 116,762 residents
-

Table 7-17. Cost Analyses Comparison for Optimization Alternatives in the Orange-Jefferson Project Area

	Objective 1					
	Net Benefits	**Net Benefits % Change**	**Annual Cost**	**Annual Cost % Change**	**Total Project Cost**	**Incremental Change in Total Project Cost**
Orange-Jefferson CSRM						
Orange 3						
11-foot Raise	$9,851,000	N/A	$14,895,000	N/A	$246,811,000	N/A
12-foot Raise	$10,232,000	3.9%	$16,711,000	12.2%	$288,284,000	$41,473,000
Beaumont A						
12-foot Raise	$2,992,000	N/A	$3,075,000	N/A	$70,202,000	N/A
13-foot Raise	$3,037,000	1.5%	$3,405,000	10.7%	$77,743,000	$7,541,000
Jefferson Main						
11-foot Raise	$22,461,000	N/A	$3,250,000	N/A	$64,726,000	N/A
12-foot Raise	$22,580,000	0.5%	$4,212,000	29.6%	$87,674,000	$22,948,000

The risk assessment for the Orange-Jefferson CSRM is largely qualitative. Defining the population at risk, above, and the depth of flooding is evaluated in a risk assessment. Other considerations include populations in high risk areas with special needs, such as elderly populations over 65, and care and shelter facilities including hospitals, nursing homes and schools. Figures 7-12 and 7-13 depict the locations of hospitals, nursing homes and schools in the areas of Orange and Jefferson Counties that would be protected by the TSP. Flooding depths for the Orange 3, Beaumont A, and Jefferson Main Alternative Reaches are approximately 6-8 feet (estimated depths of flooding at the 1% ACE from the economic analysis). Disabled residents are a high risk population that would be particularly vulnerable in 6 to 8 feet of flooding if there were not sufficient lead time for evacuations or if evacuation procedures are not implemented

appropriately. Approximately 19% of the 178,884 people at risk in the Orange-Jefferson CSRM project area, or 33,000 people, would be considered disabled (2015 U.S. Census). Of the approximately 500,000 people in New Orleans during Hurricane Katrina, 100,000 were too elderly, disabled, or lacked transportation and resources to evacuate, with disastrous results (2015 datacenterresearch.org) and it is assumed that the Orange-Jefferson CSRM project area could experience similar outcomes. In addition, given the critical infrastructure and refining capacity also located in the project area, a compelling argument can be made to provide a higher level of storm surge risk reduction by building a foot higher than the current TSP.

In addition to increased life-safety benefits, there are other non-traditional secondary or ancillary economic benefits not included in the NED Plan that should be considered, including preventing disruptions in business such as loss of revenue, wages, and sales tax, and their multiplier effects. The cost of emergency response and clean up would also be avoided. Most importantly, increased protection would also avoid disruption to significant industrial and manufacturing facilities located in the project area, notably, the Motiva and Exxon Mobil refineries that have the capacity to refine 945,000 barrels of crude oil per day and can produce 6.7 billion gallons of gasoline annually. In 2014 the U.S. Energy Information Administration reports that the U.S. consumed 136.78 billion gallons of gasoline. These two refineries alone can produce about 5%

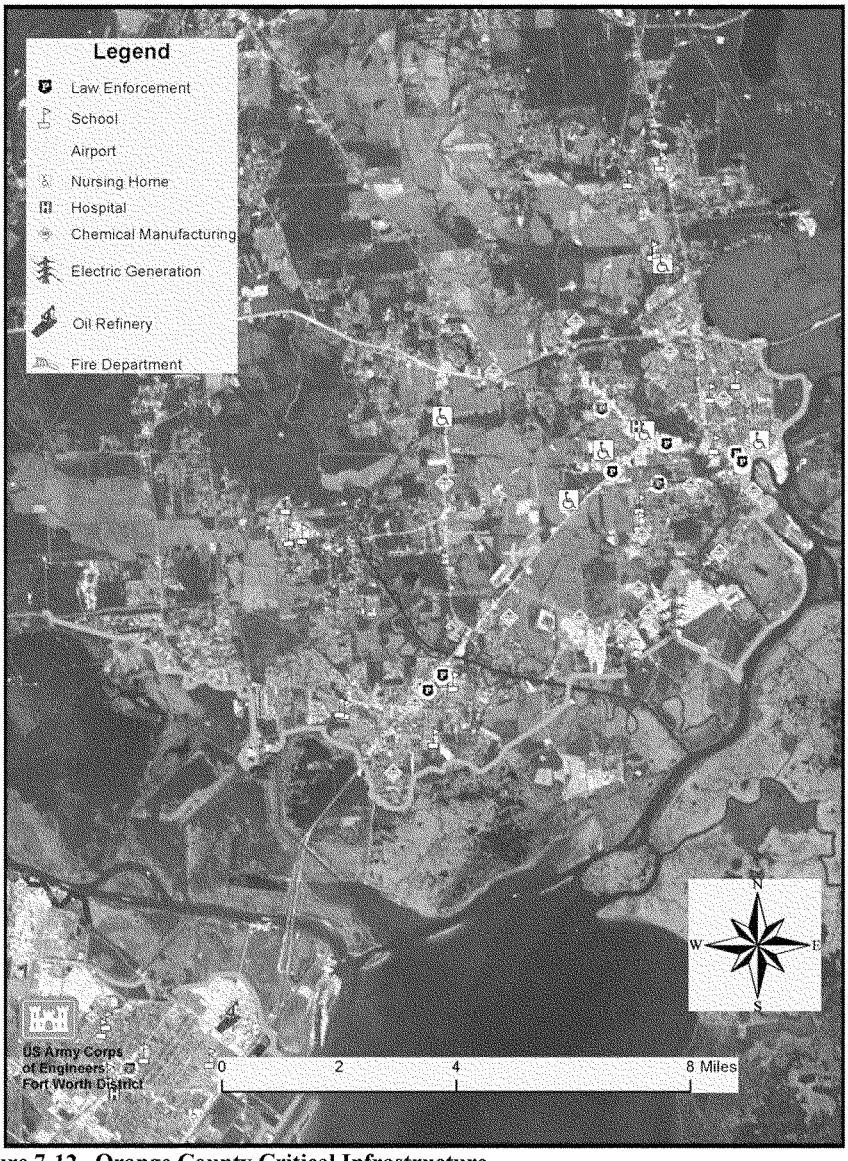


Figure 7-12. Orange County Critical Infrastructure

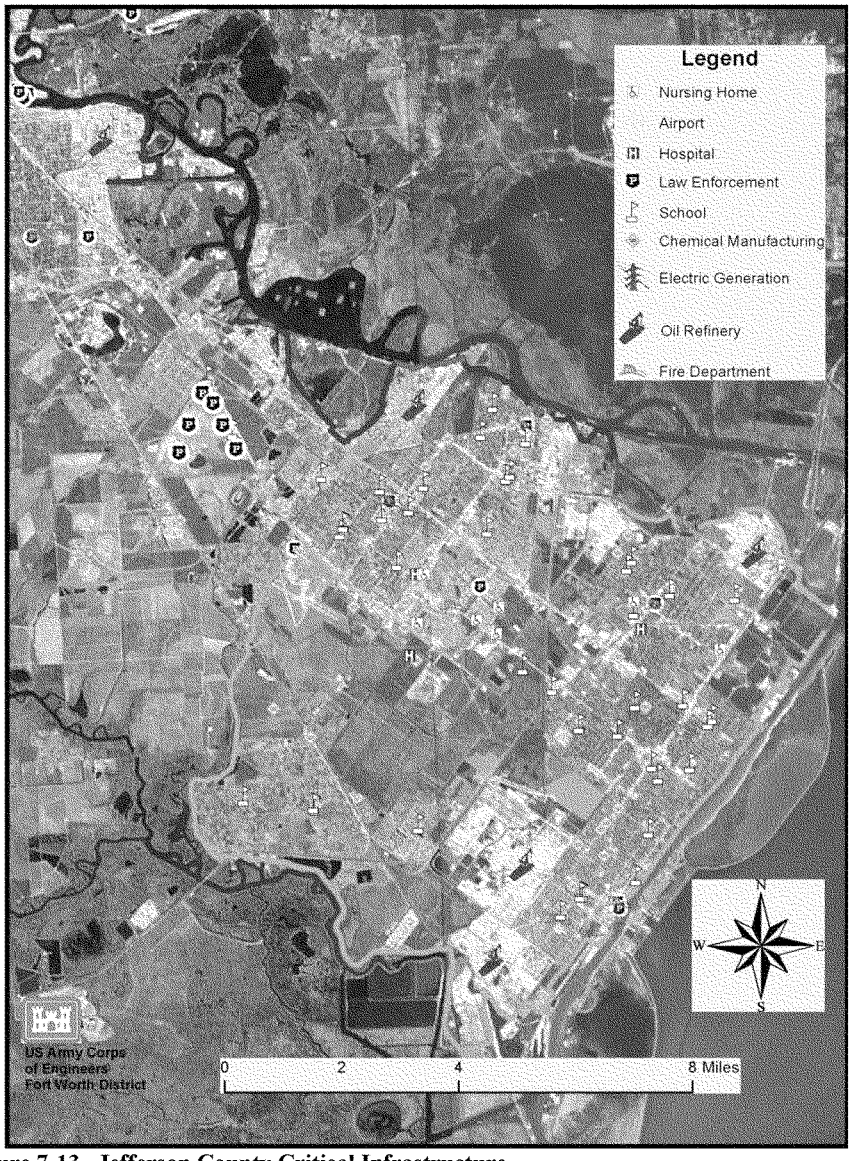


Figure 7-13. Jefferson County Critical Infrastructure

of that demand. If they were running at full production with gas prices at $2.50/gallon and were to go out of production for even a month, this could be up to a $1.4 billion hit to the national economy and would be even more significant to the regional and local economies. Spending $72 million to provide an additional foot of performance and lower the probability of being impacted would seem to be a small investment to protect such significant infrastructure and would be worth the investment.

In addition, the current TSP could result in larger future project modifications to account for RSLC in the Orange-Jefferson CSRM project area. Efficiencies would be gained by spending an additional $72 million now to account for projected RSLC. Table 7-18 displays the ranges for RSLC for each of the alternative reaches. The deficit is already a concern for feasibility-level design and would need to be taken into further consideration in the study to ensure the recommended plan would meet USACE design criteria for RSLC. With this in mind, the 12-foot levees would perform better than the NED Plan when considering RSLC scenarios and would be worth the additional Federal investment. If the NED plan remains the final recommendation from the Senior Leader Panel at the ADM, then it may still be appropriate for the Corps to consider cost sharing in the design and construction of any recommended floodwall or I-wall to accommodate future construction for RSLC adaptation. This expense would be minimal compared to the significant expense of project replacement in the future.

Table 7-18. Ranges for RSLC for the Orange-Jefferson CSRM Project Area

Orange 3	Range of RSLR Projected
11-foot Raise	-1.3 – 4.8 feet deficit
12-foot Raise	-0.5 – 3.8 feet deficit
13-foot Raise	0.5 surplus - 2.8 feet deficit
Beaumont A	
11-foot Raise	-1.3 – 4.8 feet deficit
12-foot Raise	-0.5 – 3.8 feet deficit
13-foot Raise	0.5 surplus - 2.8 feet deficit
Jefferson Main	
11-foot Raise	-1.3 – 4.8 feet deficit
12-foot Raise	-0.5 – 3.8 feet deficit
13-foot Raise	0.5 surplus - 2.8 feet deficit

7.5.1 Selection of the Recommended Plan Summary

Based on the planning objectives and USACE policy, the TSP is likely to be considered the Recommended Plan as listed in Section 7.1.8 and described in detail in Section 6 of the main report. This does not preclude a decision to refine or alter the TSP at the ADM based on responses from public, policy and technical reviews of the DIFR-EIS, specifically for the Orange-Jefferson CSRM. Compelling factors exist to support a decision to select a plan at least one foot higher than the NED Plan based on economics (the higher plans provides more net benefits), life safety (the lower the probability of flood event damaging property generally results in lower risk to loss of life), critical infrastructure (major oil refineries that could produce significant impacts to local,

regional, and the national economy), and RSLC (a resilient project would be cheaper to build it now rather than retro-fit it later). A final decision will be made at the ADM following the reviews and higher-level coordination within USACE to select a plan for feasibility-level design and recommendation for implementation. The decision made, ie., NED versus a foot higher, will be documented in the FIFR-EIS. A supplemental DIFR-EIS would not likely be produced unless there are substantial design changes that significantly alter environmental impacts. Coordination with the natural resource agencies will continue throughout the study process as required by the Fish and Wildlife Coordination Act.

7.5.2 Cost Summary of the Recommended Plan

The cost estimate included here is intended to provide an estimate of total costs of the TSP. An MCACES cost estimate will be provided for the plan selected for feasibility-level design. The TSP cost is included in Table 7-19 through 7-20. Figures 7-14 through 7-16 provide a graphic representation of the TSP.

Table 7-19. Economic Summary of the TSP for Orange-Jefferson CSRM
(FY 2015 Price Level/3.375 percent interest rate)

	Orange 3	Jefferson Main	Beaumont A
	11 - Foot	11 - Foot	12 - Foot
INVESTMENT			
Estimated First Cost	$246,811,000	$65,726,000	$70,202,000
Annual Interest Rate	3.375%	3.375%	3.375%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,587,000	$3,352,000	$3,580,000
Investment Cost	$259,398,000	$69,078,000	$73,782,000
Interest	$8,755,000	$2,331,000	$2,490,000
Amortization	$2,056,000	$548,000	$585,000
O&M ($/year)*	$4,084,000	$371,000	
TOTAL ANNUAL COSTS	**$14,895,000**	**$3,250,000**	**$3,075,000**
Without Project EAD	$29,987,000	$28,231,000	$6,937,000
Residual EAD	$5,242,000	$2,520,000	$870,000
Storm Reduction Benefits	$24,745,000	$25,711,000	$6,067,000
TOTAL BENEFITS	$24,745,000	**$25,711,000**	**$6,067,000**
NET BENEFITS	**$9,851,000**	**$22,461,000**	**$2,992,000**
BENEFIT-COST RATIO	**1.7**	**7.9**	**2.0**

Table 7-20. Economic Summary of the TSP for Port Arthur and Vicinity CSRM

(FY 2015 Price Level/3.375 percent interest rate)

	8ft-10ft I-Wall	Closure Structure	I-Wall Near Valero	I-Wall Near Tank Farm
	1-Foot Raise	1-Foot Raise	1-Foot Raise	1-Foot Raise
INVESTMENT				
Estimated First Cost	$8,915,000	$10,654,000	$8,948,000	$4,627,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50
Construction Period (months)	36	36	36	36
Interest During Construction	$455,000	$543,000	$456,000	$236,000
Investment Cost	$9,370,000	$11,197,000	$9,404,000	$4,863,000
Interest	$316,000	$378,000	$317,000	$164,000
Amortization	$74,000	$89,000	$75,000	$39,000
TOTAL ANNUAL COSTS	**$391,000**	**$467,000**	**$392,000**	**$203,000**
Without Project EAD	$23,413,000	$3,784,000	$61,867,000	$38,009,000
Residual EAD	$5,730,000	$408,000	$10,813,000	$16,874,000
Flood Reduction Benefits	$17,683,000	$3,375,000	$51,054,000	$21,135,000
TOTAL BENEFITS	**$17,683,000**	**$3,375,000**	**$51,054,000**	**$21,135,000**
NET BENEFITS	**$17,292,000**	**$2,908,000**	**$50,662,000**	**$20,932,000**
BENEFIT-COST RATIO	**45.2**	**7.2**	**130.2**	**104.1**

Table 7-21. Economic Summary of the TSP for Freeport and Vicinity CSRM

(FY 2015 Price Level/3.375 percent interest rate)

	Dow Barge Canal	Oyster Creek Levee	East Storm Levee	Freeport Dock	Old River Levee at Dow Thumb	Tide Gate I-Wall
	No Fail - Closure Structure	1-Foot Raise	1-Foot Raise	No Fail	1-Foot Raise	1-Foot Raise
INVESTMENT						
Estimated First Cost	$130,000,000	$4,869,000	$6,530,000	$2,850,000	$8,294,000	$3,800,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36
Interest During Construction	$6,630,000	$248,000	$333,000	$145,000	$423,000	$194,000
Investment Cost	$136,630,000	$5,117,000	$6,863,000	$2,995,000	$8,717,000	$3,994,000
Interest	$4,611,000	$173,000	$232,000	$101,000	$294,000	$135,000
Amortization	$1,083,000	$41,000	$54,000	$24,000	$69,000	$32,000
TOTAL ANNUAL COSTS	**$5,694,000**	**$213,000**	**$286,000**	**$125,000**	**$363,000**	**$166,000**
Without Project EAD	$166,660,000	$3,800,000	$1,701,000	$3,960,000	$2,517,000	$2,785,000
Residual EAD	$47,052,000	$1,272,000	$581,000	$1,742,000	$913,000	$897,000
Storm Reduction Benefits	$119,608,000	$2,527,000	$1,121,000	$2,218,000	$1,604,000	$1,888,000
TOTAL BENEFITS	**$119,608,000**	**$2,527,000**	**$1,121,000**	**$2,218,000**	**$1,604,000**	**$1,888,000**
NET BENEFITS	**$113,914,000**	**$2,314,000**	**$835,000**	**$2,093,000**	**$1,241,000**	**$1,721,000**
BENEFIT-COST RATIO	**21.0**	**11.9**	**3.9**	**17.7**	**4.4**	**11.4**

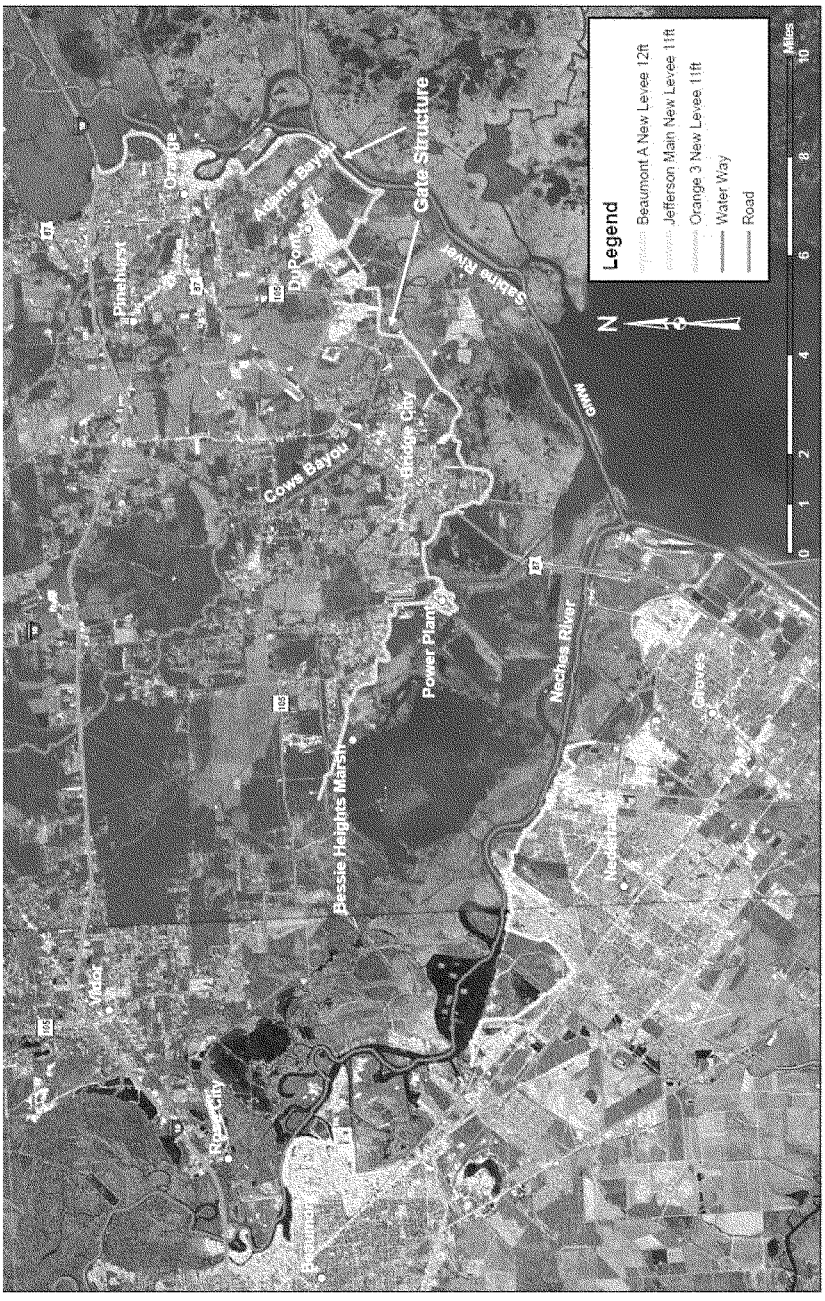


Figure 7-14. Orange-Jefferson CSRM Plan

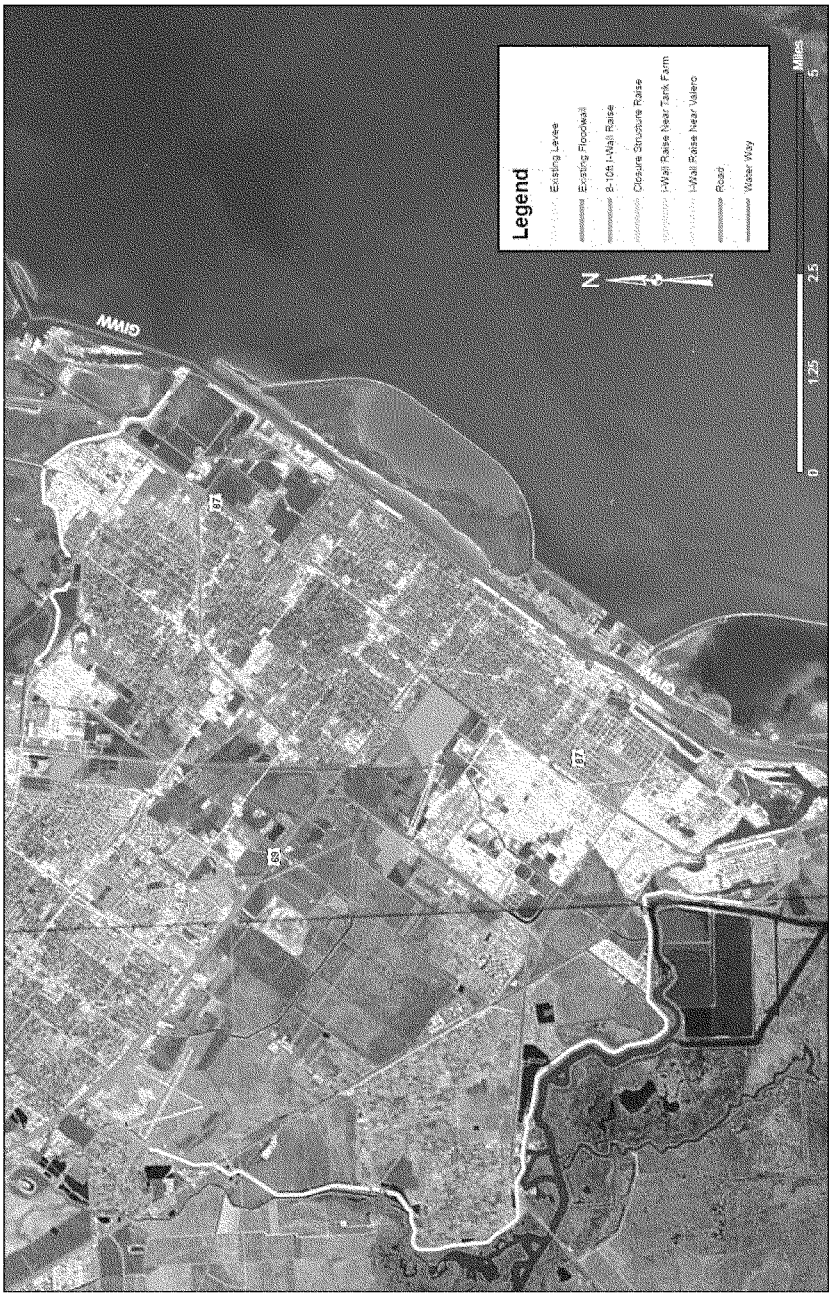


Figure 7-15. Port Arthur and Vicinity CSRM Plan

Figure 7-16. Freeport and Vicinity CSRM Plan

7.5.3 Separable Elements

A separable element is any part of a project which has separately assigned benefits and costs, and which can be implemented as a separate action (at a later date or as a separate project). Orange-Jefferson, Port Arthur, and Freeport CSRM Plans function individually and are separable. Each piece of Port Arthur and Freeport are not separable elements but need to be constructed together in order to function as a system. For Orange-Jefferson CSRM Plans on the other hand, the Alternative Reaches could potentially be separated out.

7.5.4 Changes to TSP and Selection of the Recommended Plan Summary

As described in the DIFR-EIS the alternatives in each project area were evaluated in detail, then compared against each other to identify which plan contributes most to the objectives. This process continued throughout the detailed feasibility analysis. As described in section 7.1.19., after the release of the DIFR-EIS, and after policy, public, ATR, and IEPR reviews a Senior Leader Panel Agency Decision Milestone (ADM) was held to confirm the TSP and initiate detailed feasibility-level design. Table 7.22 presents an overview of the TSP and changes from the DIFR-EIS. During technical reviews and based on new information from the feasibility level design phase of the study, additional work and other assessments were completed for several of the features presented in the DIFR-EIS as the TSP. Additional details on features such as, required pump stations, required road crossings and required OMRR&R increased the overall construction and OMRR&R cost for all plans. The sections below explain the changes that have occurred since the release of the DIFR-EIS.

Table 7-22: Overview of changes since release of DIFR-EIS

Project Area	Elements presented in Sept 11, 2015 DIFR-EIS	Elements in Final Recommendation
Orange-Jefferson CSRM	Orange 3 New Levee (11-foot)	**Included in Final Recommended Plan**
	Beaumont A New Levee (12-foot)	Removed due to limited net benefits, and recently constructed risk reduction improvements.
	Jefferson Main New Levee (11-foot)	Removed due to limited net benefits
Port Arthur and Vicinity CSRM	8-10 ft I-Wall Raise (1-foot)	**Included in Final Recommended Plan**
	Closure Structure Raise (1-foot)	**Included in Final Recommended Plan**
	I-Wall Raise Near Valero (1-foot)	**Included in Final Recommended Plan**
	I-Wall Raise Near Tank Farm (1-foot)	**Included in Final Recommended Plan**
	-------	**Final Recommended Plan included an additional 1,830 LF of new levee added to Existing Port Arthur and Vicinity HFPP to address flanking of surges**
Freeport and Vicinity CSRM	Dow Barge Canal Gate Structure	**Included in Final Recommended Plan**
	Oyster Creek Levee Raise (1-foot)	**Included in Final Recommended Plan**
	East Storm Levee Raise (1-foot)	**Included in Final Recommended Plan**
	Freeport Dock Floodwall Raise (1-foot)	**Included in Final Recommended Plan**

	Old River Levee Raise at Dow Thumb (1-foot)	**Included in Final Recommended Plan**
	Tide Gate I-Wall Raise (1-foot)	**Included in Final Recommended Plan**
Brazoria and Sabine Nonstructural	-------	Buyouts were considered ancillary to the implementation of new levees/floodwalls in Orange and Jefferson Counties and to the enhancement of features in the Port Arthur and Freeport CSRM project areas. Buyout opportunities in Brazoria were virtually non-existent and very limited in both Orange and Jefferson Counties. A quantitative analysis was conducted to determine the viability of any proposed nonstructural buyout. The analysis showed the nonstructural buyouts had negative net benefits and any potential buyouts were screened from the analysis.

7.5.5 Removal of Beaumont A New Levee (12-foot) and Jefferson Main New Levee (11-foot) from Recommended Plan

After the ADM, the Beaumont A New Levee (12-foot) and Jefferson Main New Levee (11-foot) were removed from consideration under the Recommended Plan. Beaumont A New Levee (12-foot was removed due to recent the local industrial actions to reduce the area's risk from storm surges. In the last few years the local industries have developed a levee and floodwall system at the same location as the TSP (Figure 7-14 and Figure 7-15). The structural integrity of the existing system is not fully known; however, an assessment of the systems height appears to place it above the heights considered in the Recommended Plan. Additional detailed economic evaluation of Beaumont A was not performed following the ADM; however, it was estimated that the current residual economic damages and life-safety risk are now limited. Risk from storm surge flooding is mainly concentrated to the industrial areas which is now being mitigated for with the newly constructed system. Based on the considerations above the Beaumont A New Levee (12-foot) was removed from the final Recommended Plan.

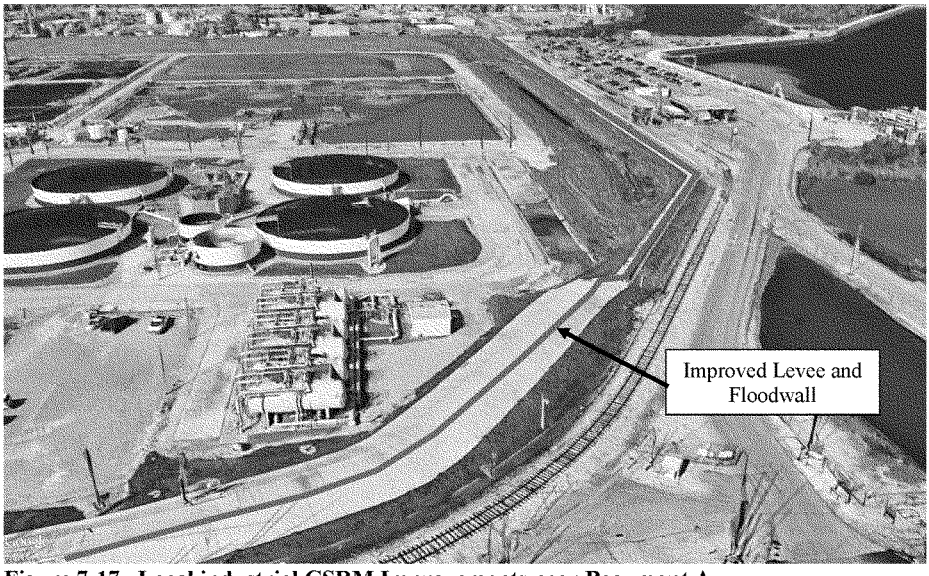


Figure 7-17. Local industrial CSRM Improvements near Beaumont A

The Jefferson Main New Levee was removed from the final Recommended Plan based on a lack of local sponsorship and due to the limited perceived benefits. During the concurrent review period, local entities suggested that the economic performance of Jefferson Main should be reevaluated because there was not a perceived need for this component of the TSP. There was limited life-safety risk due to the industrial makeup of the area. Based on results of these evaluation, the sponsor decided to not to pursue this component of the final Recommended Plan.

7.5.6 Reevaluation of Orange 3 as a component of the Recommended NED Plan

Due to the increases in construction cost and OMRR&R there were concerns on whether Orange 3 required a reevaluation against other alternatives to confirm it was still the NED component of the plan. The selected plan does obtain positive net benefits, but during final technical reviews there were question on whether other measures or alignments such as the Gate and No-Gate Alternatives discussed in section 5.3.2 would have achieved higher net benefits if carried forward through feasibility design. The sections below explains why the Orange 3 plan is still the plan that reasonably maximizes net benefits.

7.5.6.1 Revaluation of Orange 3 vs Gate

As described in section 6.2.11 an analysis for an alternatives to cross the Neches River was developed to investigate cost saving with the Gate and No-Gate Alternatives. At the time of the DIFR-EIS the cost of the Gate Alternative was approximately $865 million more expensive than the No-Gate Alternative. Although there were significant cost increases from the TSP to the

Recommended Plan the estimated first cost differences presented under the DIFR-EIS would not have changed plan selection by making the "gate" alternative a cheaper alternative. Cost increases would have also been applied to the gate alternative. The "gate" alternative includes additional factors, shown in table 7-23, limited its viability.

Table 7-23: Planning Review of "gate" alternative

Areas of Focus	Planning Evaluation
Cost	West of Bridge City the final Recommendation included 33,700 lf of levees and 9,500 lf of floodwalls (43,200 lf Total) and although the "gate" is approximately half that length, the cost per linear foot for a floodwall crossing a river system is significantly higher vs a levee system built near upland areas due to soil stability in the area.
	The two largest pump stations Adams and Cow Bayou would still be included in the Orange 3 system with or without the gate option. The overall structure cost account will just increase with another structure across the Neches River.
	A gate across the Neches River would significantly increase the annual OMRR&R.
Benefits	There would be limited benefits to be gained on the east and west side of the Neches River above the point of the gate closure. As described in section 7.1.23, the current residual economic damages and life-safety risk are now limited. Risk from storm surge flooding is mainly concentrated to the industrial areas which is now being mitigated for with the newly constructed system.
Environmental Impacts	The floodwall and gate crossing the Neches River would impact additional wetlands. Also, there would be concerns with indirect impacts. None of these cost were included in the original evaluation.

7.5.6.2 Reevaluation of Orange 3 vs Ring Levees or Nonstructural Measures

As described in section 7.1.22 additional details on features such as, required pump stations, required road crossings and required OMRR&R increased the overall construction and OMRR&R cost for the Recommended Plan. One of the largest cost changes for Orange 3 was the addition of the two largest pump stations in the system at Adams and Cow Bayou. Due to the large increases in cost with these features additional investigation into removing these features were conducting. Based on the FWOP conditions it was determined that the only two viable alternatives investigating were smaller ring levee systems avoiding the gates and pump stations on Adams and Cow Bayou or complete acquisitions of structures at risk.

Nonstructural Measures, such as acquisitions of structures to achieve the same level of benefits as the Recommended Plan were deemed to be infeasible and would be detrimental to community cohesion in the area. Over 9,000 residential and nonresidential structures are in the 100 yr floodplain (Figure 6-3 and Figure 7-18) and would have to be relocated out of the floodplain.

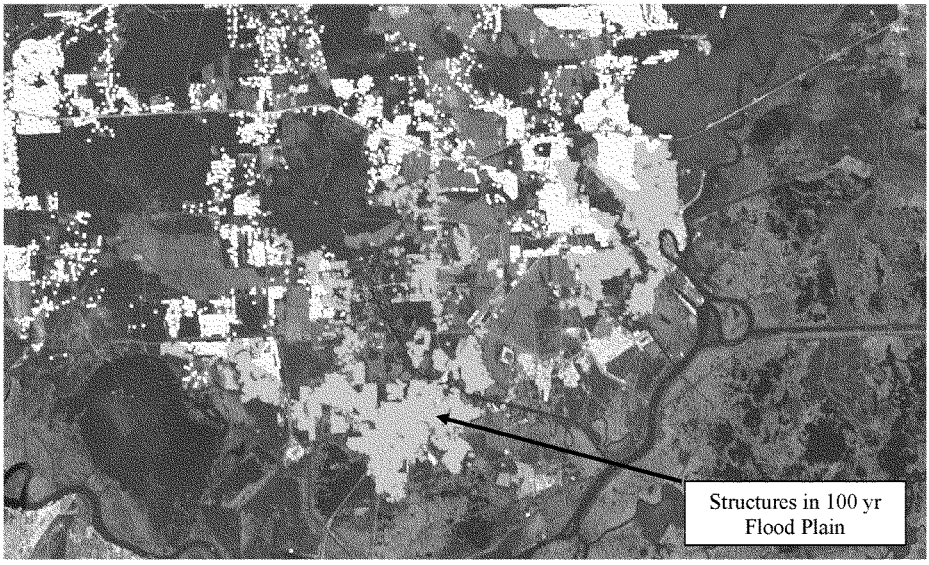


Figure 7-18. Orange 3 Structures in 100 yr Flood Plain

(Note: As shown structures in geographic view. Structures' first floor maybe above the 100 yr Flood Plain)

Structures would have to be relocated outside of the existing communities and rough order magnitude (ROM) cost estimates that this cost, $3.2 B would be well over the existing cost for Orange 3, $1.5B. Relocating outside of the floodplain would also have NED tradeoffs. Although NED damages would be avoided, residents and local municipalities would occur increased NED cost, since many of the vital commercial activities would still take place within the floodplain. Many of the residents in the area depend on the local waterways for commerce. There would be added travel times to reach these commerce centers adding to increased NED cost.

A review of measures using ring levees enclosing the same benefit areas as Orange 3 was also conducted to determine if there would be cost saving by removing the high cost features along Adams and Cow Bayou. The segments of the levee and pump stations removed are shown in yellow on Figure 7-19.

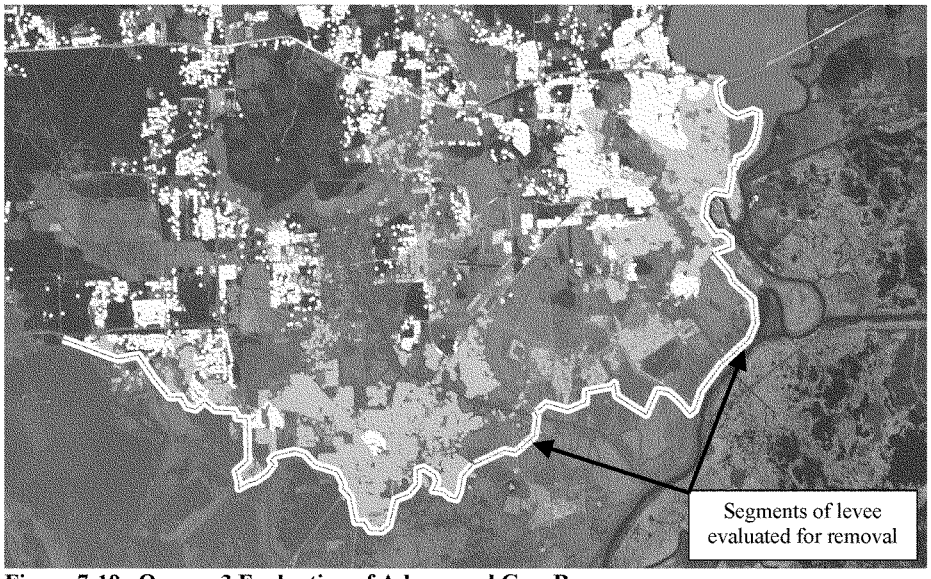


Figure 7-19. Orange 3 Evaluation of Adams and Cow Bayou

The evaluation determined that due to the extent of the flooding and very flat nature of the flood plain, ring levees would not have been a viable alternative. Although the plan would have removed two of the large pump stations, smaller ring levees would have required additional cost, further reducing the economic viability of this option. As shown on Table 7-24 smaller ring levee would have add 29 extra miles of levees and floodways to obtain the same level of risk reduction as with the Adams and Cow Bayou closures. There would also be added cost with approximately 30 extra drainage, railroad and roadway crossings. Environmental impacts, as also shown in table 7-24, would have limited this alternatives viability. All of these features would have doubled the size of the system that would have to be operated under storm event (Figure 7-20), making it an unreasonable alternative when compared to the Recommended Plan.

Table 7-24 Evaluation of Orange Ring Levees

Review Parameter	Options Reviewed			vs	Recommendation: Orange 3	Comments
	System of Ring Levees					
Cost	Ring 1 (Bridge City)	14.58 miles	Total of 55.6 Miles		Total of 27 miles	Requires ~29 extra miles of levees and floodwalls with system of ring levees option. Plan removes Adams and Cow Bayou Gate structures and pump stations, but the addition of ~29 miles of levee/floodwall, would increase the overall cost of plan when compared to the recommended plan. There could be adjacent impacts (induced flooding) to areas previously behind levee
	Ring 2 (Industrial Area)	16.32 miles				
	Ring 3 (City of Orange)	24.7 miles				
	12 Additional New Significant Roadway/Railroad Crossing				32 Closure Gates (Road/Railroad Crossings)	Most of the 32 closure gates exist near the City of Orange which wouldn't be removed with smaller ring levees. Ring Levee would cross major highways; and evacuation routes that were avoided under the single levee plan.
Environmental	Ring 1 (Bridge City)	~3 miles of habitat along Cow Bayou	~6.5 miles of habitat		Currently impacts are to less than 2 miles when crossing Cow and Adams Bayou.	A switch to ring levees would have significant impacts to the Adams and Cow Bayou habitat. The system would require significant environmental control features for the ring levees. This would also add to the overall cost.
	Ring 2 (Industrial Area)	~1 mile of habitat along Cow Bayou ~1.5 miles of habitat along Adams Bayou				
	Ring 3 (City of Orange)	~.1 miles of habitat along Adams Bayou				
Life Safety Risk	Increased Life Safety Risk to residents inside of the small ring levees. There would be minimum time to react to exceedance events due to the limited storage capacity. Also all evacuations routes would likely be flooded.	Increased Life Safety Risk to residents outside of the ring levee system. There could be induced stages outside of the ring levees and changes in historical flood patterns could catch resident off guard.			Under exceedance events the surge overtopping the system would be allowed to expand over the flat coastal flood plain. Under the current plan there are limited structures outside of the proposed levee system, reducing the risk of induced stages and life safety risk.	Smaller ring levees would go against a key Constraint: Structural plans do not increase life-safety risk.

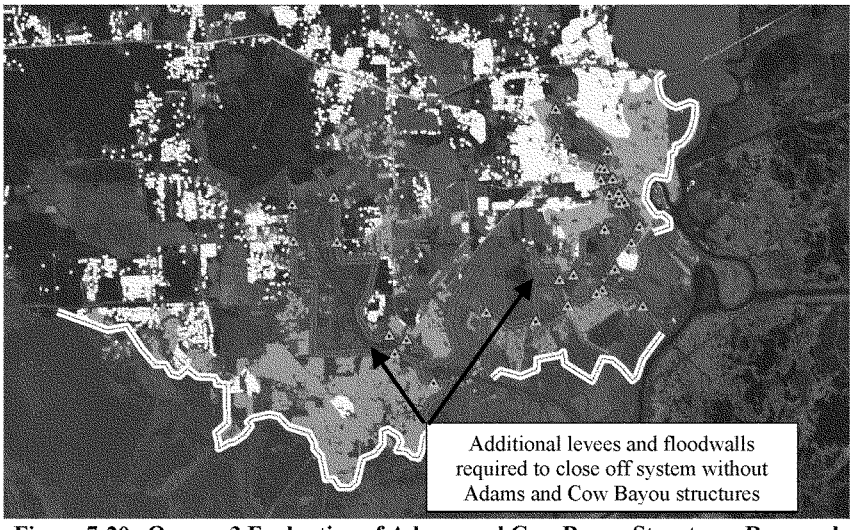


Figure 7-20. Orange 3 Evaluation of Adams and Cow Bayou Structures Removed

7.5.7 Confirmation of Orange 3 as a component of the Recommended NED Plan

Based on the information presented in Section 7.5.6, Orange 3 still would have the lowest total cost (including mitigation), the highest BC ratio, and the highest net benefits. In conclusion, Orange 3 is still the plan that maximizes NED benefits while protecting the nation's environment, pursuant to national environmental statutes, applicable executive orders, and other Federal planning requirements.

U.S. Army Corps
of Engineers

Galveston District
Southwestern Division

Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration

Volume 2
Appendix C - E

May 2017

Sabine Pass to Galveston Bay, Texas
Coastal Storm Risk Management and Ecosystem Restoration
Final Integrated Feasibility Report and Environmental Impact Study

Appendix C

Economic Analysis

May 2017

TABLE OF CONTENTS

1 COASTAL STORM RISK MANAGEMENT 1

1.1 Purpose 1
1.2 Initial Screening of Alternatives 1
1.3 Reach Determination 2
1.3.1 Orange-Jefferson CSRM 2
1.3.2 Port Arthur and Vicinity CSRM 3
1.3.3 Freeport and Vicinity CSRM 5

2 HEC-FDA ANALYSIS 8

2.1 Engineering Inputs 8
2.1.1 Stage-Probability Relationships 8
2.1.2 Fragility Curves 10
2.2 Economic Inputs 15
2.2.1 Ground Elevations 15
2.2.2 Structure Inventory 15
2.2.3 Vehicle Inventory 17
2.2.4 Depth-Damage Functions 22
2.3 Future Without-Project Structure and Content Damages 24
2.3.1 Methodology Overview 24
2.3.2 Future Without-Project Condition Expected Annual Damages 26
2.4 Alternative Analysis 26
2.4.1 Orange-Jefferson CSRM 26
2.4.2 Port Arthur and Vicinity CSRM 41
2.4.3 Freeport and Vicinity CSRM 42
2.4.4 Brazoria and Sabine Non-Structural 47
2.4.4.1 Non-Structural Measures 47
2.4.4.1.1 Floodplain Management 47
2.4.4.1.2 Flood Forecast and Warning Systems 48
2.4.4.1.3 Flood Proofing 48
2.4.4.1.4 Raising Structures in Place 49
2.4.4.1.5 Structure Relocation 49
2.4.4.1.6 Permanent Evacuation 49
2.4.4.1.7 Ancillary Permanent Evacuation 50
2.5 Adjacent Impacts/Induced Flooding 53
2.6 Risk Performance of Proposed Actions 53

2.6.1 Performance of the Tentatively Selected Plan under Relative Sea Level Change 55
2.6.2 Life Safety Considerations 59
2.7 Identification of the TSP 60
2.7.1 Orange-Jefferson CSRM 60
2.7.2 Port Arthur and Vicinity CSRM 60
2.7.3 Freeport and Vicinity CSRM 60
2.8 Re-Optimization to account for relative sea level change (RSLC) 65
2.9 Risk Performance of RSLC Revised Proposed Actions 89
2.10 Recommended Plan 97
Orange CSRM 103
Port Arthur and Vicinity CSRM 103
Freeport and Vicinity CSRM 103
2.11 Critical Infrastructure 105
2.12 Depth Damage Functions 108
2.13 Listing of Critical Infrastructure by County 116
2.13.1 Orange 116
2.13.2 Jefferson 118
2.13.3 Brazoria 123

LIST OF FIGURES

Page

Figure 1-1. Configuration of the Orange-Jefferson CSRM 4
Figure 1-2. Port Arthur and Vicinity CSRM 6
Figure 1-3. Freeport and Vicinity CSRM 7
Figure 2-1. ADCIRC Points Orange-Jefferson CSRM 11
Figure 2-2. ADCIRC Points in Port Arthur and Vicinity CSRM 12
Figure 2-3. ADCIRC Points in Freeport and Vicinity CSRM 13
Figure 2-4. Orange-Jefferson CSRM Structures at Risk (Parcels) 18
Figure 2-5. Port Arthur and Vicinity CSRM Structures at Risk 19
Figure 2-6. Freeport and Vicinity CSRM Structures at Risk – Dow Barge Canal Reach 20
Figure 2-7. Freeport and Vicinity CSRM Structures at Risk – Remaining Reaches 21
Figure 2-8. Potential Orange County Buyouts 51
Figure 2-9. Orange-Jefferson CSRM RSLC Scenarios 67
Figure 2-10. Port Arthur CSRM RSLC Scenarios 68
Figure 2-11. Freeport CSRM RSLC Scenarios 69
Figure 2-12. Orange CSRM Benefits from RSLC Scenarios 86
Figure 2-13. Port Arthur CSRM Benefits from RSLC Scenarios 87

Figure 2-14. Freeport CSRM Benefits from RSLC Scenarios 88
Figure 2-15. Orange County Critical Infrastructure 125
Figure 2-16. Jefferson County Critical Infrastructure 126
Figure 2-17. Brazoria County Critical Infrastructure 127

LIST OF TABLES

Page

Table 1-1. Sabine Pass to Galveston Bay, TX - Final Array of Alternatives 1
Table 2-1. Average Still Water Elevations at HEC-FDA Index Point 10
Table 2-2. Fragility Curves for Port Arthur and Vicinity CSRM 14
Table 2-3. Fragility Curves for Freeport and Vicinity CSRM 14
Table 2-4. Structure and Content Values of Inventoried Structures by CSRM and Type 2015 Price and Development Levels 16
Table 2-5. Depth-Damage CSVR, and Uncertainties. 23
Table 2-6. Equivalent Annual Damages Future Without-Project Condition (2015 price level) 28
Table 2-7. Structures and Damages by Event for Orange-Jefferson CSRM 29
Table 2-8. Structures and Damages by Event for Port Arthur CSRM 32
Table 2-9. Structures and Damages by Event for Freeport CSRM 34
Table 2-10. Economic Performance of Orange-Jefferson CSRM 38
Table 2-11. Economic Performance of Port Arthur and Vicinity CSRM 44
Table 2-12. Economic Performance of Freeport and Vicinity CSRM 45
Table 2-13. Non-structural Analysis 51
Table 2-14. Project Performance for the Tentatively Selected Plan 56
Table 2-15. Tentatively Selected Plan Relative Sea Level Change Project Performance 58
Table 2-16. Population at Risk by CSRM 59
Table 2-17. TSP for Orange-Jefferson CSRM 60
Table 2-18. TSP for Port Arthur and Vicinity CSRM 61
Table 2-19. TSP for Freeport and Vicinity CSRM 63
Table 2-20. Updated Structure and Content Values of Inventoried Structures by CSRM and Type - 2016 Price and 2015 Development Levels 70
Table 2-21. Updated Structure Counts and Damages by CSRM and RSLC ACE 72
Table 2-22. Economic Performance of Orange-Jefferson CSRM 74
Table 2-23. Economic Performance of Port Arthur and Vicinity CSRM 75
Table 2-24. Economic Performance of Freeport and Vicinity CSRM 76
Table 2-25. Incremental Benefits for the Orange Jefferson, Port Arthur, and Freeport CSRM Alternatives 77
Table 2-26. Benefit Sensitivities by CSRM System 79

Table 2-27. Economic Performance of Orange-Jefferson CSRM Under 50-Year Low RSLC Scenario....81
Table 2-28. Economic Performance of Port Arthur and Vicinity CSRM Under 50-Year Low RSLC Scenario....81
Table 2-29. Economic Performance of Freeport and Vicinity CSRM Under 50-Year Low RSLC Scenario....83
Table 2-30. Economic Performance of Orange CSRM Under 50-Year High RSLC Scenario....84
Table 2-31. Economic Performance of Port Arthur and Vicinity CSRM Under 50-Year High RSLC Scenario....84
Table 2-32. Economic Performance of Freeport and Vicinity CSRM Under 50-Year High RSLC Scenario....85
Table 2-33. Project Performance for the Revised Tentatively Selected Plan – 20-Year Epoch...90
Table 2-34. Project Performance for the Revised Tentatively Selected Plan – 50-Year Epoch...92
Table 2-35. Project Performance for the Revised Tentatively Selected Plan – 100-Year Epoch.94
Table 2-36. Values for Debris Removal and Cleanup and Roads, Highways, and Railroads....98
Table 2-37. Values for Major and Minor Roads and Highways Based Orange County EDC Report....98
Table 2-38. Without and With-Project Equivalent Annual Damages for the Recommended Plan....100
Table 2-39. Economic Performance of Recommended Plan....101
Table 2-40. Interest During Construction for the Recommended Plan....104
Table 2-41. Probability Distribution....105

1 COASTAL STORM RISK MANAGEMENT

1.1 PURPOSE

The purpose of this appendix is to describe the economic methodology, its associated assumptions, and the use of economic and engineering tools used to assess, evaluate, and recommend a plan for the Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study.

1.2 INITIAL SCREENING OF ALTERNATIVES

Prior to the Alternatives Milestone Meeting, development of an initial array of alternatives from a wide range of measures for three regions covering six counties along the Texas Gulf Coast that would address coastal storm risk management and ecosystem restoration. The initial study was scoped during a planning charrette in August 2012 to comply with SMART Planning guidelines. Following the first Alternatives Milestone Meeting (AMM) in July 2013, a determination was made that a study encompassing the three-region, six-county area could not be done within the constraints of SMART Planning. Options were developed in order to minimize risk as much as possible and while still adhering to the basic tenets of SMART Planning. The Galveston District developed an option for completing a study of low to moderate risk that would cost $4.4 million and would drop the Galveston region concentrating instead on the Brazoria and Sabine regions. The study also dropped any ecosystem restoration measures and would only analyze CSRM alternatives in Brazoria, Jefferson, and Orange Counties.

The initial array of alternatives can be found in Appendix B – Plan Formulation. The final array of alternatives is shown in Table 1-1. This array was agreed to in the Alternatives Milestone Meeting (AMM) that occurred on April 9, 2014. This final array of alternative plans does not include alternatives in Galveston Bay region, nor does it include Ecosystem Restoration (ER) measures. Instead, those potential actions are to be included in future interim feasibility studies, including the ongoing Coastal Texas study. Appendix B further describes the formulation process that produced this final array.

Table 1-1. Sabine Pass to Galveston Bay, TX - Final Array of Alternatives

Alternative Number	Alt Name / Description
No Action	No Action or Future Without Project (FWOP)
S5	Sabine Inland Barrier CSRM Focus (Neches Gate/Sabine Levees/Hurricane Flood Protection)
S11	Sabine Nonstructural Alternative/ Buyouts and Lone Star-type Conservation Plan
B2	Brazoria Coastal Barrier CSRM Focus (revised)

Alternative Number	Alt Name / Description
B5	Brazoria Nonstructural Alternative/ Buyouts and Lone Star-type Conservation Plan

An IPR was conducted on May 30, 2014, to discuss the results in the analysis supporting whether the Neches Gate should be dropped from further consideration. As a result of the decision to drop the Neches Gate and as means of clarifying the nomenclature for the final array, alternatives in the final array were renamed. The Sabine Inland Barrier Alternative has been split into two parts, one addressing the new levee system in Orange and Jefferson Counties, and the other addressing improvements to the existing Port Arthur hurricane flood protection (HFP). The Brazoria Coastal Barrier Coastal Storm Risk Management (CSRM) Focus has been renamed after its primary component – Freeport and Vicinity CSRM. Non-structural plans will be evaluated for both Brazoria and Sabine regions.

- Orange-Jefferson Coastal Storm Risk Management (CSRM)
- Freeport and Vicinity CSRM
- Port Arthur and Vicinity CSRM
- Brazoria and Sabine Non-Structural

1.3 REACH DETERMINATION

The determination of reaches for the initial array of alternatives was based on the original designation of the three regions with measures and the subsequent alternatives being assigned to the appropriate region. Following the approval of the exemption from SMART Planning and the successful concurrence of the final array of alternatives following the April 2014 AMM, reaches were developed for the areas according to the final array of alternatives. This was required since a different methodology would be employed for the optimization of any new proposed levees/floodwalls and for improvements to any of the existing hurricane flood protection systems (HFP). While the initial screening of alternatives used HEC-FIA with 1 % annual chance exceedance (ACE) depth grids in conjunction with HAZUS-MH data to determine without and with-project economic damages, the analysis for evaluating the final array would incorporate a risk-based analysis in compliance with ER-1105-2-101. The following describes the reaches that were established for evaluating the final array.

1.3.1 Orange-Jefferson CSRM

The initial configuration of new levees was based on alignments from the Orange County Flood Protection Planning Study (Orange Report), completed in 2012. Refinement of the alignments was made in some areas to increase potential benefits, reduce costs, and reduce potential

environmental impacts, and to protect critical infrastructure. Without-project storm surge values were used to optimize levee heights and further refinement of the alignment for identification of the National Economic Development (NED) Plan and TSP. As part of the identification of the NED and TSP, analysis was conducted to determine levee sections that are incrementally justified. Alternatives analysis was based on utilizing the without-project surge elevations and frequencies. Without-project storm surge and waves were based on previous work by FEMA and revised to current joint probability method – optimum sampling (JPM-OS) methods to the appropriate ACE values. Figure 1-1 displays the initial configuration to be evaluated for these new levees at Jefferson and Orange Counties following the exclusion of the Neches Gate from further consideration. The system was set up with three major components based on their location. The following lists the major features.

- Orange 1 – 3
- Jefferson Main
- Beaumont A – C

The Orange component runs along the north side of the Neches River and was divided into three sections; Orange 1 on the western end that primarily protects Rose City, Orange 2 which begins just east of Rose City and ends roughly halfway between Rose City and Bridge City, and Orange 3 which encompasses the remainder of the Orange County component. Orange 1 consists of approximately 27,000 linear feet (LF) of levee and 16,500 LF of floodwall (total of 8.2 miles). Orange 2 consists of approximately 34,600 LF of levee (6.6 miles), while Orange 3 consists of a combination of 113,600 LF of levee and 29,800 LF of floodwall (total of 27 miles).

The Jefferson Main component consists of approximately 41,700 LF of levee and 16,200 LF of floodwall (11 miles). Beaumont A is combination of 3,100 LF of levee and 200 LF of floodwall (0.6 mile). Beaumont B is 2,500 LF of levee (0.5 mile) and Beaumont C is 6,800 LF of levee (1.3 mile).

1.3.2 Port Arthur and Vicinity CSRM

The draft findings of the Semi-Quantitative Risk Assessment (SQRA) for the Freeport system (to be discussed next) were applied to the plan formulation for the Port Arthur because one has not yet been done for this system. For the Port Arthur system, the detailed description of the needs is similar to what will be presented in the Freeport HFPS section. However, the Port Arthur system is different because there are no known deferred maintenance issues for the Port Arthur system at this time.

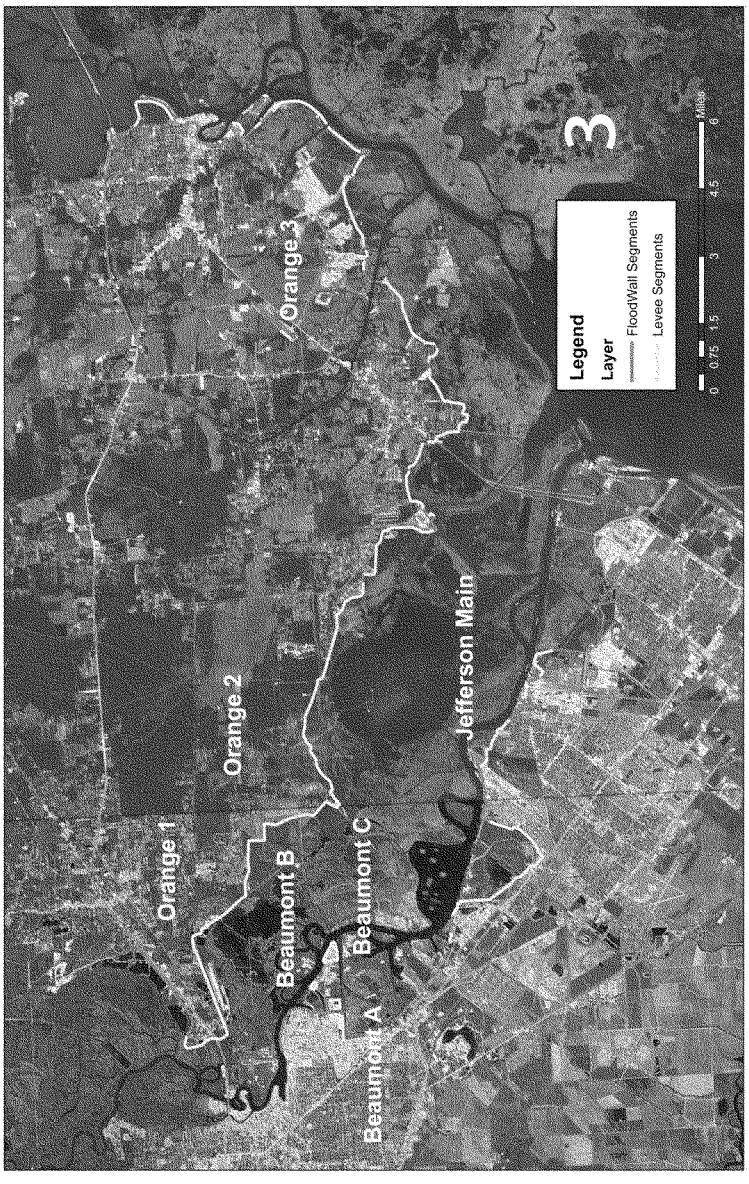


Figure 1-1. Configuration of the Orange-Jefferson CSRM

The formulation of alternatives for the Port Arthur and Vicinity CSRM began with defining reaches for the system. These were based on the failure locations identified by the levee safety program in the absence of a SQRA. Figure 1-2 displays the Port Arthur HFPS failure locations. These locations were included in formulation where improvements would positively impact the system's capacity for protection. The following lists the reaches at Port Arthur.

- Port Arthur 8feet-10feet I-Wall
- Port Arthur Closure Structure
- Port Arthur I-Wall Near Valero
- Port Arthur I-Wall Near Tank Farm

1.3.3 Freeport and Vicinity CSRM

The draft findings of the SQRA for the Freeport system show vulnerabilities primarily associated with floodwall and levee overtopping. Other performance issues identified during the SQRA were the result of deferred local sponsor maintenance, or alterations that local industrial stakeholders have constructed over time. Floodwall performance issues, at locations where the originally constructed floodwall is still in place and has been operated and maintained in an acceptable manner, are being evaluated to include stability and resiliency. Levee reaches that are non-uniform in height or otherwise susceptible to concentrated overtopping erosion during an event are being evaluated for raising or armoring to reduce the likelihood of breach.

The formulation of alternatives for the Freeport and Vicinity CSRM began with defining reaches for the system. These were based on the failure locations identified in the SQRA (Figure 1-3). These locations were then narrowed during formulation to those locations where improvements would positively impact the system's capacity for protection and to reduce any redundancies. For example, improvements to the Dow Barge Canal would negate any failures at the Dow Turning Basin. The following is the resulting list of reaches at the Freeport and Vicinity CSRM.

- Dow Barge Canal
- East Storm Levee
- Freeport Dock
- Old River at Dow Thumb
- Oyster Creek Levee
- South Storm Levee
- Tide Gate I-Wall

Figure 1-2. Port Arthur and Vicinity CSRM

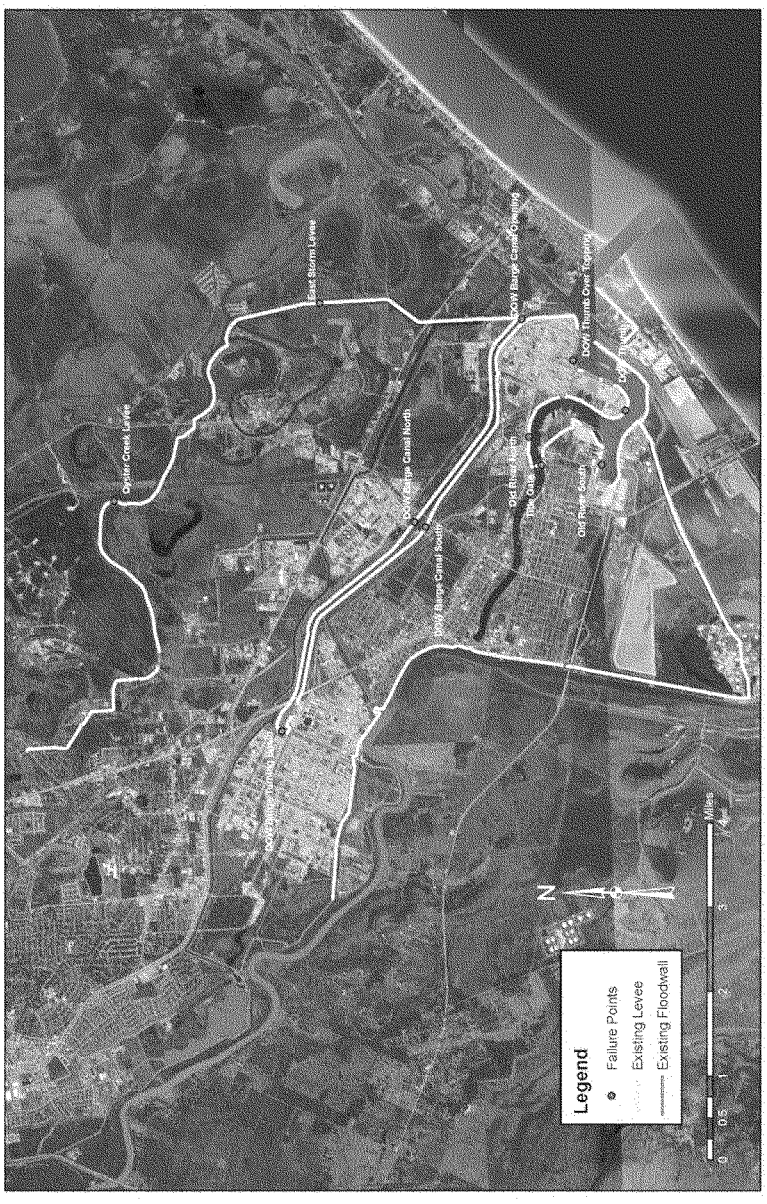


Figure 1-3. Freeport and Vicinity CSRM

2 HEC-FDA ANALYSIS

Note: Sections 2.1 to 2.8 describes the HEC-FDA ANALYSIS used for alternative development, formulation, and evaluation processes that led to the identification of the TSP. The information contained herein was presented in the Sept 11, 2015 DIFR-EIS that was released for public review. Changes to the TSP have occurred since that public review which are briefly described explained in Section 2.9. The changes to the TSP resulted in the Recommended Plan presented in this final section.

2.1 ENGINEERING INPUTS

2.1.1 Stage-Probability Relationships

Water surface profiles representing stage-probability functions were imported into HEC-FDA utilizing data from Advanced Circulation model (ADCIRC) points for without-project storm surge and waves. This sub-set of 62 total storms (based on previous FEMA work and revised by ERDC using subject matter expertise for storms having the most effect on stage-frequency) was used in the revised to current JPM-OS simulation technique for the appropriate ACE values analysis. Mean water level, wave height and wave period responses were defined for each of the modeled return periods. In the absence of a Hydrologic Engineering Centers River Analysis System (HEC-RAS) stationing scheme which would also use a stage-discharge function, those ADCIRC points falling closest to the location of the levee/floodwall footprint were used to develop average ACE values for the seven events modeled by ERDC. For the existing Port Arthur and Freeport HFP systems, ADCIRC points representing average still water levels closest to the failure locations were used to quantify damages. An equivalent record length (15 years) for each study reach was used to generate a stage-probability relationship with uncertainty for the without-project and the with-project alternatives through the use of graphical analysis based on the appropriate gage data. A sensitivity analysis on the 0.1 percent modeled points found a consistent one standard deviation difference of 2.1 feet for the Freeport Region and 2.0 feet difference for the Sabine region. Stage/probability functions entered into HEC-FDA using the fifteen year period of record found the average difference for one standard deviation to be 1.64 for Jefferson, 1.8 feet for Orange, and 2.17 feet for Port Arthur. The average difference for Freeport was 3.18 feet. Increasing the period of record resulted in actual increases in the difference between the stated stage and the subsequent one standard deviation. Based on the fact that the storms ERDC used for modeling all occurred within the historical period of the last fifteen years and considering the results from analyzing the variation between data modeled by ERDC and what was entered into HEC-FDA, the fifteen year period of record is appropriate. The model used the eight stage-probability events together with the equivalent record length to define the full range of the stage-probability or stage-probability functions by interpolating between the data points. Values for the 0.999 and 0.5 percent ACE were

set at 0.25 and 1.0 feet respectively in order to make HEC-FDA operational. Table 2-1 lists these values used for each region. The ADCIRC points for the Orange-Jefferson CSRM are shown in Figure 2-1. Points for the Port Arthur CSRM are shown in Figure 2-2 and the ADCIRC points for the Freeport CSRM are in Figure 2-3.

Still water levels were used to compare the economic efficiency of the alternatives. Once the recommended plan is determined, wave run-up and overtopping will be analyzed at specific system locations in conjunction with any necessary interior drainage analysis. The horizontal and vertical datums used in the engineering inputs are referenced to North American Datum (NAD) of 1983.

Table 2-1. Average Still Water Elevations at HEC-FDA Index Point

Orange-Jefferson

Exceedance Probability/Reach	*0.1 ACE*	*0.05 ACE*	*0.02 ACE*	*0.01 ACE*	*0.005 ACE*	*0.002 ACE*	*0.001 ACE*
Orange 1	3.62	5.05	6.69	7.76	8.66	9.66	10.35
Orange 2	3.6	5.36	7.24	8.52	9.6	10.77	11.57
Orange 3	2.78	4.25	6.11	7.51	8.64	9.81	10.57
Beaumont A	2.92	4.26	6	7.25	8.47	9.73	10.51
Beaumont B	2.71	3.88	5.62	6.86	7.94	9.07	10.34
Beaumont C	3.55	5.1	6.85	8.02	9	10.1	10.85
Jefferson Main	3.08	4.63	6.31	7.49	8.47	9.51	10.22

Port Arthur

Exceedance Probability/Reach	*0.1 ACE*	*0.05 ACE*	*0.02 ACE*	*0.01 ACE*	*0.005 ACE*	*0.002 ACE*	*0.001 ACE*
8ft-10ft I-Wall	2.85	4.31	6.98	9.25	10.94	12.68	13.81
Closure Structure	3.45	5.01	6.9	8.2	9.3	10.46	11.2
I-Wall Near Valero	3.87	5.97	8.47	10.47	12.61	14.77	16.08
I-Wall Near Tank Farm	3.77	5.72	8.1	9.99	12.02	14.08	15.31

Freeport Region

Exceedance Probability/Reach	*0.1 ACE*	*0.05 ACE*	*0.02 ACE*	*0.01 ACE*	*0.005 ACE*	*0.002 ACE*	*0.001 ACE*
South Storm Levee	4.21	6.68	9.59	11.63	13.71	16.31	17.93
Old River levee at Dow Thumb	4.43	7.08	10.15	12.41	14.69	17.43	18.97
Freeport Dock	4.47	7.17	10.3	12.63	14.97	17.79	19.38
Tide Gate	4.46	7.18	10.32	12.65	15.02	17.9	19.52
East Storm Levee	5.08	7.81	11.05	13.38	15.55	17.99	19.5
Dow Barge Canal	4.6	7.46	10.82	13.28	15.76	18.55	20.12
Oyster Creek	4.44	8.49	12.21	14.63	16.62	18.77	20.19

2.1.2 Fragility Curves

Fragility curves (the relationship between water surface stage on the exterior side of the levee versus the probability of levee failure) were developed based on the use of average still water levels for damage estimates. Fragility curves for the Freeport HFP system were initially developed as a result of the Freeport SQRA and were modified slightly due to the use of average still water levels for damage estimates. A similar approach was used for the development of the curves for the Port Arthur system. These curves for the Port Arthur and Freeport systems are listed in Tables 2-2 and 2-3, respectively. These fragility curves assume that all O&M is current and will be accomplished before implementing the Recommended Plan..

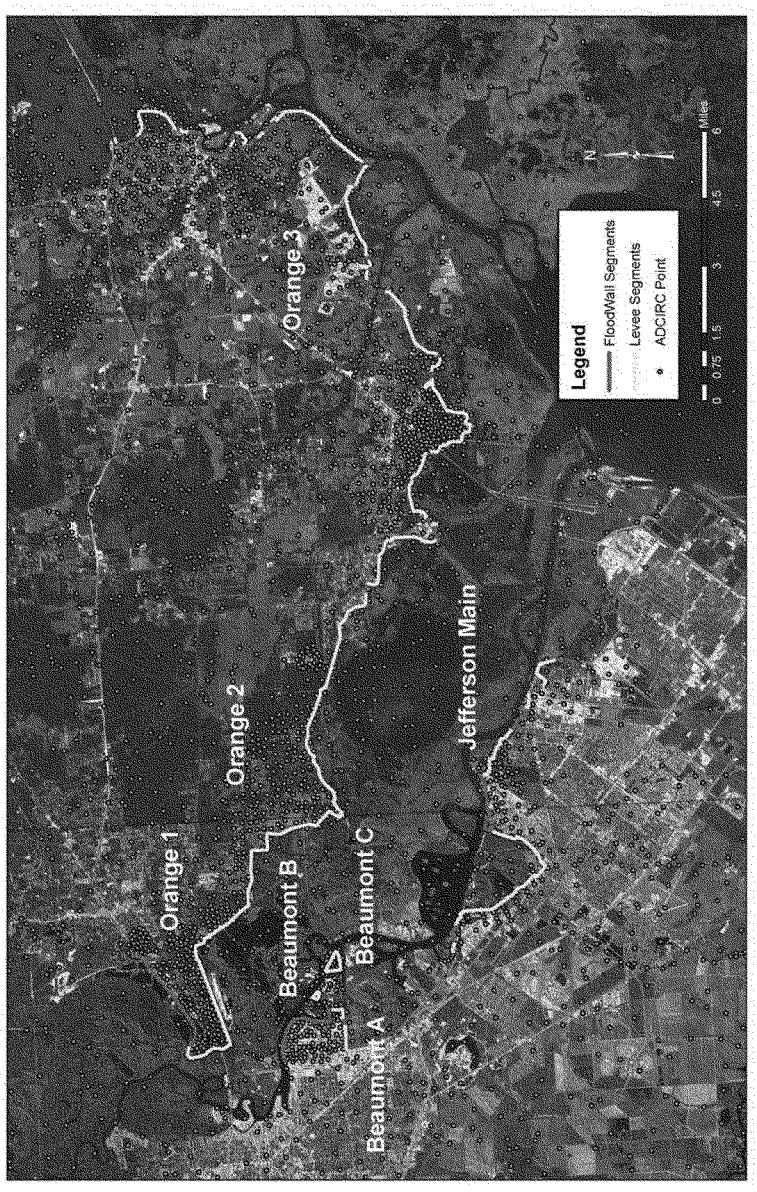


Figure 2-1. ADCIRC Points Orange-Jefferson CSRM

Figure 2-2. ADCIRC Points in Port Arthur and Vicinity CSRM

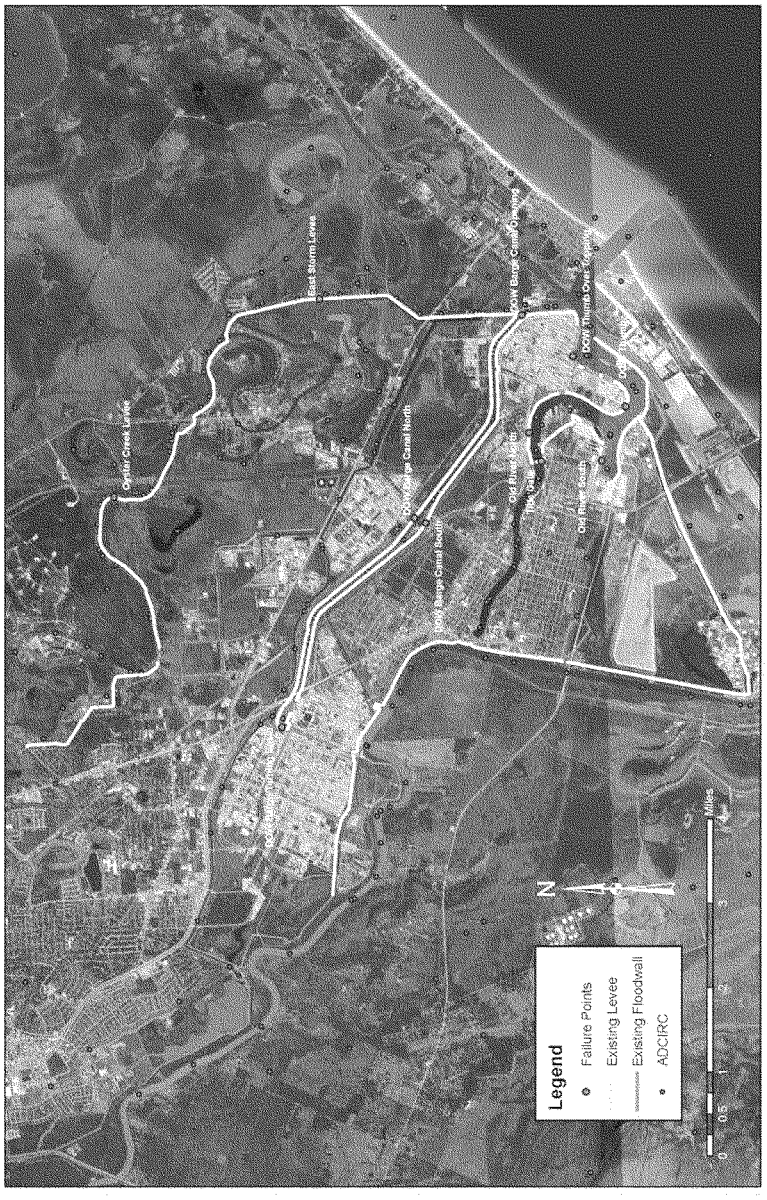


Figure 2-3. ADCIRC Points in Freeport and Vicinity CSRM

Table 2-2. Fragility Curves for Port Arthur and Vicinity CSRM

Stage	Tank Farm	8ft-10ft I-Wall	I-Wall Near Valero	Closure Structure
14	-	0.10	-	-
14.5	-	0.28	0.10	0.20
15	0.20	0.45	0.50	0.40
15.5	0.35	0.63	0.70	0.60
16	0.50	0.80	0.90	0.90
16.5	0.90	0.90	0.92	0.95
17	1.00	1.00	0.93	1.00
17.5	-	-	0.95	-
18	-	-	0.97	-
18.5	-	-	0.98	-
19	-	-	1.00	-

Table 2-3. Fragility Curves for Freeport and Vicinity CSRM

Stage	Dow Barge Canal	East Storm	Oyster Creek Levee	Freeport Dock	Tide Gate I-Wall	Old River at Dow Thumb
10.5	-	-	0.03	-	0.04	0.04
11	-	-	0.06	-	0.08	0.08
11.5	-	-	0.1	-	0.11	0.11
12	-	-	0.13	-	0.15	0.15
12.5	-	-	0.16	0.05	0.19	0.19
13	-	-	0.19	0.75	0.23	0.23
13.5	-	-	0.23	1.00	0.26	0.26
14	-	-	0.26	1.00	0.3	0.3
14.5	-	0.08	0.29	1.00	0.34	0.34
15	-	0.15	0.32	1.00	0.38	0.38
15.5	-	0.23	0.35	-	0.41	0.41
16	-	0.3	0.39	-	0.45	0.45
16.5	-	0.38	0.42	-	0.6	0.68
17	-	0.45	0.45	-	0.75	1.00
17.5	-	0.54	0.68	-	1.00	-
18	-	0.63	1.00	-	-	-
18.5	-	0.72	-	-	-	-
19	-	0.81	-	-	-	-
19.5	-	1.00	-	-	-	-
20	-	-	-	-	-	-
20.5	0.11	-	-	-	-	-
21	0.23	-	-	-	-	-
21.5	0.34	-	-	-	-	-
22	0.45	-	-	-	-	-
22.5	0.53	-	-	-	-	-
23	0.6	-	-	-	-	-

Table 2-3, continued

23.5	0.68	-	-	-	-	-
24	0.75	-	-	-	-	-
24.5	0.83	-	-	-	-	-
25	1.00	-	-	-	-	-

2.2 ECONOMIC INPUTS

2.2.1 Ground Elevations

Centroids were created for each parcel to represent the structures associated with that parcel. Ground elevations were derived from data processed using U.S. Geological Survey Digital Elevation Model (DEM) 0.05m elevation data for the appropriate Gulf Coast Counties. These data were obtained from Texas Natural Resources Information System (TNRIS). Residential structures in inland areas generally received a 0.5-foot floor correction (some areas were raised 1 to 1.5 feet) while many of the coastal areas received much higher raises as appropriate. Industrial, commercial, and public structures received floor corrections from 0 to 5 feet. The point at which damages for many high-value industrial and commercial structures is reflected in the ground elevation making floor correction was necessary. These floor corrections assumptions were verified through spot checks utilizing Google Earth and Google Street View. The horizontal and vertical datums used in the economic inputs are referenced to North American Datum (NAD) of 1983 or North American Vertical Datum (NAVD) of 1988.

2.2.2 Structure Inventory

All three study areas can be described as being relatively fully developed. As discussed under the study area demographics, Brazoria is expected to be the one county among the three that is expected to grow at a rate outpacing the State. Orange and Jefferson Counties are expected to grow at rates well below that of the State of Texas. For the purpose of this analysis, housing stock is assumed to remain relatively constant over the period of analysis. Since commercial and industrial make up a substantial amount of the structure inventory, those developments that are expected to come online with a reasonable amount of certainty and in the relatively near future are include in the inventory. The structure inventory was derived from data obtained from each of the appropriate appraisal districts for the 2015 tax appraisal year (Table 2-4). These data were adjusted to reflect a replacement cost less depreciation value. Due to tax abatements and incentives given to large industrial developers and due to the competitive nature of the petrochemical industry in the region, many high-value industrial and commercial properties are not listed on the tax appraisal rolls. In these instances, square footage values were developed from those properties that were listed on the tax rolls based on square footage values of similar structures from appraisal data. Therefore, a certain amount of uncertainty exists for these values in many cases, which could lead to an over- or underestimation of damages. Values to reflect replacement minus depreciation were

calculated using Marshall and Swift Commercial and Residential Estimator based on information contained within the appraisal district data including structure type, age, square footage, building materials, and condition on a random selection of both residential and non-residential structures on the following the TSP milestone. Samples were taken for each of the residential and non-residential damage categories based on the depth/damage function applied to the specific structures. These adjustments were then averaged and applied to the appropriate damage category. Residential structures were adjusted by 24.4 percent and non-residential structures were adjusted by 14.6 percent. Two separate structure files with a high degree of overlap were created for the system since failures would impact slightly different numbers of structures. One structure file was used for a failure at the Dow Barge Canal and another for the remaining reaches. The following tables and figures depict the structure files used in the damage analyses. Parcels representing the structures at risk for the Orange-Jefferson CSRM are in Figure 2-4, while the parcels representing the structures at risk for the Port Arthur and Freeport CSRM are in Figures 2-5, 2-6, and 2-7 respectively.

Table 2-4. Structure and Content Values of Inventoried Structures by CSRM and Type 2015 Price and Development Levels

Orange-Jefferson CSRM

Orange County				
Category Name	**Count**	**Structure Value**	**Content Value**	**Total**
Commercial	268	$109,778,000	$109,203,000	$218,981,000
Industrial	20	$1,711,063,000	$1,711,061,000	$3,422,124,000
Multi-Family	193	$23,828,000	$23,828,000	$47,656,000
Mobile	699	$10,573,000	$10,573,000	$21,146,000
Public	214	$76,324,000	$83,913,000	$160,237,000
Vehicles	16,045	$200,448,000	$0	$200,448,000
Single-Family	12,734	$1,038,476,000	$1,038,443,000	$2,076,919,000
Grand Total	30,173	$3,170,490,000	$2,977,021,000	$6,147,511,000
Jefferson County				
Category Name	**Count**	**Structure Value**	**Content Value**	**Total**
Commercial	893	$319,062,000	$431,769,000	$750,831,000
Industrial	22	$662,341,000	$827,820,000	$1,490,161,000
Multi-Family	226	$186,264,000	$186,264,000	$372,528,000
Public	140	$124,284,000	$136,882,000	$261,166,000
Vehicles	15,954	$167,781,000	$0	$167,781,000
Single-Family	12,662	$2,539,056,000	$2,538,915,000	$5,077,971,000
Grand Total	29,897	$3,998,788,000	$4,121,650,000	$8,120,438,000

Port Arthur and Vicinity CSRM

Category Name	Count	Structure Value	Content Value	Total

Commercial	1,152	$5,190,935,000	$8,777,567,000	$13,968,502,000
Industrial	9	$201,486,000	$338,497,000	$539,983,000
Multi-Family	269	$69,382,000	$69,382,000	$138,764,000
Public	452	$217,266,000	$228,574,000	$445,840,000
Vehicles	26,431	$350,231,000	$0	$350,231,000
Single-Family	20,977	$1,911,200,000	$1,911,068,000	$3,822,268,000
Grand Total	43,968	$7,869,963,000	$11,325,088,000	19,265,588,000

Freeport and Vicinity CSRM

Dow Barge Canal				
Category Name	**Count**	**Structure Value**	**Content Value**	**Total**
Commercial	903	$117,426,000	$156,275,000	$273,701,000
Industrial	45	$5,557,849,000	$9,339,639,000	$14,897,488,000
Multi-Family	375	$68,916,000	$69,123,000	$138,039,000
Mobile	6	$135,000	$135,000	$270,000
Public	207	$225,032,000	$248,092,000	$473,124,000
Vehicles	8,832	$185,858,000	$0	$185,858,000
Single-Family	8,826	$377,405,000	$377,572,000	$754,977,000
Grand Total	19,194	$6,532,621,000	$10,190,836,000	$16,723,457,000

Lower Reaches				
Category Name	**Count**	**Structure Value**	**Content Value**	**Total**
Commercial	244	$39,019,000	$30,565,000	$69,584,000
Industrial	5	$13,383,000	$22,406,000	$35,789,000
Multi-Family	117	$13,168,000	$13,168,000	$26,336,000
Public	76	$28,620,000	$29,784,000	$58,404,000
Vehicles	2,323	$38,847,000	$0	$38,847,000
Single-Family	1,844	$74,744,000	$74,744,000	$149,488,000
Grand Total	4,609	$207,781,000	$170,667,000	$378,448,000

2.2.3 Vehicle Inventory

The number of vehicles associated with a residence was estimated based on the average number of vehicles per residence characteristic of the study area, and the probability of their being present at the time of a flood. This value is 1.26 vehicles per residence. Values were based on the national average price of new and used vehicles as reported by the U.S. Bureau of Transportation Statistics (BTS) prices for new vehicles. The most recent price reported by BTS is $13,105. Adjusting this value based on the percent difference in median income for each county compared to the median income for the U.S., the resulting value for Orange County vehicles was set at $15,411 and $13,251 for Jefferson County. Vehicle values for Brazoria were set at $21,044.

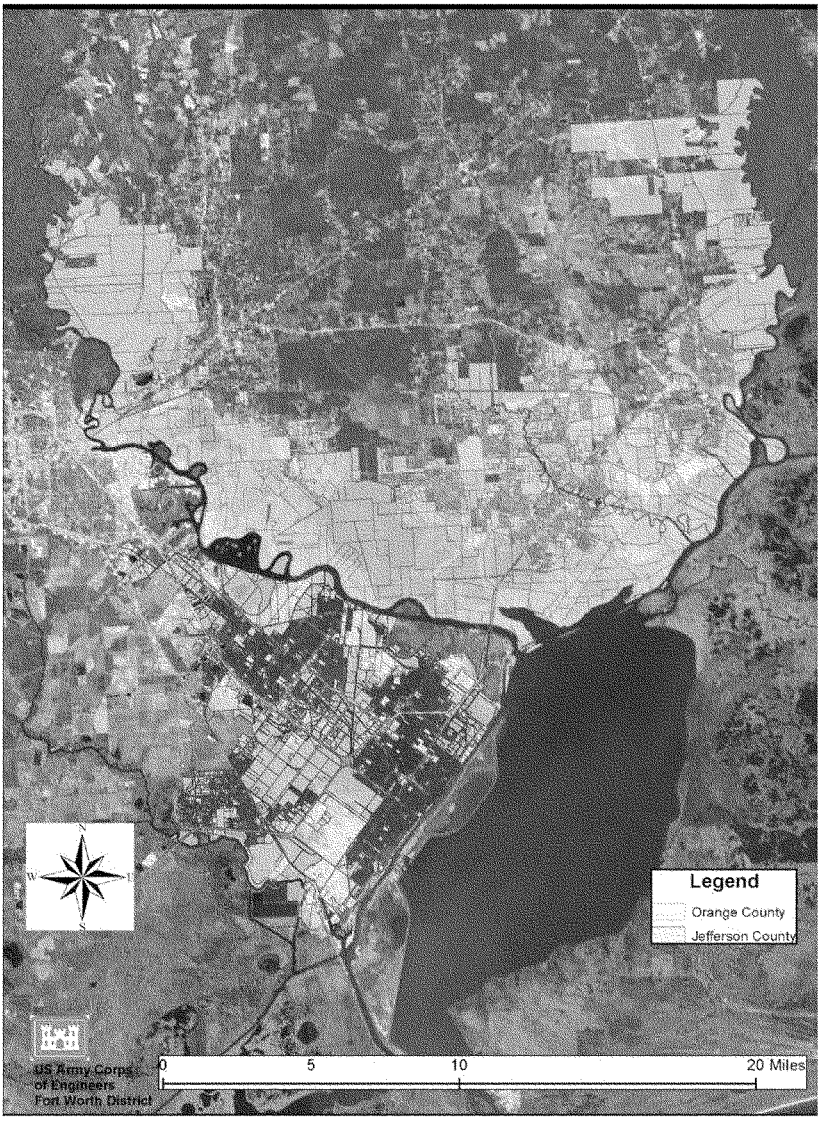


Figure 2-4. Orange-Jefferson CSRM Structures at Risk (Parcels)

Figure 2-5. Port Arthur and Vicinity CSRM Structures at Risk

Figure 2-6. Freeport and Vicinity CSRM Structures at Risk – Dow Barge Canal Reach

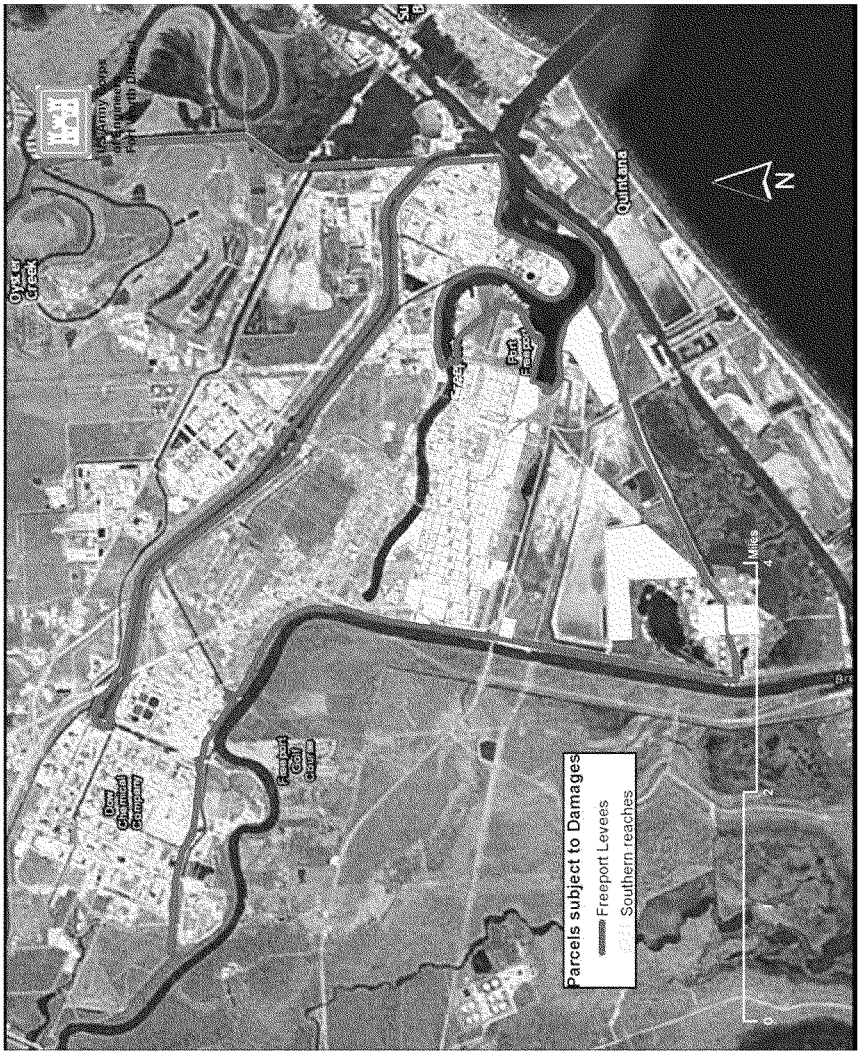


Figure 2-7. Freeport and Vicinity CSRM Structures at Risk – Remaining Reaches

2.2.4 Depth-Damage Functions

Depth-damage functions were obtained from the New Orleans District from the *Lower Atchafalaya and Morganza to the Gulf, Louisiana, Feasibility Study*. These functions reflect saltwater inundation for short durations. The following table lists the functions covering the following structure types and also the content-to-structure value ratio (CSVR) along with the uncertainties associated with the structure content values and the first-floor corrections. Uncertainties assumed a normal distribution (with the exception of vehicles which assumes a triangular distribution) and were based on coefficient of variation calculations for each of the sources of uncertainty and were also based on historic knowledge gleaned from based studies in the region.

These functions were used primarily since they addressed the incidence of inundation from saltwater for short durations and because these damage functions, while not derived from locally oriented data, were more reflective current building guidelines and potential damage estimation. Graphical representations for these for these functions are depicted at the end of this appendix.

Table 2-5. Depth-Damage CSVR, and Uncertainties.

Name	Description	CSVR (%)	Struc. Unc. (%)	Cont. Unc. (%)	FF Unc. (ft.)
1STY-SLAB	One-Story Single -Family Residential Slab Foundation	71	7.5	24	0.70
2STY-PIER	Two-Story single -Family Residential Pier and Beam Foundation	50	7.5	30	0.70
AUTO	Automobiles	0	15.4-21	0	0.55
EAT	Restaurants	428	17.97	36	0.66
GROC	Grocery Stores	128	6.6	98	0.70
MOBHOM	Mobile Homes	148	7.5	69	0.79
MULT	Multi-Family Residential	23	6.6	29.38	0.53
PROF	Professional Businesses	78	8.67	193.4	0.57
PUBL	Public & Semi Public Structures	82	6.5	71.4	0.70
REPA	Repairs & Home Use	251	5.98	62.2	0.71
RETA	Retail & Personal Services	148	13.37	39.7	0.62
WARE	Warehouse & Contractor Services	372	8.72	194.6	0.57
RESEMERG	Residential Emergency Cleanup Costs	-	13	-	0.70
COMEMERG	Commercial Emergency Cleanup Costs	-	20	-	0.65
HWY	Damage to Highways	-	-	-	0.55
RAILROAD	Damage to Railroads	-	-	-	0.80
STREETS	Damage to Streets	-	-	-	0.75

630

2.3 FUTURE WITHOUT-PROJECT STRUCTURE AND CONTENT DAMAGES

2.3.1 Methodology Overview

The methodology employed for this economic analysis is in accordance with current principles and guidelines and standard economic practices, as outlined in the Planning Guidance Notebook – ER 1105-2-100. Economic analysis is conducted at a given price level using the current Federal discount rate and a period of analysis of 50 years. Per the Planning Guidance Notebook, flood events will be expressed in probabilistic terms rather than the classic "x-Year" event. For example, the 100-Year event will be called a 1 percent ACE (equivalent to the HEC-FDA term Annual Exceedance Probability Event). Other equivalent probabilities can be obtained by dividing 1 by the year occurrence interval; the 500-year event is 1/500 = 0.2 percent ACE, and so forth.

A risk-based analysis (RBA) procedure has been used to evaluate without-project flood damages in the study area. Guidance for conducting RBA is included in Corps Engineering Regulation 1105-2-101, Risk-Based Analysis for Evaluation of Hydrology/Hydraulics, Geotechnical Stability and Economics in Flood Damage Reduction Studies (January 3, 2006).

The guidance specifies that the derivation of expected annual flood damage must take into account the uncertainty in hydrologic, hydraulic, and economic factors. Risk and uncertainty are intrinsic in water resource planning and design. They arise from measurement errors and the inherent variability of complex physical, social and economic situations. Best estimates of key variables, factors, parameters and data components are developed, but are often based on short periods of record, small sample sizes, measurements subject to error, and innate residual variability in estimating methods. RBA explicitly and analytically incorporates these uncertainties by defining key variables in terms of probability distributions, rather than single-point estimates. The focus of RBA is to concentrate on the uncertainties of variables having the largest impact on study conclusions.

The following are the primary sources of uncertainty for coastal storm damage analysis studies along with a discussion of the uncertainties associated with each of these sources.

- Stage/Probability – Uncertainty in the stage/probability curves are addressed by utilizing graphical exceedance probability functions which sets confidence limits for discharges at each discrete exceedance probability based on the equivalent record length. Uncertainties is also addressed by assigning distributions to stage-damage functions. In the case of this

study, the equivalent record length is set at 15 years and the error for the stage-damage functions is set at 0.5 feet.

- Geo-technical Features – Fragility curves were developed for the two existing HFPSs from either completed or draft SQRAs conducted by a risk cadre in accordance to ER 110-2-1156 for various identified breach locations on each of the two systems. These curves were developed as part of the reevaluation of the initial SPRAs at each system. These curves were developed to a much higher definition than is typically done for flood-risk analysis in HEC-FDA. No uncertainties were assigned to the fragility curves themselves since HEC-FDA has no way of entering any uncertainty parameters.
- Structure Elevation – Stated earlier, USGS DEM 0.05m elevation data was obtained from TNRIS and used for ground elevations with the observed foundation elevations added to ground elevation for the first-floor elevations. Uncertainties based on calculated coefficients of variation produced first-floor errors ranging from 0.493 to 0.788 feet depending on structure type.
- Structure and Content Values – Uncertainties for structure and content values are based on calculated standard deviations by structure type. These standard deviations are expressed in terms of percentages and range anywhere from 6.5 to almost eighteen percent for structure values and range from 30 to almost 195 percent for content-to-structure ratios.
- Inundation Depth/Percent Damage – Depth/Damage functions were obtained from the New Orleans District and are based on a triangular probability density functions using minimum, maximum, and most likely estimates for the damage percentage at various stages based on the input from a panel of experts. These estimates were generated for the District's *Lower Atchafalaya and Morganza to the Gulf, Louisiana, Feasibility Study*. These curves are displayed in the back of this appendix.

The Army Corps of Engineers Hydrologic Engineering Center has developed software specifically designed for conducting risk based analysis, referred to as the HEC-FDA Program. Version 1.2.5 was used for this analysis with the exception of the final recommended plan which was run in Version 1.4. This program applies Monte Carlo simulation process, whereby the expected value of damages is determined explicitly through a numerical integration technique accounting for uncertainty in the basic parameters described above. For this analysis, the number of Monte Carlo simulations is set at 100 with the minimum and maximum number of intervals set at 20 and 30 respectively. Data requirements for the program include:

- Structure data, including structure I.D., category (single or multi-family residential, commercial, industrial, and public), stream location, ground and/or first floor elevation, structure value and content value. These data were developed in a Microsoft Excel spreadsheet and imported into the HEC-FDA program

- Hydrologic and hydraulic data, including water surface profiles and stage/probability relationships
- Depth-Damage functions

2.3.2 Future Without-Project Condition Expected Annual Damages

Estimates of Expected Annual Damages (EAD) under future without-project conditions were calculated, using the risk and uncertainty model, through integration of frequency-damage data. The future expected annual damages shown here are projected over the project life of 50 years. Table 2-6 shows a breakdown of where these damages are predicted to occur for each CSRM. Tables 2-7, 2-8, and 2-9 break down the number of structures by event in each reach of the three project areas along with the corresponding still water level for that event.

For the Orange 1, Orange 2, and Orange 3 alternative reaches, significant damages start at approximately the 1 percent ACE; the depth of flooding at the 1 percent ACE is approximately 8 feet. In the Jefferson Main alternative reach, significant damages start between the 2 percent and 1 percent ACE; the depth of flooding between the 2 percent and 1 percent ACE is approximately 6.5 feet and 7.5 feet. For the Beaumont A, Beaumont B and Beaumont C the significant damages start at the 1 percent ACE; the depth of flooding is approximately 7.5 feet.

The estimated start of damages for the Port Arthur and Vicinity alternative reaches is approximately 15 feet, which corresponds to an estimated high probability of failure of the existing HFPS based on the fragility curves. Flooding depths approximate the stage on the exterior side of the existing HFPS, and goes up to approximately 14 feet for the 0.1 percent ACE.

The estimated start of damages for the Freeport and Vicinity alternative reaches is approximately 15 feet, which corresponds to an estimated high probability of failure of the existing HFPS based on the fragility curves. Flooding depths approximate the stage on the exterior side of the existing HFPS, and goes up to approximately 19 feet for the 0.1 percent ACE.

2.4 ALTERNATIVE ANALYSIS

2.4.1 Orange-Jefferson CSRM

As agreed at the Alternative Milestone Meeting (AMM), future without-project (FWOP) damages were run with a rough order of magnitude costs to identify NED benefits. Costs representing a linear foot in both length and height for both levees and floodwalls were developed. The costs per linear foot of levee were estimated at $237.50 and floodwalls were estimated at $475.00. These costs included contingency, engineering and design, and constriction management. Real estate

costs were also included with commercial and residential estimates of $100,000 per acre, industrial at $70,000 per acre, undeveloped land at $9,000 per acre, and marsh at $750. Operation, Maintenance, Repair, Replacement and Rehabilitation

Table 2-6. Equivalent Annual Damages Future Without-Project Condition (2015 price level) (FY 2015 Price Level/3.375 percent interest rate)

	Damage Categories							
Reach	**Commercial**	**Industrial**	**Multifamily**	**Mobile**	**Public**	**POV**	**SFR**	**Total**
Orange Jefferson CSRM								
Orange 1	$73,000	$0	$0	$7,000	$10,000	$33,000	$190,000	$312,000
Orange 2	$0	$0	$0	$4,000	$0	$10,000	$54,000	$68,000
Orange 3	$21,833,000*	$0	$93,000	$98,000	$409,000	$969,000	$6,585,000	$29,987,000
Beaumont A	$0	$6,937,000	$0	$0	$0	$0	$0	$6,937,000
Beaumont B	$0	$23,000	$0	$0	$0	$0	$0	$23,000
Beaumont C	$0	$262,000	$0	$0	$0	$0	$0	$262,000
Jefferson Main	$4,600,000	$929,000	$4,834,000	$0	$1,824,000	$536,000	$15,509,000	$28,231,000
Port Arthur CSRM								
8ft-10ft I-Wall	$19,302,000	$560,000	$83,000	$0	$368,000	$275,000	$2,824,000	$23,413,000
Closure Structure	$3,128,000	$86,000	$13,000	$0	$59,000	$44,000	$453,000	$3,784,000
I-Wall Near Valero	$50,798,000	$1,587,000	$228,000	$0	$975,000	$726,000	$7,553,000	$61,867,000
I-Wall Near Tank Farm	$31,139,000	$1,012,000	$143,000	$0	$599,000	$446,000	$4,670,000	$38,009,000
Freeport CSRM								
Dow Barge Canal	$3,070,000	$145,903,000	$884,000	$2,000	$4,815,000	$3,088,000	$8,897,000	$166,660,000
East Storm Levee	$346,000	$247,000	$99,000	$0	$233,000	$191,000	$587,000	$1,701,000
Freeport Dock	$768,000	$583,000	$217,000	$0	$549,000	$456,000	$1,387,000	$3,960,000
Old River at Dow Thumb	$489,000	$367,000	$139,000	$0	$349,000	$290,000	$882,000	$2,517,000
South Storm Levee	$52,000	$37,000	$15,000	$0	$35,000	$28,000	$87,000	$254,000
Tide Gate I-Wall	$541,000	$406,000	$154,000	$0	$387,000	$321,000	$977,000	$2,785,000
Oyster Creek	$744,000	$553,000	$211,000	$0	$526,000	$436,000	$1,329,000	$3,800,000

*Most of these commercial values are actually associated with industrial facilities. These were corrected in later analyses

Table 2-7. Structures and Damages by Event for Orange-Jefferson CSRM
(FY 2015 Price Level, $1,000)

Orange 1														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	3.62		5.05		6.69		7.76		8.66		9.66		10.35	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	0	$0	1	$469	1	$939	1	$1,150	1	$1,229	1	$1,288	7	$1,733
Industrial	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
MultiFamily	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Mobile	2	$24	2	$35	7	$49	7	$69	8	$74	8	$93	19	$326
Public	0	$0	0	$0	2	$49	2	$285	2	$317	2	$410	4	$765
Vehicles	0	$0	11	$139	13	$185	72	$543	81	$1,134	87	$1,251	202	$1,322
Single-Family	2	$262	14	$675	23	$1,473	82	$3,581	92	$4,818	98	$5,899	232	$9,989
Grand Total	4	$286	28	$1,318	46	$2,695	164	$5,629	184	$7,572	196	$8,942	464	$14,136

Orange 2														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	3.60		5.36		7.24		8.51		9.60		10.77		11.57	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	0	$0	0	$0	1	$0	1	$1	1	$1	1	$1	1	$1
Industrial	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Mobile	0	$0	0	$0	4	$61	4	$63	4	$77	11	$301	11	$317
Public	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Vehicles	0	$0	3	$31	15	$46	16	$244	18	$270	40	$277	42	$607
Single-Family	1	$3	3	$123	15	$676	17	$999	17	$1,264	35	$2,460	36	$2,906
Grand Total	1	$3	6	$154	35	$783	38	$1,307	40	$1,612	87	$3,038	90	$3,831

Orange 3														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	2.78		4.25		6.11		7.51		8.64		9.81		10.57	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.

Commercial	0	$0	3	$2,832	4	$7,667	42	$15,849	48	$22,486	51	$31,342	198	$58,526
Industrial	0	$0	1*	$52,625	1*	$139,876	6*	$505,494	6*	$800,283	6*	$1,169,796	8*	$1,572,382
MultiFamily	0	$0	3	$32	3	$72	99	$2,702	102	$4,354	111	$6,810	180	$10,380
Mobile	0	$0	20	$385	23	$565	167	$2,769	173	$2,960	185	$3,489	385	$7,415
Public	2	$0	5	$36	6	$61	70	$10,642	76	$20,067	79	$26,546	166	$48,532
Vehicles	8	$105	267	$170	319	$4,563	3,157	$5,319	3,345	$49,671	3,506	$52,245	9,180	$54,070
Single-Family	11	$772	287	$15,608	347	$27,250	3,247	$171,623	3,404	$236,983	3,621	$294,110	9,146	$591,898
Grand Total	21	$876	586	$71,686	703	$180,054	6,788	$714,399	7,154	$1,136,804	7,559	$1,584,338	19,263	$2,343,202

* Represents the number of actual parcels containing damageable structures. Parcels may contain anywhere from one to several dozen structures.

Jefferson Main														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	3.08		4.63		6.31		7.49		8.47		9.51		10.22	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	0	$154	20	$22,233	22	$38,014	153	$87,131	160	$138,157	164	$167,493	240	$194,754
Industrial	0	$0	0	$2	1	$684	3	$40,301	3	$53,133	3	$68,150	4	$73,108
MultiFamily	0	$488	9	$33,171	10	$61,258	31	$90,713	31	$106,705	31	$118,311	55	$126,228
Public	1	$1,945	5	$5,859	5	$7,611	22	$14,466	22	$16,132	22	$18,555	32	$21,796
Vehicles	0	$0	267	$2,273	348	$4,137	1909	$5,034	1974	$25,480	2047	$26,425	2097	$27,102
Single-Family	0	$482	290	$63,639	388	$118,128	1940	$398,790	2010	$509,002	2078	$607,949	3418	$762,789
Grand Total	1	$3,070	591	$127,178	774	$229,832	4,058	$636,436	4,200	$848,609	4,345	$1,006,883	5,846	$1,205,777

Beaumont A														
Event (ACE)	**0.1**		**0.05**		**0.02**		**0.01**		**0.005**		**0.002**		**0.001**	
Elevation (MSL)	2.92		4.26		6.00		7.25		8.47		9.73		10.51	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Industrial	0	$0	0	$0	0	$0	1	$121,360	1	$207,110	1	$273,565	2	$340,322
MultiFamily	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Public	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0
Grand Total	0	$0	0	$0	0	$0	1	$121,360	1	$207,110	1	$273,565	2	$340,322

Beaumont B&C														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	3.55		5.09		6.85		8.02		9.00		10.10		10.85	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Industrial	1	$385	1	$1,119	1	$1,584	1	$1,980	1	$3,334	1	$4,956	1	$4,956
Grand Total	1	$385	1	$1,119	1	$1,584	1	$1,980	1	$3,334	1	$4,956	1	$4,956

Table 2-8. Structures and Damages by Event for Port Arthur CSRM
(FY 2015 Price Level, $1,000)

8ft-10ft I-Wall														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	2.85		4.31		6.98		9.25		10.94		12.68		13.81	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	50	$12,673	549	$1,964,562	938	$4,551,332	956	$6,636,919	1,050	$7,946,501	1,057	$9,271,555	1,143	$9,589,158
Industrial	0	$0	4	$829	6	$2,068	7	$4,959	9	$92,393	9	$161,616	9	$194,575
MultiFamily	15	$245	119	$7,270	215	$27,158	217	$44,413	249	$55,287	252	$62,567	261	$67,713
Public	16	$2,802	189	$98,180	399	$202,523	401	$275,467	435	$311,283	437	$329,585	445	$337,484
Vehicles	939	$8,440	9,129	$24,024	12,007	$132,922	16,998	$223,811	19,478	$233,279	19,584	$258,901	20,538	$259,840
Single Family	1,197	$52,822	9,262	$486,400	16,626	$1,162,179	16,947	$1,710,962	19,378	$2,122,765	19,492	$2,395,681	20,443	$2,554,936
Grand Total	2,217	$76,981	19,252	$2,581,265	30,191	$6,078,183	35,526	$8,896,531	40,599	$10,761,508	40,831	$12,479,904	42,839	$13,003,707

I-Wall Near Valero														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	3.87		5.97		8.47		10.47		12.61		14.77		16.08	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	535	$1,657,699	637	$3,713,146	950	$6,101,335	1,050	$7,593,867	1,056	$9,240,514	1,144	$9,746,974	1,146	$9,866,247
Industrial	4	$586	5	$1,548	7	$4,147	9	$77,050	9	$159,439	9	$236,777	9	$272,478
MultiFamily	117	$5,718	124	$16,147	217	$39,439	247	$52,984	252	$62,231	261	$73,521	262	$81,171
Public	188	$70,949	315	$140,451	400	$256,829	435	$303,194	437	$328,916	445	$346,872	446	$355,637
Vehicles	8,981	$14,225	9,682	$124,636	16,888	$222,467	19,450	$226,172	19,581	$258,840	20,611	$272,392	20,680	$273,417
Single Family	9,126	$405,918	11,610	$750,402	16,838	$1,586,428	19,348	$2,024,867	19,484	$2,388,605	20,500	$2,677,915	20,582	$2,787,254
Grand Total	18,951	$2,155,095	22,373	$4,746,330	35,300	$8,210,645	40,539	$10,278,134	40,819	$12,438,545	42,970	$13,354,449	43,125	$13,636,204

639

Closure Structure														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	3.45		5.01		6.90		8.20		9.30		10.46		11.20	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	518	$581,099	562	$2,774,267	938	$4,483,372	948	$5,869,655	956	$6,672,436	1,050	$7,585,987	1,050	$8,139,242
Industrial	3	$193	5	$1,171	6	$2,005	7	$3,841	7	$5,002	9	$76,772	9	$105,511
MultiFamily	114	$2,160	119	$10,779	215	$25,754	216	$37,614	217	$44,713	247	$52,927	250	$56,575
Public	186	$25,192	192	$107,413	399	$195,062	400	$253,214	401	$276,761	435	$303,013	435	$314,034
Vehicles	1,269	$11,581	9,340	$120,815	11,949	$129,070	16,847	$221,849	17,003	$223,898	19,449	$226,151	19,495	$249,305
Single Family	9,002	$180,669	9,493	$582,269	16,611	$1,110,282	16,793	$1,513,337	16,955	$1,718,340	19,348	$2,023,183	19,392	$2,163,792
Grand Total	11,092	$800,894	19,711	$3,596,716	30,118	$5,945,545	35,211	$7,899,510	35,539	$8,941,150	40,538	$10,268,032	40,631	$11,028,459

Tank Farm														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	3.77		5.72		8.10		9.99		12.02		14.08		15.31	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	531	$1,567,287	572	$3,449,143	946	$5,752,432	1,050	$7,210,661	1,052	$8,861,927	1,143	$9,616,172	1,144	$9,850,235
Industrial	3	$526	5	$1,463	7	$3,743	9	$27,351	9	$140,998	9	$206,100	9	$251,925
MultiFamily	116	$5,323	123	$14,395	216	$36,807	246	$48,984	250	$59,898	261	$68,935	261	$77,359
Public	188	$63,836	208	$129,134	400	$251,210	434	$290,941	436	$322,815	445	$339,456	446	$352,879
Vehicles	1,580	$13,552	9,585	$123,602	16,836	$221,595	17,114	$225,227	19,549	$258,373	20,564	$260,222	20,636	$272,876
Single Family	9,102	$382,410	9,749	$707,373	16,781	$1,479,447	19,319	$1,852,854	19,445	$2,324,783	20,464	$2,590,490	20,530	$2,738,829
Grand Total	11,520	$2,032,933	20,242	$4,425,110	35,186	$7,745,233	38,172	$9,656,019	40,741	$11,968,794	42,886	$13,081,375	43,026	$13,544,104

640

Table 2-9. Structures and Damages by Event for Freeport CSRM
(FY 2015 Price Level, $1,000)

Dow Barge Canal														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	4.60		7.46		10.82		13.28		15.76		18.55		20.12	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	242	$23,201	284	$46,104	288	$60,385	289	$64,029	289	$65,606	289	$65,967	289	$65,999
Industrial	11	$42,981	13	$768,756	14	$1,859,908	14	$2,567,500	14	$3,217,335	14	$3,381,792	14	$3,382,450
MultiFamily	111	$7,963	115	$14,013	115	$16,356	115	$19,079	115	$23,671	115	$24,386	115	$24,403
Mobile	0	$0	0	$0	2	$64	2	$67	2	$75	2	$75	2	$75
Public	59	$45,413	62	$72,465	65	$85,390	65	$92,968	65	$98,788	65	$99,975	65	$99,987
Vehicles	2,342	$41,345	2,566	$50,260	2,605	$54,308	2,606	$54,830	2,607	$54,851	2,607	$54,851	2,607	$54,851
Single Family	2,348	$103,013	2,571	$142,945	2,605	$166,359	2,607	$173,954	2,607	$177,031	2,607	$177,640	2,607	$177,729
Grand Total	5,113	$263,916	5,611	$1,094,543	5,694	$2,242,770	5,698	$2,972,427	5,699	$3,637,358	5,699	$3,804,687	5,699	$3,805,494

Tide Gate														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	4.46		7.18		10.32		12.65		15.02		17.90		19.52	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	206	$8,898	238	$23,406	242	$34,982	242	$41,374	243	$46,185	243	$48,705	243	$49,016
Industrial	3	$6,132	3	$12,524	3	$19,426	3	$24,018	3	$25,000	3	$25,107	3	$25,107
MultiFamily	114	$6,788	117	$11,531	117	$13,472	117	$15,579	117	$18,985	117	$20,344	117	$20,380
Public	62	$25,274	68	$38,183	70	$43,033	70	$45,463	70	$46,474	70	$46,860	70	$46,941
Vehicles	1,656	$26,696	1,816	$35,404	1,832	$38,378	1,845	$38,819	1,846	$38,840	1,846	$38,840	1,846	$38,840
Single Family	1,657	$70,032	1,816	$94,166	1,843	$109,968	1,843	$115,628	1,844	$117,760	1,844	$118,518	1,844	$118,682
Grand Total	3,698	$143,821	4,058	$215,214	4,107	$259,258	4,120	$280,881	4,123	$293,244	4,123	$298,373	4,123	$298,966

East Storm Levee														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	5.08		7.81		11.05		13.38		15.55		17.99		19.50	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	209	$11,308	238	$26,277	242	$37,159	243	$42,674	243	$47,499	243	$48,748	243	$49,016
Industrial	3	$8,117	3	$14,301	3	$20,825	3	$24,693	3	$25,107	3	$25,107	3	$25,107
MultiFamily	115	$8,049	117	$12,212	117	$13,887	117	$16,277	117	$19,717	117	$20,348	117	$20,380
Public	65	$27,074	68	$39,777	70	$43,669	70	$45,664	70	$46,713	70	$46,871	70	$46,941
Vehicles	1,661	$34,822	1,820	$36,906	1,845	$38,622	1,845	$38,819	1,846	$38,840	1,846	$38,840	1,846	$38,840
Single Family	1,666	$78,199	1,819	$98,338	1,843	$111,773	1,844	$116,192	1,844	$118,109	1,844	$118,539	1,844	$118,682
Grand Total	3,719	$167,569	4,065	$227,811	4,120	$265,935	4,122	$284,319	4,123	$295,985	4,123	$298,452	4,123	$298,966

Oyster Creek														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	4.44		8.49		12.21		14.63		16.62		18.77		20.19	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	206	$8,803	239	$29,591	242	$40,613	243	$45,125	243	$48,497	243	$49,014	243	$49,019
Industrial	3	$6,065	3	$16,061	3	$23,456	3	$24,839	3	$25,107	3	$25,107	3	$25,107
MultiFamily	114	$6,746	117	$12,772	117	$15,171	117	$18,098	117	$20,185	117	$20,373	117	$20,383
Public	62	$25,222	68	$41,228	70	$45,271	70	$46,168	70	$46,777	70	$46,939	70	$46,941
Vehicles	1,656	$26,183	1,821	$38,266	1,845	$38,819	1,846	$38,840	1,846	$38,840	1,846	$38,840	1,846	$38,840
Single Family	1,657	$69,814	1,820	$103,564	1,843	$115,232	1,844	$117,425	1,844	$118,263	1,844	$118,663	1,844	$118,708
Grand Total	3,698	$142,833	4,068	$241,481	4,120	$278,561	4,123	$290,496	4,123	$297,669	4,123	$298,936	4,123	$298,998

642

Old River at Dow														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	4.43		7.08		10.15		12.41		14.69		17.43		18.97	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	206	$8,755	238	$22,955	242	$34,546	242	$40,986	243	$45,288	243	$48,539	243	$49,015
Industrial	3	$6,031	3	$12,331	3	$19,097	3	$23,760	3	$24,863	3	$25,107	3	$25,107
MultiFamily	114	$6,725	117	$11,406	117	$13,377	117	$15,346	117	$18,235	117	$20,322	117	$20,375
Public	62	$25,195	68	$37,976	70	$42,839	70	$45,396	70	$46,217	70	$46,821	70	$46,941
Vehicles	1,656	$25,927	1,814	$35,376	1,828	$38,361	1,845	$38,819	1,846	$38,840	1,846	$38,840	1,846	$38,840
Single Family	1,657	$69,706	1,816	$93,721	1,843	$109,306	1,843	$115,488	1,844	$117,485	1,844	$118,440	1,844	$118,672
Grand Total	3,698	$142,339	4,056	$213,765	4,103	$257,526	4,120	$279,794	4,123	$290,930	4,123	$298,069	4,123	$298,949

South Storm Levee														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	4.21		6.68		9.59		11.63		13.71		16.31		17.93	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	205	$7,965	238	$18,251	241	$33,086	242	$39,164	243	$43,275	243	$48,253	243	$48,719
Industrial	3	$5,396	3	$11,560	3	$18,009	3	$22,091	3	$24,693	3	$25,107	3	$25,107
MultiFamily	114	$6,284	117	$10,879	117	$13,106	117	$14,553	117	$16,658	117	$20,122	117	$20,345
Public	62	$23,852	68	$36,779	69	$42,203	70	$44,466	70	$45,756	70	$46,754	70	$46,864
Vehicles	1,654	$21,887	1,686	$35,277	1,824	$38,320	1,845	$38,819	1,846	$38,819	1,846	$38,840	1,846	$38,840
Single Family	1,657	$66,993	1,814	$89,695	1,825	$107,559	1,843	$113,575	1,844	$116,633	1,844	$118,222	1,844	$118,525
Grand Total	3,695	$132,376	3,926	$202,441	4,079	$252,283	4,120	$272,668	4,123	$285,834	4,123	$297,298	4,123	$298,399

643

Freeport Dock														
Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL)	4.47		7.17		10.30		12.63		14.97		17.79		19.38	
Damage Category	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.	No.	Dam.
Commercial	206	8,946	238	23,361	242	34,931	242	41,340	243	46,050	243	48,652	243	49,016
Industrial	3	6,166	3	12,504	3	19,388	3	23,996	3	24,979	3	25,107	3	25,107
MultiFamily	114	6,809	117	11,519	117	13,461	117	15,560	117	18,872	117	20,338	117	20,379
Public	62	25,301	68	38,162	70	43,011	70	45,457	70	46,437	70	46,848	70	46,941
Vehicles	1,656	26,952	1,816	35,402	1,831	38,376	1,845	38,819	1,846	38,840	1,846	38,840	1,846	38,840
Single Family	1,657	70,141	1,816	94,122	1,843	109,907	1,843	115,615	1,844	117,725	1,844	118,498	1,844	118,679
Grand Total	3,698	144,315	4,058	215,069	4,106	259,072	4,120	280,787	4,123	292,902	4,123	298,282	4,123	298,962

Table 2-10. Economic Performance of Orange-Jefferson CSRM
(FY 2015 Price Level/3.375 percent interest rate)

	Orange 1 New Levee				Orange 2 New Levee				Orange 3 New Levee			
	10 - Foot	11 - Foot	12 - Foot	13 - Foot	10 - Foot	11 - Foot	12 - Foot	13 - Foot	10 - Foot	11 - Foot	12 - Foot	13 - Foot
INVESTMENT												
Estimated First Cost	$32,300,000	$46,617,000	$60,935,000	$75,252,000	$32,870,000	$41,088,000	$49,305,000	$57,523,000	$205,338,000	$246,811,000	$288,284,000	$329,762,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36	36	36	36	36	36	36
Interest During Construction	$1,647,000	$2,377,000	$3,108,000	$3,838,000	$1,676,000	$2,095,000	$2,515,000	$2,934,000	$10,472,000	$12,587,000	$14,702,000	$16,818,000
Investment Cost	$33,947,000	$48,995,000	$64,043,000	$79,090,000	$34,546,000	$43,183,000	$51,820,000	$60,456,000	$215,810,000	$259,398,000	$302,986,000	$346,580,000
Interest	$1,146,000	$1,654,000	$2,161,000	$2,669,000	$1,166,000	$1,457,000	$1,749,000	$2,040,000	$7,284,000	$8,755,000	$10,226,000	$11,697,000
Amortization	$269,000	$388,000	$508,000	$627,000	$274,000	$342,000	$411,000	$479,000	$1,711,000	$2,056,000	$2,402,000	$2,747,000
OMRR&R ($/year)*									$4,084,000	$4,084,000	$4,084,000	$4,084,000
TOTAL ANNUAL COSTS	**$1,415,000**	**$2,042,000**	**$2,669,000**	**$3,296,000**	**$1,440,000**	**$1,800,000**	**$2,160,000**	**$2,520,000**	**$13,078,000**	**$14,895,000**	**$16,711,000**	**$18,528,000**
Without Project EAD	$312,000	$312,000	$312,000	$312,000	$68,000	$68,000	$68,000	$68,000	$29,987,000	$29,987,000	$29,987,000	$29,987,000
Residual EAD	$62,000	$39,000	$23,000	$12,000	$32,000	$26,000	$20,000	$16,000	$8,171,000	$5,242,000	$3,044,000	$1,654,000
Storm Reduction Benefits	$250,000	$273,000	$289,000	$300,000	$36,000	$42,000	$48,000	$52,000	$21,816,000	$24,745,000	$26,943,000	$28,333,000
TOTAL BENEFITS	**$250,000**	**$273,000**	**$289,000**	**$300,000**	**$36,000**	**$42,000**	**$48,000**	**$52,000**	$21,816,000	$24,745,000	$26,943,000	$28,333,000
NET BENEFITS	($1,165,000)	($1,769,000)	($2,380,000)	($2,996,000)	($1,404,000)	($1,757,000)	($2,112,000)	($2,467,000)	**$8,738,000**	**$9,851,000**	**$10,232,000**	**$9,804,000**
BENEFIT-COST RATIO	**0.2**	**0.1**	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**1.7**	**1.7**	**1.6**	**1.5**

*For Mitigation

645

Table 2-10. Economic Performance of Orange-Jefferson CSRM (continued)
(FY 2015 Price Level/3.375 percent interest rate)

	Beaumont A New Levee					Beaumont B New Levee					Beaumont C New Levee		
	11 - Foot	12 - Foot	13 - Foot	14 - Foot		11 - Foot	12 - Foot	13 - Foot	14 - Foot		11 - Foot	12 - Foot	13 - Foot
INVESTMENT													
Estimated First Cost	$62,661,000	$70,202,000	$77,743,000	$85,284,000		$1,695,000	$2,295,000	$2,895,000	$3,494,000		$15,793,000	$16,078,000	$19,007,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%		3.375%	3.375%	3.375%	3.375%		3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50		50	50	50	50		50	50	50
Construction Period (months)	36	36	36	36		36	36	36	36		36	36	36
Interest During Construction	$3,196,000	$3,580,000	$3,965,000	$4,349,000		$86,000	$117,000	$148,000	$178,000		$805,000	$820,000	$969,000
Investment Cost	$65,857,000	$73,782,000	$81,708,000	$89,634,000		$1,782,000	$2,412,000	$3,042,000	$3,673,000		$16,599,000	$16,898,000	$19,977,000
Interest	$2,223,000	$2,490,000	$2,758,000	$3,025,000		$60,000	$81,000	$103,000	$124,000		$560,000	$570,000	$674,000
Amortization	$522,000	$585,000	$648,000	$711,000		$14,000	$19,000	$24,000	$29,000		$132,000	$134,000	$158,000
TOTAL ANNUAL COSTS	**$2,745,000**	**$3,075,000**	**$3,405,000**	**$3,736,000**		**$74,000**	**$101,000**	**$127,000**	**$153,000**		**$692,000**	**$704,000**	**$833,000**
Without Project EAD	$6,937,000	$6,937,000	$6,937,000	$6,937,000		$23,000	$23,000	$23,000	$23,000		$262,000	$262,000	$262,000
Residual EAD	$1,449,000	$870,000	$494,000	$259,000		$7,000	$4,000	$3,000	$1,000		$12,000	$7,000	$4,000
Storm Reduction Benefits	$5,488,000	$6,067,000	$6,442,000	$6,677,000		$17,000	$19,000	$21,000	$22,000		$249,000	$255,000	$258,000
TOTAL BENEFITS	**$5,488,000**	**$6,067,000**	**$6,442,000**	**$6,677,000**		**$17,000**	**$19,000**	**$21,000**	**$22,000**		**$249,000**	**$255,000**	**$258,000**
NET BENEFITS	**$2,743,000**	**$2,992,000**	**$3,037,000**	**$2,942,000**		($58,000)	($82,000)	($106,000)	($131,000)		($443,000)	($449,000)	($574,000)
BENEFIT-COST RATIO	**2.0**	**2.0**	**1.9**	**1.8**		**0.2**	**0.2**	**0.2**	**0.1**		**0.4**	**0.4**	**0.3**

646

Table 2-10. Economic Performance of Orange-Jefferson CSRM (continued)
(FY 2015 Price Level/3.375 percent interest rate)

	Jefferson Main New Levee			
	10 - Foot	11 - Foot	12 - Foot	13 - Foot
INVESTMENT				
Estimated First Cost	$46,948,000	$65,726,000	$87,674,000	$104,747,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50
Construction Period (months)	36	36	36	36
Interest During Construction	$2,394,000	$3,352,000	$4,471,000	$5,342,000
Investment Cost	$49,342,000	$69,078,000	$92,145,000	$110,089,000
Interest	$1,665,000	$2,331,000	$3,110,000	$3,715,000
Amortization	$391,000	$548,000	$730,000	$873,000
OMRR&R ($/year)*	$371,000	$371,000	$371,000	$371,000
TOTAL ANNUAL COSTS	**$2,428,000**	**$3,250,000**	**$4,212,000**	**$4,960,000**
Without Project EAD	$28,231,000	$28,231,000	$28,231,000	$28,231,000
Residual EAD	$4,207,000	$2,520,000	$1,440,000	$776,000
Flood Reduction Benefits	$24,025,000	$25,711,000	$26,791,000	$27,456,000
TOTAL BENEFITS	**$24,025,000**	**$25,711,000**	**$26,791,000**	**$27,456,000**
NET BENEFITS	**$21,597,000**	**$22,461,000**	**$22,580,000**	**$22,496,000**
BENEFIT-COST RATIO	**9.9**	**7.9**	**6.4**	**5.5**

* For Mitigation

(OMRR&R) (with the exception of mitigation) was not taken into account, since these are expected to be proportional among alternatives and would not impact the ranking of alternatives. Mitigation was estimated using the Wetlands Value Assessment Model (WVA), and preliminary wetland mitigation costs were developed for use in plan comparison. These costs were based on compensation for a loss of 85.2 Average Annual Habitat Units (AAHUs) from forested wetlands and 181.7 AAHUs from coastal wetlands and applied to only the Orange 3 and Jefferson Main sections, since Beaumont B and C were already not economically viable, and to Beaumont A because they were small. The same costs were applied to all analyzed levee heights and did not vary. Since the alignment may change as a result of public, technical, and policy review, conceptual mitigation plans and preliminary cost estimates were developed to support TSP plan comparison and selection. The primary determinant in differentiating benefits is the scale of the levee being proposed along with the associated cost for that levee/floodwall height.

It should be noted that the initial evaluations of economic performance, as depicted in Tables up through 2-20, did not incorporate relative sea level change (RSLC). Subsequent analyses will

incorporate a number of changed conditions as the analysis progressed through the study including changes in interest rates, increases and other changes in costs and price levels of structure inventories, addressing the potential for repetitive damages, and the inclusion of additional damage categories. The changes in conditions of the analysis are documented in the appropriate sections of this economics appendix.

Table 2-10 displays the economic evaluation for a range of levee/floodwall heights modifications based on the beginning at 10 feet mean sea level (MSL) up to 13 feet MSL NAVD88. They show the economic performance of the Orange 1, 2, and 3 with new levees and the economic performance of Jefferson Main with new levee as well as Beaumont A, B, and C with new levees. All are calculated at a FY 2015 price level and interest rate.

Based on the information provided in the preceding tables the alternative with the highest net benefits for the Orange-Jefferson CSRM is a levee/floodwall at a height of 12 feet at Orange 3 with Orange 1 and 2 being removed from further consideration. For Beaumont, B and C are removed from consideration and the alternative with the highest net benefits for this area is a 13-foot levee/floodwall at Beaumont A. At Jefferson Main, the alternative with the highest net benefits is a 12-foot levee/floodwall. Residual economic damages in the reaches where an alternative is considered range from $1.7 to $8.1 million in Orange 3. At Beaumont A, annual residual economic damages run from $0.3 to $1.5 million. For the Jefferson Main reach, residual economic damages run from $0.8 to $4.2 million annually.

While both of the 12-foot raises at Orange 3 and Jefferson Main produce higher net benefits than the 11-foot raises, ER-1105-2-100 states "Where two cost-effective plans produce no significantly different levels of net benefits, the less costly plan is to be the NED plan, even though the level of outputs may be less" (Appendix G, pp. G-7 to G-8). The same scenario exists for the 13-foot Raise at Beaumont A versus the 12-foot raise. Based on this guidance, the 11-foot raise at Orange 3 and Jefferson Main and the 12-foot raise at Beaumont A are included as part of the TSP.

2.4.2 Port Arthur and Vicinity CSRM

Just as with the alternative selection with the Freeport CSRM and the Orange-Jefferson CSRM, FWOP damages will have rough order of magnitude costs to identify the NED. Parametric costs were estimated for the first-added resiliency features. The same costs per linear foot both length and height for both levees and floodwalls used for Orange-Jefferson were used for the next added 1- and 2-foot raises to the system. No environmental impacts were identified, and no mitigation costs were included in the comparison. The primary determinant in differentiating benefits lies in the without project damages which is based on the fragility curve at each potential failure location. Additional determinants include the raise of the levee being proposed along with the associated

costs associated with those required features, allowing for the removal of the fragility curve in the analysis and the costs for the increases in the levee/floodwall height.

Just as with the Freeport system, costs for any modifications above these resiliency and raise options begin to escalate significantly since reconstruction would be required for providing additional protection from these features. These additional costs include highway raises, gravity structures, closure structure replacement, replacement of I-wall, and additional pump stations, which are not incrementally justified.

The following tables display the economic evaluation for a range of alternatives beginning with "No Fail" resiliency measures (meaning that the levee/floodwall will not fail prior to overtopping) followed by raises to each reach. All are calculated at a FY 2015 price level and interest rate.

Based on the information provided in Table 2-11, the NED components for the Port Arthur and Vicinity CSRM are generally a "No Fail, One-Foot Raise" for the system. Net benefits for each reach range from $2.9 million to $50.7 million. Residual economic damages for the Port Arthur CSRM range from $3.3 to $10.0 million for 8-foot to10-foot I-Wall, $0.2 to $1.0 million at the Closure Structure, $7.1 to $16.3 million at the I-Wall near Valero, and $10.9 to $25.1 million at the Tank Farm.

2.4.3 Freeport and Vicinity CSRM

Just as with the alternative selection for the Orange-Jefferson CSRM, FWOP damages will have rough order of magnitude costs to identify NED benefits. The same costs per linear foot both length and height for both levees and floodwalls used for Orange-Jefferson were used for the next added 1- and 2-foot raises to the system. No environmental impacts were identified, and no mitigation costs were included in the comparison.

Costs for any modifications above these resiliency and raise options begin to escalate significantly since reconstruction would be required for providing additional protection from these features. These additional costs include features such as high performance turf reinforcement mats, replacement of the Tide gate, gravity structures, intake structures, and rebuilding the dock and floodwalls, which are not incrementally justified.

Table 2-11 displays the economic evaluation for a range of alternatives beginning with "No Fail" resiliency measures followed by raises to each reach. All are evaluated at a FY 2015 price level and interest rate. Just as with the Port Arthur CSRM, the primary determinant in differentiating benefits lies in the without-project damages, which is based on the fragility curve at each potential

failure location. Additional determinants include the raise of the levee being proposed along with the associated costs associated with those required features, allowing for the removal of the fragility curve in the analysis and the costs for the increases in the levee/floodwall height.

Table 2-11. Economic Performance of Port Arthur and Vicinity CSRM
(FY 2015 Price Level/3.375 percent interest rate)

	8ft-10ft I-Wall Raise			Closure Structure Raise			I-Wall Raise Near Valero			I-Wall Raise Near Tank Farm		
	No Fail	1-Foot Raise	2 -Foot Raise	No Fail	1- Foot Raise	2-Foot Raise	No Fail	1-Foot Raise	2-Foot Raise	No Fail	1-Foot Raise	2-Foot Raise
INVESTMENT												
Estimated First Cost	$3,330,000	$8,915,000	$66,744,000	$3,804,000	$10,654,000	$22,822,000	$7,655,000	$8,948,000	$312,523,000	$2,756,000	$4,627,000	$188,878,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36	36	36	36	36	36	36
Interest During Construction	$170,000	$455,000	$3,404,000	$194,000	$543,000	$1,164,000	$390,000	$456,000	$15,938,000	$141,000	$236,000	$9,633,000
Investment Cost	$3,500,000	$9,370,000	$70,148,000	$3,998,000	$11,197,000	$23,986,000	$8,045,000	$9,404,000	$328,461,000	$2,897,000	$4,863,000	$198,511,000
Interest	$118,000	$316,000	$2,367,000	$135,000	$378,000	$810,000	$272,000	$317,000	$11,086,000	$98,000	$164,000	$6,700,000
Amortization	$28,000	$74,000	$556,000	$32,000	$89,000	$190,000	$64,000	$75,000	$2,604,000	$23,000	$39,000	$1,574,000
TOTAL ANNUAL COSTS	**$146,000**	**$391,000**	**$2,924,000**	**$167,000**	**$467,000**	**$1,000,000**	**$335,000**	**$392,000**	**$13,689,000**	**$121,000**	**$203,000**	**$8,273,000**
Without Project EAD	$23,413,000	$23,413,000	$23,413,000	$3,784,000	$3,784,000	$3,784,000	$61,867,000	$61,867,000	$61,867,000	$38,009,000	$38,009,000	$38,009,000
Residual EAD	$9,962,000	$5,730,000	$3,274,000	$995,000	$408,000	$156,000	$16,379,000	$10,813,000	$7,101,000	$25,130,000	$16,874,000	$10,893,000
Flood Reduction Benefits	$13,451,000	$17,683,000	$20,138,000	$2,788,000	$3,375,000	$3,628,000	$45,488,000	$51,054,000	$54,766,000	$12,879,000	$21,135,000	$27,116,000
TOTAL BENEFITS	**$13,451,000**	**$17,683,000**	**$20,138,000**	**$2,788,000**	**$3,375,000**	**$3,628,000**	**$45,488,000**	**$51,054,000**	**$54,766,000**	**$12,879,000**	**$21,135,000**	**$27,116,000**
NET BENEFITS	**$13,305,000**	**$17,292,000**	**$17,215,000**	**$2,622,000**	**$2,908,000**	**$2,628,000**	**$45,153,000**	**$50,662,000**	**$41,076,000**	**$12,758,000**	**$20,932,000**	**$18,843,000**
BENEFIT-COST RATIO	**92.1**	**45.2**	**6.9**	**16.7**	**7.2**	**3.6**	**135.8**	**130.2**	**4.0**	**106.4**	**104.1**	**3.3**

Table 2-12. Economic Performance of Freeport and Vicinity CSRM
(FY 2015 Price Level/3.375 percent interest rate)

	Dow Barge Canal Protection		Oyster Creek Levee Raise				East Storm Levee Raise				Freeport Dock Floodwall Raise		
	No Fail - Closure Structure		No Fail	1-Foot Raise	2 Foot Raise		No Fail	1-Foot Raise	2- Foot Raise		Partial Fail	No Fail	1-Foot Raise
INVESTMENT													
Estimated First Cost	$130,000,000		$1,663,000	$4,869,000	$54,244,000		$3,415,000	$6,530,000	$26,402,000		$1,500,000	$2,850,000	$150,000,000
Annual Interest Rate	3.375%		3.375%	3.375%	3.375%		3.375%	3.375%	3.375%		3.375%	3.375%	3.375%
Project Life (years)	50		50	50	50		50	50	50		50	50	50
Construction Period (months)	36		36	36	36		36	36	36		36	36	36
Interest During Construction	$6,630,000		$85,000	$248,000	$2,766,000		$174,000	$333,000	$1,346,000		$76,000	$145,000	$7,650,000
Investment Cost	$136,630,000		$1,748,000	$5,117,000	$57,010,000		$3,590,000	$6,863,000	$27,748,000		$1,576,000	$2,995,000	$157,650,000
Interest	$4,611,000		$59,000	$173,000	$1,924,000		$121,000	$232,000	$937,000		$53,000	$101,000	$5,321,000
Amortization	$1,083,000		$14,000	$41,000	$452,000		$28,000	$54,000	$220,000		$12,000	$24,000	$1,250,000
TOTAL ANNUAL COSTS	**$5,694,000**		**$73,000**	**$213,000**	**$2,376,000**		**$150,000**	**$286,000**	**$1,156,000**		**$66,000**	**$125,000**	**$6,570,000**
Without Project EAD	$166,660,000		$3,800,000	$3,800,000	$3,800,000		$1,701,000	$1,701,000	$1,701,000		$3,960,000	$3,960,000	$3,960,000
Residual EAD	$47,052,000		$1,717,000	$1,272,000	$933,000		$782,000	$581,000	$425,000		$3,771,000	$1,742,000	$1,333,000
Storm Reduction Benefits	$119,608,000		$2,083,000	$2,527,000	$2,866,000		$919,000	$1,121,000	$1,276,000		$189,000	$2,218,000	$2,627,000
TOTAL BENEFITS	**$119,608,000**		**$2,083,000**	**$2,527,000**	**$2,866,000**		**$919,000**	**$1,121,000**	**$1,276,000**		**$189,000**	**$2,218,000**	**$2,627,000**
NET BENEFITS	**$113,914,000**		**$2,010,000**	**$2,314,000**	**$490,000**		**$769,000**	**$835,000**	**$120,000**		**$123,000**	**$2,093,000**	($3,944,000)
BENEFIT-COST RATIO	**21.0**		**28.5**	**11.9**	**1.2**		**6.1**	**3.9**	**1.1**		**2.9**	**17.7**	**0.4**

652

Table 2-12. Economic Performance of Freeport and Vicinity CSRM (continued)
(FY 2015 Price Level/3.375 percent interest rate)

	Old River Levee Raise at Dow Thumb				South Storm Levee Raise			Tide Gate I-Wall Raise		
	No Fail	1-Foot Raise	2- Foot Raise		1-Foot Raise	2- Foot Raise		No Fail	1-Foot Raise	2- Foot Raise
INVESTMENT										
Estimated First Cost	$7,581,000	$8,294,000	$92,088,000		$3,325,000	$6,650,000		$1,720,000	$3,800,000	$35,644,000
Annual Interest Rate	3.375%	3.375%	3.375%		3.375%	3.375%		3.375%	3.375%	3.375%
Project Life (years)	50	50	50		50	50		50	50	50
Construction Period (months)	36	36	36		36	36		36	36	36
Interest During Construction	$387,000	$423,000	$4,696,000		$170,000	$339,000		$88,000	$194,000	$1,818,000
Investment Cost	$7,968,000	$8,717,000	$96,784,000		$3,495,000	$6,989,000		$1,808,000	$3,994,000	$37,462,000
Interest	$269,000	$294,000	$3,266,000		$118,000	$236,000		$61,000	$135,000	$1,264,000
Amortization	$63,000	$69,000	$767,000		$28,000	$55,000		$14,000	$32,000	$297,000
TOTAL ANNUAL COSTS	**$332,000**	**$363,000**	**$4,034,000**		**$146,000**	**$291,000**		**$75,000**	**$166,000**	**$1,561,000**
Without Project EAD	$2,517,000	$2,517,000	$2,517,000		$254,000	$254,000		$2,785,000	$2,785,000	$2,785,000
Residual EAD	$1,215,000	$913,000	$679,000		$182,000	$127,000		$1,184,000	$897,000	$675,000
Storm Reduction Benefits	$1,302,000	$1,604,000	$1,838,000		$72,000	$127,000		$1,601,000	$1,888,000	$2,110,000
TOTAL BENEFITS	**$1,302,000**	**$1,604,000**	**$1,838,000**		**$72,000**	**$127,000**		**$1,601,000**	**$1,888,000**	**$2,110,000**
NET BENEFITS	**$969,000**	**$1,241,000**	($2,196,000)		($74,000)	($164,000)		**$1,526,000**	**$1,721,000**	**$549,000**
BENEFIT-COST RATIO	**3.9**	**4.4**	**0.5**		**0.5**	**0.4**		**21.4**	**11.4**	**1.4**

Based on the information provided in the preceding table, the NED components for the Freeport and Vicinity CSRM are generally a "No Fail, One-Foot Raise" for the system. The exception is a "No Fail" closure structure at the Dow Barge Canal and a "No Fail" floodwall at Freeport Dock. No further consideration is given to the South Storm Levee, since neither of the two potential raises analyzed is economically justified. A "no fail" alternative was not analyzed, since this levee was not expected to fail prior to overtopping and it also has the highest crest elevation of 21 feet MSL. Residual economic damages are $47.1 million at the Dow Barge Canal, range from $0.9 to 1.7 million at the Oyster Creek Levee, range from $0.4 to $0.8 million at the East Storm Levee, $1.3 to $3.8 at Freeport Dock, $0.7 to $1.2 million at Old River Levee at the Dow thumb, and $0.7 to $1.2 million at the Tide Gate I-Wall.

2.4.4 Brazoria and Sabine Non-Structural

2.4.4.1 Non-Structural Measures

The following describes the non-structural measures considered to reduce the risk of flooding in the study area.

2.4.4.1.1 Floodplain Management

Floodplain management is most effective in controlling future development of the floodplain, thereby assuring that the existing flood problems do not become worse. However, floodplain management cannot, by itself, significantly alleviate existing flooding conditions within a highly urbanized floodplain. The technique of controlled land use is particularly helpful in planning for future development, but is of limited use in highly developed areas.

Effective regulation of the floodplain is dependent on developing enforceable ordinances to ensure that floodplain uses are compatible with the flood hazard. Several means of regulation are available, including zoning ordinances, subdivision regulations, and building codes. Zoning regulations require prudent use and development of the floodplain to prevent excessive property damage, expenditure of public funds, inconvenience, and most importantly, loss of life due to flooding. Subdivision regulations guide the division of large land parcels into smaller lots and requires proof of compliance with other regulations and ordinances. A subdivision ordinance with special reference to flood hazards would require installation of adequate drainage facilities, prohibit encroachment in floodway areas, require the placement of critical streets and utilities above a selected flood elevation, and require that building lots be filled or structures be elevated above a selected flood elevation.

Floodplain management is the most effective means to control future development of the floodplain, and ensure that existing flood problems do not worsen. This alternative did not require

further consideration because the municipalities participate in the National Flood Insurance Program.

2.4.4.1.2 Flood Forecast and Warning Systems

Flood forecasting and warning systems involves the determination of imminent flooding, implementation of a plan to warn the public, and organization of assistance in the evacuation of persons and some personal property. Notification of impending flooding can be accomplished by radio, siren, individual notification, or by elaborate remote sensor devices. Some type of flood warning and emergency evacuation effort should be a part of any FRM plan. These measures normally serve to reduce the hazards to life and damage to portable personal property.

Broad warnings as storm systems develop are coordinated through various agencies, such as the National Weather Service, which provides reports to the essential print and electronic media outlets. The National Weather Service generally releases tropical storm watches 48 hours in advance of any anticipated onset of tropical storm force winds. Since outside preparedness activities become difficult once winds reach tropical storm force, warnings are issued 36 hours in advance of any anticipated onset of tropical storm force winds. The Texas Department of Public Safety's Division of Emergency Management coordinates the state emergency management program, as well as implementing the Texas Emergency Tracking Network (ETN), part of a comprehensive data-management system that provides real-time information before, during, and after a disaster. Orange and Jefferson Counties are members of the Southeast Texas Alerting Network, which can alert users of emergencies, plant operations, traffic, and weather information or other outreach from emergency management. Both counties as well as Brazoria, also have emergency management departments that engage their respective cities, including specific evacuation plans and processes.

2.4.4.1.3 Flood Proofing

Damage to existing structures can be reduced or eliminated through various flood proofing measures. These methods protect damageable property by preventing flood waters from entering the building and/or reaching the contents inside. Flood proofing is most easily applied to new construction, and is most applicable where flooding is of short duration, low velocity, and infrequent occurrence of shallow depths. Flood proofing is usually employed in locations where structural flood protection is not feasible or where collective action is not possible. Typically, flood proofing techniques include water-tight door and window seals, raising of structures, installation of check valves on gravity-flow water and sewer lines, incorporation of seepage controls, and sandbagging of door openings during emergency situations. Due to the relatively large number of structures and the depth of flooding, this measure was not given further consideration.

2.4.4.1.4 Raising Structures in Place

One method of flood proofing involves raising the structures at their existing site. This plan is most applicable where a limited number of structures are receiving a large portion of the total flood damages along a given reach. Structure raising in Port Arthur and Freeport CSRM project areas would be ancillary to the improvement to existing levees/floodwalls system. Since a large portion of the total flood damages were already being addressed by the levee system the structure raising in Port Arthur and Freeport CSRM were removed from consideration. In the other areas the opportunities for structure raising was limited. Most structure would have to be raised several feet off the ground, which then would result in additional problems, such as access concerns, and increased wind damage during storm events. Based on these findings, a raise-in-place plan was determined to be not consistent with the goals and objectives of the project

2.4.4.1.5 Structure Relocation

Plans for structure relocation would involve moving the existing structures to a more non-flood-prone site. The practicality of this measure depends on the frequency of flooding, the value of the property, its importance to the community, and the need for land use areas that are more compatible with floodplain constraints. Relocation of the structures subject to catastrophic flood events within the existing systems to provide additional protection in the event of levee overtopping would be an impractical and potentially cost prohibitive solution. In areas without existing risk reduction systems it was determined that structure relocations were also not consistent with the goals and objectives of the project. Relocation of residential structures would be detrimental to community cohesion in the area. Many of the local industries employ local residents in the area. Due to the large flat floodplain, implementing structure relocations would place residents over an hour's drive away from their work place. Also many of the local communities rely on direct access to waterways to support the good and service in the area. Removing structures would have significant impacts on the local communities ability to provide services if structures would be relocated. Based on these findings, relocation was not considered any further.

2.4.4.1.6 Permanent Evacuation

Evacuation involves the acquisition and removal or demolition of frequently flooded structures from the floodplain. One advantage of floodplain evacuation is it generally provides high marginal benefits, because targeted structures are those being damaged at the most frequent events. Floodplain evacuation can also expand open space and enhance natural and beneficial uses and facilitate the secondary use of newly vacated land. Similar to the relocation measure, evacuation to provide additional protection can be impractical and potentially cost prohibitive. One area was analyzed for the potential for additional risk reduction due to it not receiving and flood risk benefits

from the proposed levee alignments at the Orange-Jefferson CSRM. An examination of the existing damages determined that there were limited opportunities for large scale reductions in damages with permanent structure evacuations due to the fact that there are limited damages to the residential structures associated with the Orange 3 project area. Only 15 percent of the total without equivalent annual damages are to residential structures. 65 percent of the damages in Orange 3 are to the industrial damage category, which are not conducive permanent structure evacuations. As stated above many of these local industries are dependent on the local waterways and transportation corridors.

In addition there would be OSE concerns with leaving local communities exposed while trying to only address industrial damages. Developing risk reduction systems (i.e. levees and floodwalls) for only the industrial areas could potentially induce stages in the local communities. Even with if structure relocations were included (i.e. flood proofing and raising), the area would still face detrimental flooding depths, limiting their ability to recover post storm events in the industrial areas. Based on these findings, permanent structure evacuations was not considered any further.

2.4.4.1.7 Ancillary Permanent Evacuation

Surveys of aerial imagery for the three counties were done to look for the potential for buyouts. Buyouts would be ancillary to the implementation of new levees/floodwalls in Orange and Jefferson Counties and to the enhancement of features in the Freeport and Port Arthur systems. Buyout opportunities in Brazoria are virtually non-existent and very limited in both Orange and Jefferson Counties. Several structures in Jefferson have the potential for being bought out. All of these structures, however, are commercial and buying out these structures is very unlikely to be the economically viable. Figure 2-8 shows the potential for buyouts in Orange County. There are approximately 20 residential structures that could be potentially economically viable and are currently being evaluated. While some of the parcels appeared to have no structures located on them, inspection of county appraisal records in many cases showed improvements on many of these parcels. Visual inspections of aerial photos and further inspection of the appraisal records showed that many of these were agricultural improvements and would therefore not be subject to any permanent evacuation analysis. A quantitative analysis was conducted to determine the viability of any proposed evacuation. Water surface profiles and stage/probability functions were developed from the ADCIRC points that intersected those parcels of interest and imported into HEC-FDA along with depth-damage functions and structure files representing these structures of interest and evaluated. The original list of 20 structures was whittled down to six. Four of these structures were in the 2 percent ACE, with the other two being in the 0.05 percent ACE. Without-project EADs were estimated for these structures which totaled $8,700. Costs for buying out these structures were low-balled to include merely the appraised value of the structure plus $10,000 to demolish the structure. Annual costs for evacuating all six were $21,700, creating net benefits of

-$13,000. Buying only the four in the 2 percent ACE produced net benefits of -$8,600. Based on this analysis, any potential buyouts to be included in the TSP are eliminated. The results of the analysis are captured in Table 2-13.

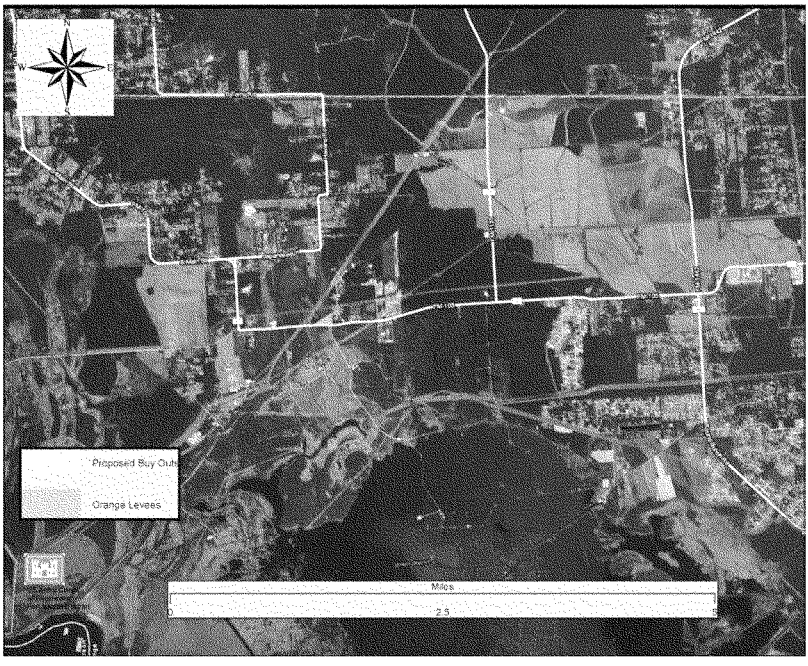


Figure 2-8. Potential Orange County Buyouts

Table 2-13. Non-structural Analysis

	0.02 to 0.01 % ACE Buyout	Total Buyout
INVESTMENT		
Estimated First Cost	$396,400	$511,900
Annual Interest Rate	3.375%	3.375%
Project Life (years)	50	50
Construction Period (months)	12	12
Interest During Construction	$7,200	$9,300
Investment Cost	$403,600	$521,200
Interest	$13,600	$17,600
Amortization	$3,200	$4,100
TOTAL ANNUAL COSTS	**$16,800**	**$21,700**
Without Project EAD	$8,700	$8,700

	0.02 to 0.01 % ACE Buyout	Total Buyout
Residual EAD	$500	$0
Flood Reduction Benefits	$8,200	$8,700
TOTAL BENEFITS	**$8,200**	**$8,700**
NET BENEFITS	($8,600)	($13,000)
BENEFIT-COST RATIO	**0.5**	**0.4**

2.5 ADJACENT IMPACTS/INDUCED FLOODING

The ERDC surge model ran a full "maximum" footprint for the Freeport, Port Arthur, Jefferson, and Orange levees and showed induced impacts could reach levels of nearly 1 to 1.5 feet in some areas along the Neches River and the Orange County levee. The levees on the Neches River that could induce damages in this area have been removed from the recommended plan eliminating these impacts. The existing systems of Port Arthur and Freeport showed negligible impacts during a 100-year event. Some induced flooding was at Orange 3 but these sections of levee were removed from the final selected plan and impacts in this area were negligible. This drastically reduces adjacent impacts caused by the proposed levee.

Adjacent impacts to the south and southeast of the levee were also analyzed and determined that most areas impacted are vacant areas of grasslands and wetlands. Surge modeling data for a 1 percent ACE were calculated and mapped for differences between the with-project and without-project water surface elevations which showed adjacent impacts to be minimal. The map showing adjacent impacts for a 1 percent ACE can be found in Engineering Map D-11 near the end of the Engineering Appendix. Most values are negligible with the exception of the areas previously mentioned with impacts measuring from 0.02 to 0.05 feet.

2.6 RISK PERFORMANCE OF PROPOSED ACTIONS

Engineer Regulation 1105-2-101 states that risk and uncertainty are intrinsic in water resources planning and design with inaccuracy in all measured or estimated values in project planning and design to some varying degrees. Invariably, the true values are different from any single, point values presently used in project formulation, evaluation, and design. The best estimates of key variables, factors, parameters, and data components in the planning and design of flood damage reduction projects are considered the "most likely" values. These values, however, are frequently based on small periods of record, sample sizes, and measurements that are subject to error.

The ER also states that risk analyses "captures and quantifies the extent of the risk and uncertainty in the various planning and design components of an investment project. The total effect of uncertainty on the project's design and economic viability can be examined and conscious decisions made reflecting an explicit tradeoff between risks and costs. Risk analysis can be used to compare plans in terms of the variability of their physical performance, economic success, and residual risks."

Engineer Manual 1110-2-1619 identifies a number of potential sources of uncertainty. These include (1) uncertainty about future hydrologic events such as steam flow and rainfall; (2) uncertainty arising from the use of simplified models to describe complex hydraulic phenomena;

(3) economic and social uncertainty, particularly the relationship between depth and inundation damage, inaccuracies in estimates of structure values and locations, and the predictability of how the public will respond to a flood; and (4) uncertainty about structural and geotechnical performance of water-control measures when subjected to rare storm events.

Uncertainty in the hydrology and hydraulics is addressed primarily by utilizing graphical exceedance probability functions which sets confidence limits for discharges at each discrete exceedance probability based on the equivalent record length. Uncertainty for hydrology and hydraulics is also addressed by assigning distributions to stage-damage functions. In the case of this study, the equivalent record length is set at 15 years and the error for the stage-damage functions is set at 0.5 feet. No fragility curves are assigned to the proposed levee, since flooding durations are short and it would be overtopped regardless for those rare events. Economic uncertainties are similarly managed with normal distributions with standard errors assigned to the depth-damage functions and by defining uncertainty parameters for first floor corrections, structure and content values. Uncertainties are further handled by changing, if necessary, the number of Monte Carlo simulations and by varying the range of ordinates in the aggregated stage-damage functions.

HEC-FDA produces project performance reports to display the hydrologic and hydraulic performance of a particular plan. Table 2-14 shows the project performance for the proposed levee raise. For the future without-project condition, the expected annual exceedance probability (AEP) for the Orange Jefferson CSRM ranges from 2.8 percent for Beaumont A to 11.4 percent for Jefferson Main. For the Port Arthur CSRM, the expected AEP ranges from 0.0 percent for the Closure Structure to 0.2 percent for the I-Wall near Valero. For the Freeport CSRM, the expected AEP ranges from 0.1 percent for the South Storm Levee to 6.0 percent for the Dow Barge Canal. Implementing the TSP reduces these expected AEP substantially.

The lack of any long-term performance of the existing conditions at the Orange-Jefferson CSRM shows that the area where levees/floodwalls are being proposed has anywhere from a 76 percent to 99.8 chance of being inundated in 50 years and a virtually zero chance of not being exceeded by the 0.2 percent event. The long-term risk for the existing Port Arthur system is somewhat less, but the long-term risk for the existing Freeport system has a wide variation from the different potential failure locations ranging from 3.7 percent for the South Storm Levee to 95.5 percent for the Dow Barge Canal. Long-term risk is reduced considerably for all three CSRMs with implementation of the TSP. The non-exceedance probability for the 0.2 percent ACE also increases substantially with the implementation of the TSP. These results are also all listed in Table 2-14.

2.6.1 Performance of the Tentatively Selected Plan under Relative Sea Level Change

An analysis was conducted in order to assess how the TSP might perform under various relative sea level change (RSLC) scenarios. As part of this analysis, H&H determined what engineering guidance would need to be for levee/floodwall heights based on EC 1110-2-6067 and CFR 2000 Title 44 and additional guidance for the three CSRMs to address the projected 50-year RSLC under low, intermediate, and high scenarios. These required heights were averaged so that they could be compared to the recommended heights specified in the TSP. Table 2-15 shows these required engineering heights in the left side of the table, while the right side specifies the recommend heights based on the criteria to determine the TSP and the difference between the two sets of criteria. Under the three RSLC scenarios, the TSP addresses relative sea level change well for the Port Arthur and Freeport CSRMs. The Orange-Jefferson CSRM shows deficiencies ranging from 2.24 to 4.77 feet. These results are also in Table 2-15.

Table 2-14. Project Performance for the Tentatively Selected Plan

Without Project

		Long-Term Risk (years)			Assurance by Event				
Damage Reach	**Expected AEP**	**10**	**30**	**50**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Orange -Jefferson CSRM										
Orange 3	7.7%	55.0%	86.4%	98.2%	85.4%	11.4%	2.1%	0.5%	0.2%	0.0%
Beaumont A	2.8%	24.8%	50.9%	75.9%	100.0%	77.7%	35.3%	13.0%	3.8%	1.8%
Jefferson Main	11.4%	70.2%	95.1%	99.8%	55.7%	5.3%	1.3%	0.4%	0.2%	0.0%
Port Arthur CSRM										
8ft-10ft I-Wall	0.1%	0.5%	1.2%	2.4%	100.0%	100.0%	100.0%	99.8%	94.2%	82.7%
Closure Structure	0.0%	0.0%	0.1%	0.1%	100.0%	100.0%	100.0%	100.0%	99.5%	98.0%
I-Wall Near Valero	0.2%	2.3%	6.8%	11.0%	100.0%	100.0%	99.9%	97.1%	75.4%	55.9%
I-Wall Near Tank Farm	0.1%	1.1%	2.7%	5.2%	100.0%	100.0%	100.0%	99.3%	87.2%	70.7%
Freeport CSRM										
Dow Barge Canal	6.0%	46.3%	78.9%	95.5%	83.6%	59.4%	43.1%	27.2%	12.3%	6.9%
East Storm Levee	0.5%	4.7%	11.3%	21.3%	100.0%	99.9%	97.1%	84.8%	59.2%	42.4%
Freeport Dock	1.2%	10.9%	25.1%	43.8%	100.0%	99.1%	84.2%	52.7%	21.6%	11.3%
Old River at Dow Thumb	0.7%	7.1%	16.8%	30.8%	100.0%	98.9%	91.8%	75.9%	46.4%	29.3%
South Storm Levee	0.1%	0.7%	2.2%	3.7%	100.0%	100.0%	100.0%	100.0%	97.7%	89.4%
Tide Gate I-Wall	0.8%	7.4%	17.5%	32.0%	100.0%	98.7%	91.0%	74.5%	44.9%	27.8%
Oyster Creek	0.6%	6.2%	14.9%	27.5%	100.0%	99.8%	94.2%	76.1%	49.7%	34.8%

Table 2-14. Project Performance for the Tentatively Selected Plan (continued)

With Project

		Long-Term Risk (years)				Assurance by Event			
Damage Reach	**Expected AEP**	**10**	**30**	**50**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Orange -Jefferson CSRM										
Orange 3 New Levee (11-Foot)	0.2%	1.7%	1.7%	4.1%	100.0%	100.0%	100.0%	98.8%	87.0%	72.5%
Beaumont A New Levee (12-Foot)	0.1%	0.8%	2.1%	4.1%	100.0%	100.0%	100.0%	99.9%	95.9%	86.9%
Jefferson Main New Levee (11-Foot)	0.1%	0.8%	1.9%	3.8%	100.0%	100.0%	100.0%	99.7%	96.1%	89.3%
Port Arthur CSRM										
8- to 10-foot I-Wall Raise (1-foot)	0.4%	0.4%	1.2%	2.0%	100.0%	100.0%	100.0%	100.0%	99.8%	98.3%
Closure Structure Raise (1-foot)	0.0%	0.4%	1.1%	2.1%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
I-Wall Raise Near Valero (1-foot)	0.1%	0.5%	1.6%	2.7%	100.0%	100.0%	100.0%	100.0%	99.0%	94.3%
I-Wall Raise Near Tank Farm (1-foot)	0.1%	0.7%	2.1%	3.6%	100.0%	100.0%	100.0%	100.0%	97.4%	89.5%
Freeport CSRM										
Dow Barge Canal Gate Structure	0.6%	5.8%	16.4%	25.9%	100.0%	100.0%	97.7%	80.9%	45.2%	27.1%
East Storm Levee Raise (1-foot)	0.2%	1.6%	4.8%	7.9%	100.0%	100.0%	100.0%	98.7%	87.3%	72.7%
Freeport Dock (No Fail)	0.5%	4.8%	11.5%	21.7%	100.0%	100.0%	98.9%	87.0%	53.5%	32.9%
Old River Levee Raise at Dow Thumb (1-foot)	0.3%	2.5%	7.4%	12.1%	100.0%	100.0%	99.9%	97.3%	77.1%	55.6%
South Storm Levee	-	-	-	-	-	-	-	-	-	-
Tide Gate I-Wall - 1-foot	0.3%	2.5%	6.1%	11.9%	100.0%	100.0%	100.0%	97.5%	77.6%	55.8%
Tide Gate I-Wall Raise (1-foot)	0.3%	3.3%	8.0%	15.4%	100.0%	100.0%	99.5%	92.3%	69.8%	52.3%

Table 2-15. Tentatively Selected Plan Relative Sea Level Change Project Performance

	Engineering Criteria - FT NAVD				TSP Project Performance				
	Without RSLC	*Low RSLC*	*Intermediate RSLC*	*High RSLC*	*Recommended Height - TSP*	*Surplus/ Deficit (Without)*	*Surplus/ Deficit (Low)*	*Surplus/Deficit (Intermediate)*	*Surplus/ Deficit (High)*
Orange-Jefferson Floodwall	12.50	13.43	13.98	15.77	11.00	-1.50	-2.43	-2.98	-4.77
Orange-Jefferson Levee	12.33	13.24	13.83	15.59	11.00	-1.33	-2.24	-2.83	-4.59
Port Arthur Floodwall	13.25	16.10	16.72	18.25	19.00	5.75	2.90	2.28	0.75
Port Arthur Levee	12.94	13.86	14.43	16.20	18.00	5.06	4.14	3.58	1.80
Dow Barge Canal	15.85	16.58	17.15	18.93	26.00	10.15	9.43	8.85	7.08
Freeport Levee	16.42	17.13	17.66	19.45	20.75	4.33	3.63	3.09	1.30
Oyster Creek	16.41	16.41	16.41	16.41	19.00	2.59	2.59	2.59	2.59

2.6.2 Life Safety Considerations

The population at risk (PAR) is displayed by project area is included in Table 2-16. The PAR was developed based on the 2010 census blocks that intersect the damageable properties in the project areas. This population reflects the residential population that may be exposed to flood risk. This does not include transportation routes for evacuation or those at work in commercial or industrial areas. The PAR the same is due to the fact that virtually the same structures being protected by the levee at Jefferson Main are also being protected by the existing hurricane flood protection system at Port Arthur. In the case of Jefferson Main, the levee is protecting against surge coming up the Neches River. For Port Arthur, damages are being quantified from the failure locations along the HFPS. In the case of Beaumont A – C, all three reaches fall within the same census block.

Table 2-16. Population at Risk by CSRM

CSRM	Population at Risk
Orange-Jefferson	
Orange 1	17,014
Orange 2	13,952
Orange 3	60,044
Beaumont A	2,078
Beaumont B	2,078
Beaumont C	2,078
Jefferson Main	116,762
Port Arthur	116,762
Freeport	16,559

Discussed previously, broad warnings as storm systems develop are coordinated through various agencies, such as the National Weather Service, which provides reports to the essential print and electronic media outlets. The National Weather Service generally releases tropical storm watches 48 hours in advance of any anticipated onset of tropical storm force winds. Since outside preparedness activities become difficult once winds reach tropical storm force, warnings are issued 36 hours in advance of any anticipated onset of tropical storm force winds. The Texas Department of Public Safety's Division of Emergency Management coordinates the state emergency management program, as well as implementing the Texas Emergency Tracking Network (ETN), part of a comprehensive data-management system that provides real-time information before, during, and after a disaster. Orange and Jefferson Counties are members of the Southeast Texas Alerting Network, which can alert users of emergencies, plant operations, traffic, and weather information or other outreach from emergency management. Both counties as well as Brazoria,

also have emergency management departments that engage their respective cities, including specific evacuation plans and processes.

2.7 IDENTIFICATION OF THE TSP

The primary planning objective to select the TSP is to reduce economic damage for the 50-year period of analysis. The TSP also meets the Federal objective of maximizing net benefits. Alternatives were evaluated to show reductions in expected annual damages towards a plan that maximizes net benefits. To that end, the following summarizes each of the CSRMs with their respective alternatives with the highest net benefits to be included in the TSP.

2.7.1 Orange-Jefferson CSRM

- Orange 3 New Levee – 11-Foot Levee/Floodwall
- Jefferson Main New Levee –11-Foot Levee/Floodwall
- Beaumont A New Levee –12-Foot Levee/Floodwall

2.7.2 Port Arthur and Vicinity CSRM

- 8-10 ft I-Wall Raise (1-Foot)
- Closure Structure Raise (1-Foot)
- I-Wall Raise Near Valero (1-Foot)
- I-Wall Raise Near Tank Farm (1-Foot)

2.7.3 Freeport and Vicinity CSRM

- Dow Barge Canal Gate Structure
- Oyster Creek Levee Raise (1-Foot)
- East Storm Levee Raise (1-Foot)
- Freeport Dock No Fail
- Old River Levee Raise at Dow Thumb (1-Foot)
- Tide Gate I-Wall Raise (1-Foot)

The following tables display each of the maximized NED alternatives which comprise the TSP beginning with the Orange-Jefferson CSRM, then the Port Arthur and Vicinity CSRM, and finally the Freeport and Vicinity CSRM (Tables 2-16 through 2-18). It should be noted that no OMRR&R was calculated for Beaumont A since initial estimates were not found to be particularly sensitive across alternative ranking. This was also true for the existing CSRMs.

Table 2-17. TSP for Orange-Jefferson CSRM

(FY 2015 Price Level/3.375 percent interest rate)

	Orange 3	Jefferson Main	Beaumont A
	11 - Foot	11 - Foot	12 - Foot
INVESTMENT			
Estimated First Cost	$246,811,000	$65,726,000	$70,202,000
Annual Interest Rate	3.375%	3.375%	3.375%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,587,000	$3,352,000	$3,580,000
Investment Cost	$259,398,000	$69,078,000	$73,782,000
Interest	$8,755,000	$2,331,000	$2,490,000
Amortization	$2,056,000	$548,000	$585,000
OMRR&R ($/year)	$4,084,000	$371,000	
TOTAL ANNUAL COSTS	**$14,895,000**	**$3,250,000**	**$3,075,000**
Without Project EAD	$29,987,000	$28,231,000	$6,937,000
Residual EAD	$5,242,000	$2,520,000	$870,000
Storm Reduction Benefits	$24,745,000	$25,711,000	$6,067,000
TOTAL BENEFITS	$24,745,000	**$25,711,000**	**$6,067,000**
NET BENEFITS	**$9,851,000**	**$22,461,000**	**$2,992,000**
BENEFIT-COST RATIO	**1.7**	**7.9**	**2.0**

Table 2-18. TSP for Port Arthur and Vicinity CSRM
(FY 2015 Price Level/3.375 percent interest rate)

	8ft-10ft I-Wall	Closure Structure	I-Wall Near Valero	I-Wall Near Tank Farm
	1-Foot Raise	1-Foot Raise	1-Foot Raise	1-Foot Raise
INVESTMENT				
Estimated First Cost	$8,915,000	$10,654,000	$8,948,000	$4,627,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50
Construction Period (months)	36	36	36	36
Interest During Construction	$455,000	$543,000	$456,000	$236,000
Investment Cost	$9,370,000	$11,197,000	$9,404,000	$4,863,000
Interest	$316,000	$378,000	$317,000	$164,000
Amortization	$74,000	$89,000	$75,000	$39,000
TOTAL ANNUAL COSTS	**$391,000**	**$467,000**	**$392,000**	**$203,000**
Without Project EAD	$23,413,000	$3,784,000	$61,867,000	$38,009,000
Residual EAD	$5,730,000	$408,000	$10,813,000	$16,874,000

	8ft-10ft I-Wall	Closure Structure	I-Wall Near Valero	I-Wall Near Tank Farm
	1-Foot Raise	1-Foot Raise	1-Foot Raise	1-Foot Raise
Flood Reduction Benefits	$17,683,000	$3,375,000	$51,054,000	$21,135,000
TOTAL BENEFITS	**$17,683,000**	**$3,375,000**	**$51,054,000**	**$21,135,000**
NET BENEFITS	**$17,292,000**	**$2,908,000**	**$50,662,000**	**$20,932,000**
BENEFIT-COST RATIO	**45.2**	**7.2**	**130.2**	**104.1**

As stated earlier, the TSP for the Orange-Jefferson CSRM includes a 113,600 LF of levee and 29,800 LF of floodwall (total of 27 miles) combination at a levee crest of 11 feet MSL at Orange 3. This has an estimated first cost of $246.8 million annualized to $14.9 million. Total annual benefits are $24.7 million which produces $9.85 million in annual net benefits and benefit-to-cost ratio of 1.7. Also included are a 41,700 LF of levee and 16,200 LF of floodwall (11 miles) combination at Jefferson Main with 11-foot crest elevation and an estimated first cost of $65.7 million with annual costs of $3.3 million. Total annual benefits come to $25.7 million, leaving an estimate of $22.5 million in net benefits and 7.9 benefit-to-cost ratio. Finally, it also includes a combination of 3,100 LF of levee and 200 LF of floodwall (0.6 mile) with a 12-foot crest elevation with first cost of $70.2 million, annual costs of $3.1 million, annual benefits of $6.1 million, and annual net benefits of $3.0 million, and a 2.0 benefit-to-cost ratio.

Table 2-19. TSP for Freeport and Vicinity CSRM
(FY 2015 Price Level/3.375 percent interest rate)

	Dow Barge Canal	Oyster Creek Levee	East Storm Levee	Freeport Dock	Old River Levee at Dow Thumb	Tide Gate I-Wall
	No Fail - Closure Structure	1-Foot Raise	1-Foot Raise	No Fail	1-Foot Raise	1-Foot Raise
INVESTMENT						
Estimated First Cost	$130,000,000	$4,869,000	$6,530,000	$2,850,000	$8,294,000	$3,800,000
Annual Interest Rate	3.375%	3.375%	3.375%	3.375%	3.375%	3.375%
Project Life (years)	50	50	50	50	50	50
Construction Period (months)	36	36	36	36	36	36
Interest During Construction	$6,630,000	$248,000	$333,000	$145,000	$423,000	$194,000
Investment Cost	$136,630,000	$5,117,000	$6,863,000	$2,995,000	$8,717,000	$3,994,000
Interest	$4,611,000	$173,000	$232,000	$101,000	$294,000	$135,000
Amortization	$1,083,000	$41,000	$54,000	$24,000	$69,000	$32,000
TOTALANNUAL COSTS	**$5,694,000**	**$213,000**	**$286,000**	**$125,000**	**$363,000**	**$166,000**
Without Project EAD	$166,660,000	$3,800,000	$1,701,000	$3,960,000	$2,517,000	$2,785,000
Residual EAD	$47,052,000	$1,272,000	$581,000	$1,742,000	$913,000	$897,000
Storm Reduction Benefits	$119,608,000	$2,527,000	$1,121,000	$2,218,000	$1,604,000	$1,888,000
TOTAL BENEFITS	**$119,608,000**	**$2,527,000**	**$1,121,000**	**$2,218,000**	**$1,604,000**	**$1,888,000**
NET BENEFITS	**$113,914,000**	**$2,314,000**	**$835,000**	**$2,093,000**	**$1,241,000**	**$1,721,000**
BENEFIT-COST RATIO	**21.0**	**11.9**	**3.9**	**17.7**	**4.4**	**11.4**

The TSP for the Port Arthur and Vicinity CSRM includes a one-foot raise above the existing elevation of 8-foot to 10-foot I-Wall, 7,500 LF of 15-foot wide scour pad, and 2,000 LF of levee raised one foot. First costs are $8.9 million, annual costs are $0.4 million, and annual benefits are $17.7 million. Net benefits are $17.3 million with a benefit-to-cost ratio of 45.2. Next is a one-foot raise above the existing elevation at the Port Arthur Closure Structure. The structure would be replaced and 300 LF of 100-foot wide scour pad along with 12,000 LF of levee raised one foot. First costs are $10.7 million, annual costs are $0.5 million, annual benefits of $3.4 million with net benefits of $2.9 million, and a benefit-to-cost ration of 7.2. Next is another one-foot raise above the existing elevation at the I-Wall near Valero with 5,000 LF of 15-foot scour pad and 3,000 LF of levee raised one foot. First costs are $8.9 million annualized to $0.4 million, with annual benefits of $51.1 million. Net benefits are $50.7 million and the benefit-to-cost ratio us 130.2. Finally, the TSP would include a one-foot raise above the existing elevation near the Port Arthur Tank Farm and have 1,800 LF of 15-foot-wide scour pad and 7,000 feet of levee raised one foot. First costs are $4.6 million, annual costs are $0.2 million with annual benefits of $21.1 million. Net benefits are $20.9 million with a 104.1 benefit-to-cost ratio.

The TSP for the Freeport and Vicinity CSRM includes a No-Fail closure structure at the Dow Barge Canal with two sector gates approximately 500 feet long and 80 feet in width for vessel traffic with an estimated first cost of $130 million, annual costs of $5.7 million, annual benefits of $119.6 million and $113.9 in annual net benefits. The benefit-to-cost ratio is 21. Also included are a one-foot raise above the existing elevation at the Oyster Creek Levee 10,000 LF in length. First costs are $4.9 million, annual costs are $0.2 million, annual benefits of $2.5 million and net benefits of $2.3 million, with a benefit-to-cost ration of 11.9. Next, it would include a one-foot raise above the existing elevation at the East Storm Levee and 13,115 LF of High Performance Turf Reinforcement Mat (HPTRM). First costs are $6.5 million, annual costs are $0.3 million, annual benefits are $1.1, and net benefits of $0.8 million with a 3.9 benefit-to cost ratio. Next is a 3,000 LF of No-Fail floodwall at Freeport Dock with first costs of $2.9 million, annual costs of $0.1 million and annual benefits of $2.2 million. Net benefits are $2.1 million and the benefit to-cost ratio is 17.7. Next would be a one-foot raise above the existing elevation at the Old River Levee at the Dow Thumb with a distance of 3,000 LF. First costs are $8.3 million, annual costs $0.4 million, annual benefits are $1.6 million, and net benefits are $1.2 million with a benefit-to-cost ratio of 4.4. Finally, it would also include a reconstructed I-Wall raised one foot above the existing elevation, 700 LF in length. It would also have 2,000 LF of levee raised one foot. First costs are $3.8 million, annual costs are $0.2 million, annual benefits are $1.9 million with $1.7 million in net benefits, and an 11.4 benefit-to-cost ratio.

2.8 RE-OPTIMIZATION TO ACCOUNT FOR RELATIVE SEA LEVEL CHANGE (RSLC)

ER 1100-2-8162 provides "guidance for incorporating the direct and indirect physical effects of projected future sea level change across the project life cycle in managing, planning, engineering, designing, constructing, operating, and maintaining USACE projects and systems of projects" and "Alternatives should be evaluated using "low," "intermediate," and "high" rates of future SLC for both "with" and "without" project conditions." ETL 1100-2-1 states that "Using a longer adaptation horizon enables us to improve robustness and resilience compared to planning for shorter time frames" and an "initial assessment that evaluates the exposure and vulnerability of the project area over the 100-year adaptation horizon will assist planners and engineers in determining the long-term approach that best balances risks for the project." The ETL goes on to "strongly recommend that some predictions of how the project or system might perform, as well as its ability to adapt beyond the typical 50-year economic analysis period, be considered in the decision-making."

One approach for addressing RSLC is to consider that the optimization has already taken place with the analysis that identified the TSP and using the identified levee/floodwall crest elevations from the average SWLs as the "base." Any increases to the crest elevation due to wave action and RSLC based on engineering criteria can be added followed by a fresh run HEC-FDA analysis to capture the additional benefits from the increased protection. Another approach is to perform a more rigorous re-optimization based on the 50-year, intermediate RSLC scenario. The following depicts the results for addressing RSLC both for the initial 50-year period of analysis. Based on the 2080 RSLC projections for the USACE intermediate curve at the Freeport NOAA gauge for the Freeport and Vicinity CSRM and the Sabine Pass North NOAA gauge for the Port Arthur and Vicinity CSRM and the Orange-Jefferson CSRM, water surface elevations were adjusted 1.94 and 2.32 feet respectively as provided by SWG's H&H Section. The following graphs depict the water surface elevations as they would be adjusted to reflect various RSLC scenarios for the 20-, 50, and 100-year epochs for each of the three CSRM systems along with the USACE low, intermediate, and high scenarios.

As discussed in the introduction of Section 2.0, after the TSP was verified, the team developed feasibility-level designs for the Recommended Plan. Investigations included detailed cost estimates, benefits, impacts, and implementation requirements. After the ADM, the Beaumont A New Levee (12-foot) and Jefferson Main New Levee (11-foot) were removed from consideration under the Recommended Plan. Beaumont A New Levee (12-foot) was removed due to the local industrial recent actions to reduce the area's risk from storm surges. In the last few years the local industries have developed a levee and floodwall system at the same location as the TSP. The

structural integrity of the existing system is not fully known; however, an assessment of the systems height appears to place it above the heights considered in the Recommended Plan. Additional detailed economic evaluation of Beaumont A was not performed following the ADM; however, it was estimated that the current residual economic damages and life-safety risk are now limited. Risk from storm surge flooding is mainly concentrated to the industrial areas which is now being mitigated for with the newly constructed system. Based on the considerations above the Beaumont A New Levee (12-foot) was removed from the final Recommended Plan.

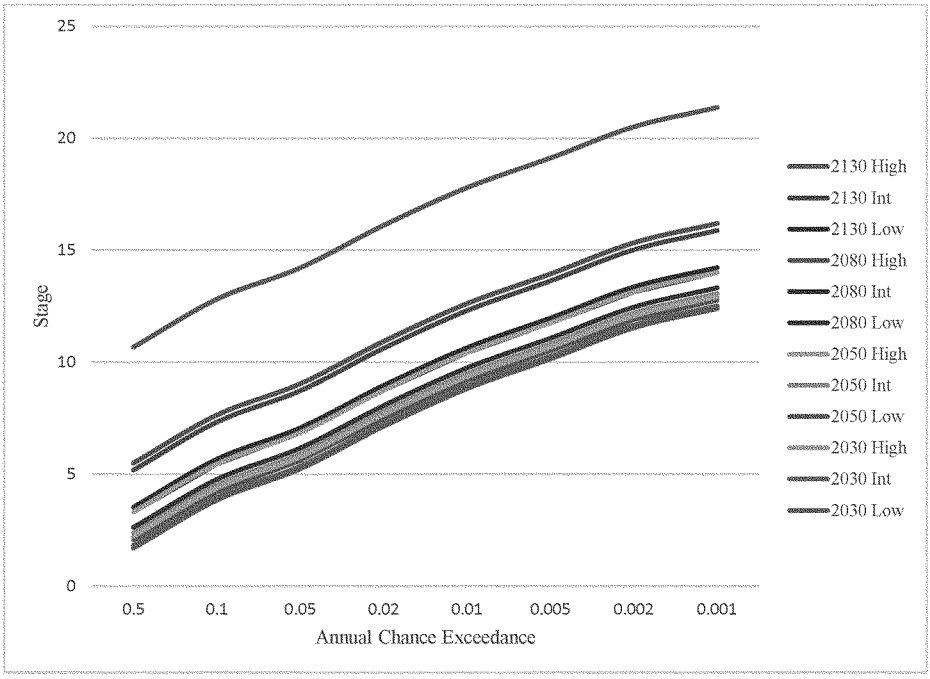


Figure 2-9. Orange-Jefferson CSRM RSLC Scenarios

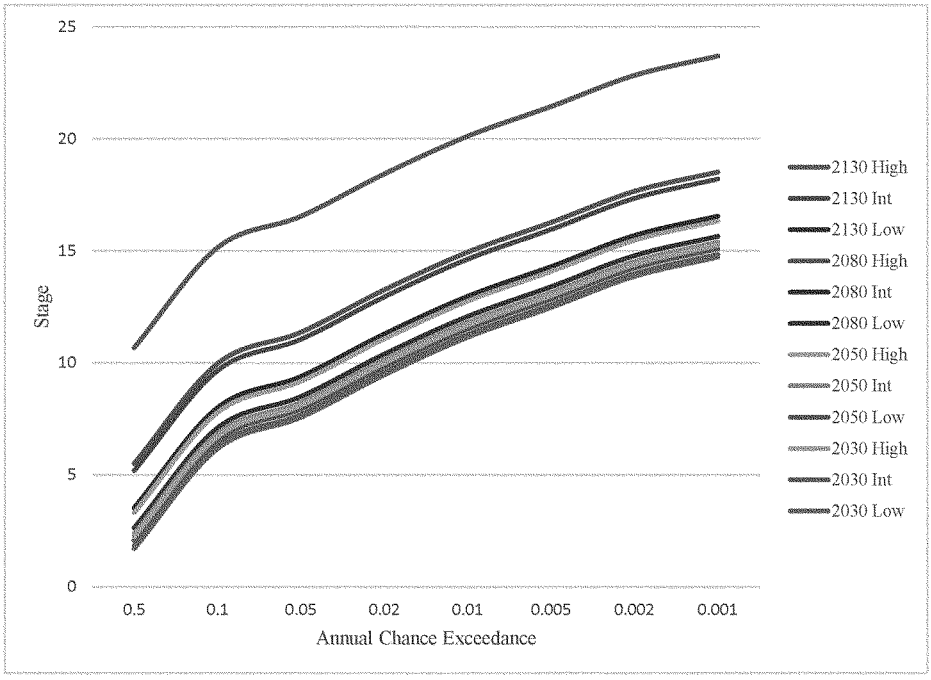


Figure 2-10. Port Arthur CSRM RSLC Scenarios

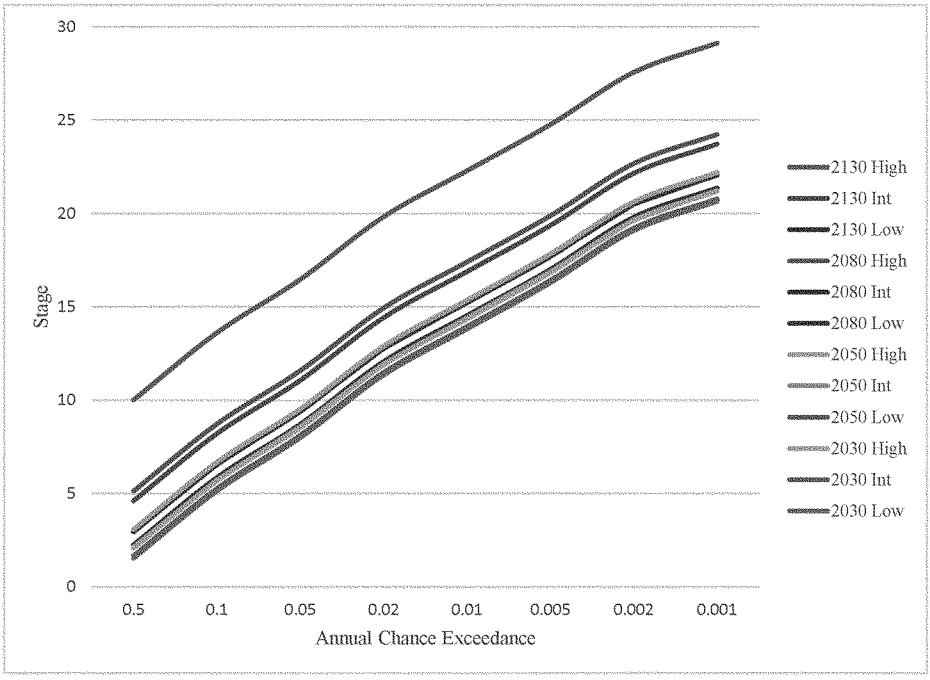


Figure 2-11. Freeport CSRM RSLC Scenarios

Systems Approach for Existing and New CSRMs

The previous analysis related to the identification of the TSP modeled damages at the existing Freeport and Port Arthur CSRMs as independent events at various locations as identified by GeoTech based on either completed or draft SQRAs. As part of the RSLC analysis in response to ATR comments from the Risk Management Center (RMC), without-project damages are estimated at one location identified to be the most likely of having a failure occur. For the Freeport CSRM that location is at the Dow Barge Canal. For the Port Arthur CSRM, that location is at the I-Wall near the Valero Refinery. This approach reduces the potential to overestimate benefits that may accrue at each of these systems. For the Orange-Jefferson CSRM, an "indicator geo-node" was identified for the basis of economic optimization. Once an "optimized" levee crest elevation was identified, the return interval associated with this height would then be applied to the remainder of the system.

Repetitive Damages and Net Benefits of Orange 3 Levee

An additional revision to the RSLC analysis was to address the potential for repetitive damages. No adjustments were done for the Freeport and Port Arthur systems since existing levees are already in place. The following without and with-project damage estimates to compensate for the potential for repetitive damages are based on results done under the 50-year intermediate RSLC scenario and under a reasonably aggressive repetitive damage scenario. All first-floor elevations that fell below the 2050 10-year ACE water surface elevation (4.52 feet) were raised to the 2050 100-year ACE water surface elevation (9.49 feet). This adjustment is similar to the approach used for other Gulf studies but more aggressive than the New Orleans District's *Morganza to the Gulf of Mexico* study and may therefore understate both the without and with-project damages. Damage estimates are based on equivalent annual damages using the water surface elevations and stage-probability functions with 2030 as the base year and 2080 as the most likely future year.

Updated Structure and Content Values

The following tables describe updated structure counts and values to reflect changes made to the structure inventory to match updated costs and to take into account changes due to repetitive damages and by changes in what structures are impacted by annual chance exceedances when RSLC is considered. The first table shows the update structure inventory while the second shows the structure counts by RSLC ACE.

Table 2-20. Updated Structure and Content Values of Inventoried Structures by CSRM and Type - 2016 Price and 2015 Development Levels

Orange 3

Category Name	Count	Structure Value	Content Value	Total
Commercial	265	174,588,000	174,588,000	349,176,000
Industrial	8*	1,908,899,000	1,908,899,000	3,817,798,000
Multi-Family	192	29,482,000	29,482,000	58,964,000
Mobile	600	10,796,000	10,796,000	21,592,000
Public	207	76,621,000	87,546,000	164,167,000
Vehicles	15,033	187,102,000	0	187,102,000
Single-Family	11,931	1,228,101,000	1,228,101,000	2,456,202,000
Grand Total	28,236	3,615,589,000	3,439,412,000	7,055,001,000

* Represents the number of actual parcels containing damageable structures. Parcels may contain anywhere from one to several dozen structures.

Freeport

Category Name	Count	Structure Value	Content Value	Total
Commercial	903	134,576,000	186,747,000	321,323,000

Industrial	49	6,369,294,000	11,160,863,000	17,530,157,000
Multi-Family	375	85,731,000	82,602,000	168,333,000
Mobile	6	168,000	161,000	329,000
Public	207	257,887,000	296,474,000	554,361,000
Vehicles	11,128	212,956,000	0	212,956,000
Single-Family	8,832	469,498,000	451,198,000	920,696,000
Grand Total	21,500	7,530,110,000	12,178,045,000	19,708,155,000

Port Arthur

Category Name	Count	Structure Value	Content Value	Total
Commercial	1,152	5,948,811,000	10,489,192,000	16,438,003,000
Industrial	9	230,903,000	404,504,000	635,407,000
Multi-Family	269	86,311,000	82,911,000	169,222,000
Public	452	248,987,000	273,145,000	522,132,000
Vehicles	26,431	0	0	0
Single-Family	20,977	2,377,533,000	2,283,727,000	4,661,260,000
Grand Total	49,290	8,892,545,000	13,533,479,000	22,426,024,000

Table 2-21. Updated Structure Counts and Damages by CSRM and RSLC ACE
(FY 2016 Price Level, $1,000)

Orange 3

Event (ACE)	0.1		0.05		0.02		0.01		0.005		0.002		0.001	
Elevation (MSL Ft.)	5.46		6.86		8.76		10.44		11.76		13.15		14.02	
Damage Category	**No.**	**Dam.**	**No.**	**Dam.**	**No.**	**Dam.**	**No.**	**Dam.**	**No.**	**Dam.**	**No.**	**Dam.**	**No.**	**Dam.**
Commercial	4	$6,532	40	$13,988	49	$26,876	198	$65,768	201	$94,814	257	$139,523	257	$171,585
Industrial	1*	$118,920	6*	$397,175	6*	$964,017	8*	$1,765,198	8*	$2,158,850	8*	$2,606,137	8*	$2,768,134
Multifamily	0	$0	96	$1,624	100	$5,648	180	$12,417	180	$16,580	190	$20,422	190	$23,600
Mobile	2	$53	141	$1,777	154	$3,242	384	$9,092	386	$9,516	537	$10,851	539	$14,425
Public	5	$47	66	$3,565	77	$22,915	166	$49,975	166	$62,312	188	$74,512	188	$93,195
Vehicles	300	$4,296	3,591	$4,935	3,931	$49,927	11,513	$53,731	11,637	$141,890	14,065	$143,549	14,103	$145,123
Single-Family	25	$1,000	2,850	$87,206	3,120	$262,449	9,137	$689,907	9,236	$942,397	11,163	$1,118,302	11,193	$1,337,077
Grand Total	337	$130,848	6,790	$510,270	7,437	$1,335,074	21,586	$2,646,088	21,814	$3,426,358	26,408	$4,113,297	26,478	$4,553,138

* Represents the number of actual parcels containing damageable structures. Parcels may contain anywhere from one to several dozen structures.

Freeport

Elevation (MSL Ft.)	6.54		9.4		12.76		15.22		17.7		20.49		22.06	
Commercial	250	$39,042	287	$57,367	288	$63,783	289	$65,386	289	$65,813	289	66,000	289	$66,005
Industrial	12	$90,361	14	$1,453,293	14	$2,434,612	14	$3,086,560	14	$3,336,371	14	3,382,495	14	$3,382,539
Multifamily	114	$12,536	115	$15,535	115	$18,506	115	$23,168	115	$24,342	115	24,403	115	$24,403
Mobile	0	$0	1	$30	2	$66	2	$74	2	$75	2	75	2	$75
Public	60	$64,140	64	$81,057	65	$92,041	65	$97,818	65	$99,591	65	99,988	65	$100,014
Vehicles	3,018	$49,819	3,250	$54,136	3,284	$54,830	3,285	$54,851	3,285	$54,851	3,285	54,851	3,285	$54,851
Single-Family	2,395	$131,204	2,579	$160,383	2,606	$173,502	2,607	$176,690	2,607	$177,473	2,607	177,746	2,607	$177,795
Grand Total	5,849	$387,103	6,310	$1,821,803	6,374	$2,837,340	6,377	$3,504,548	6,377	$3,758,517	6,377	$3,805,559	6,377	$3,805,684

Port Arthur

Elevation (MSL Ft.)	7.79	9.19	11.08	12.76	14.09	15.47	16.34

679

Commercial	946	$5,395,927	956	$6,596,122	1,050	$8,050,284	1,057	$9,307,032	1,143	$9,617,172	1,144	$9,858,136	1,147	$9,867,585
Industrial	7	$3,431	7	$4,900	9	$99,457	9	$164,103	9	$206,545	9	$256,028	9	$280,020
Multifamily	216	$34,261	217	$44,040	250	$55,979	252	$62,940	261	$68,980	261	$78,053	262	$82,408
Public	400	$244,265	401	$273,957	435	$312,765	437	$330,352	445	$339,534	446	$353,751	446	$356,272
Vehicles	21,087	$187,352	21,341	$223,699	24,429	$241,933	24,564	$258,971	25,785	$260,236	25,879	$273,027	25,981	$273,594
Single-Family	16,736	$1,406,104	16,937	$1,702,403	19,388	$2,144,891	19,495	$2,403,789	20,464	$2,591,879	20,539	$2,752,980	20,620	$2,799,024
Grand Total	39,392	$7,271,339	39,859	$8,845,121	45,561	$10,905,309	45,814	$12,527,188	48,107	$13,084,346	48,278	$13,571,975	48,465	$13,658,903

Re-optimized Orange-Jefferson CSRM

The re-optimized Orange-Jefferson CSRM (under a 50-year intermediate RSLC scenario) has an estimated first cost of $1,087.799 million annualized to $49.412 million. Total annual benefits are $77.070 million which produces $27.657 million in annual net benefits and benefit-to-cost ratio of 1.6.

Table 2-22. Economic Performance of Orange-Jefferson CSRM (50-Year Intermediate RSLC Scenario) (FY 2016 Price Level/3.125 percent interest rate)

	Orange 3 New Levee		
	11 - Foot	12 - Foot	13 - Foot
INVESTMENT			
Estimated First Cost	**$1,087,799,000**	**$1,228,785,000**	**$1,439,239,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$51,304,000	$57,954,000	$67,879,000
Investment Cost	$1,139,103,000	$1,286,738,000	$1,507,118,000
Interest	$35,597,000	$40,211,000	$47,097,000
Amortization	$9,731,000	$10,993,000	$12,875,000
OMRR&R ($/year)*	$4,084,000	$4,084,000	$4,084,000
TOTAL ANNUAL COSTS	**$49,412,000**	**$55,287,000**	**$64,057,000**
Without Project EAD	$102,293,000	$102,293,000	$102,293,000
Residual EAD	$25,223,000	$17,047,000	$10,881,000
Storm Reduction Benefits	$77,070,000	$85,246,000	$91,412,000
TOTAL BENEFITS	**$77,070,000**	**$85,246,000**	**$91,412,000**
NET BENEFITS	**$27,657,000**	**$29,959,000**	**$27,355,000**
BENEFIT-COST RATIO	**1.6**	**1.5**	**1.4**

*For Mitigation

Re-optimized Port Arthur CSRM

The re-optimized Port Arthur CSRM (under a 50-year intermediate RSLC scenario) has an estimated first cost of $262.011 million annualized to $10.918 million. Total annual benefits are $65.86 million which produces $54.942 million in annual net benefits and benefit-to-cost ratio of 6.0.

Table 2-23. Economic Performance of Port Arthur and Vicinity CSRM
(50-Year Intermediate RSLC Scenario)
(FY 2016 Price Level/3.125 percent interest rate)

	No Fail	NF + 1 Foot	NF + 2 Foot
INVESTMENT			
Estimated First Cost	**$255,275,000**	**$262,011,000**	**$327,011,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,040,000	$12,357,000	$15,423,000
Investment Cost	$267,315,000	$274,369,000	$342,434,000
Interest	$8,354,000	$8,574,000	$10,701,000
Amortization	$2,284,000	$2,344,000	$2,925,000
TOTAL ANNUAL COSTS	**$10,637,000**	**$10,918,000**	**$13,626,000**
Without Project EAD	$70,351,000	$70,351,000	$70,351,000
Residual EAD	$8,641,000	$4,491,000	$2,236,000
Storm Reduction Benefits	$61,711,000	$65,860,000	$68,115,000
TOTAL BENEFITS	**$61,711,000**	**$65,860,000**	**$68,115,000**
NET BENEFITS	**$51,073,000**	**$54,942,000**	**$54,489,000**
BENEFIT-COST RATIO	**5.8**	**6.0**	**5.0**

Re-optimized Freeport and Vicinity CSRM

The re-optimized Freeport and Vicinity CSRM (under a 50-year intermediate RSLC scenario) has an estimated first cost of $304.501 million annualized to $12.688 million. Total annual benefits are $184.077 million which produces $171.389 million in annual net benefits and benefit-to-cost ratio of 14.5.

Table 2-24. Economic Performance of Freeport and Vicinity CSRM (50-Year Intermediate RSLC Scenario) (FY 2016 Price Level/3.125 percent interest rate)

	No Fail	NF + 1 Foot	NF + 2 Foot
INVESTMENT			
Estimated First Cost	**$261,391,000**	**$304,501,000**	**$548,819,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,328,000	$14,361,000	$25,884,000
Investment Cost	$273,719,000	$318,862,000	$574,703,000
Interest	$8,554,000	$9,964,000	$17,959,000
Amortization	$2,338,000	$2,724,000	$4,910,000
TOTAL ANNUAL COSTS	**$10,892,000**	**$12,688,000**	**$22,869,000**
Without Project EAD	$233,118,000	$233,118,000	$233,118,000
Residual EAD	$63,212,000	$49,041,000	$37,797,000
Storm Reduction Benefits	$169,906,000	$184,077,000	$195,320,000
TOTAL BENEFITS	**$169,906,000**	**$184,077,000**	**$195,320,000**
NET BENEFITS	**$159,014,000**	**$171,389,000**	**$172,451,000**
BENEFIT-COST RATIO	**15.6**	**14.5**	**8.5**

The following tables depict the economic performance for the one- and two-foot increments above the "No-Fail" alternatives analyzed at the Orange-Jefferson, Port Arthur, and Freeport CSRMs. The purpose of this analysis is primarily to show that the costs associated with each increment above the least expensive analyzed alternative is economically justified (i.e. benefit-to-cost ratio > 1.0). This was done by using the estimated first cost for the "No-Fail" alternatives at the Port Arthur and Freeport CSRMs and the 11-Foot at the Orange-Jefferson CSRM as the "base" and annualizing the differences in first costs for the other two analyzed alternatives. The same procedure is used for the benefits in order to derive net benefits for each of the "No-Fail + 1 Foot" and "No-Fail + 2 Foot" alternatives at the existing systems and the 12- and 13-Foot alternatives at Orange-Jefferson. As the tables show, the 12-Foot levee/floodwall combination at Orange-

Jefferson generates -$1.783 million in incremental net benefits with a 0.8 benefit-to-cost ratio while the 13-Foot combination generates -$4.386 million incremental net benefits also with a 0.8 benefit-to-cost ratio. At the existing CSRMs, the "No-Fail + 1 Foot" alternative at Port Arthur provides $3.869 million in incremental net benefits while the "No-Fail + 2 Foot" alternative provides -$0.483 million in incremental net benefits with 14.8 and 0.8 benefit-to-cost ratios respectively. At Freeport, the "No-Fail + 1 Foot" alternative generates $12.374 million in incremental net benefits while the "No-Fail + 2 Foot" alternative generates $1.063 million in incremental net benefits with 7.9 and 1.1 respective benefit-to-cost ratios.

Table 2-25. Incremental Benefits for the Orange Jefferson, Port Arthur, and Freeport CSRM Alternatives
(50-Year Intermediate RSLC Scenario - FY 2016 Price Level/3.125 percent interest rate)
Orange-Jefferson CSRM

	11 - Foot	12 - Foot	13 - Foot
INVESTMENT			
Estimated First Cost	**$1,087,799,000**	**$140,986,000**	**$351,440,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$51,304,000	$6,649,000	$16,575,000
Investment Cost	$1,139,103,000	$147,635,000	$368,015,000
Interest	$35,597,000	$4,614,000	$11,500,000
Amortization	$9,731,000	$1,261,000	$3,144,000
OMRR&R ($/year)*	$4,084,000	$4,084,000	$4,084,000
TOTAL ANNUAL COSTS	**$49,412,000**	**$9,959,000**	**$18,728,000**
Without Project EAD	$102,293,000	$8,176,000	$14,342,000
Residual EAD	$25,223,000	$0	$0
Storm Reduction Benefits	$77,070,000	$8,176,000	$14,342,000
TOTAL BENEFITS	**$77,070,000**	**$8,176,000**	**$14,342,000**
NET BENEFITS	**$27,657,000**	($1,783,000)	($4,386,000)
BENEFIT-COST RATIO	**1.6**	**0.8**	**0.8**

Port Arthur CSRM

	No Fail	NF + 1 Foot	NF + 2 Foot
INVESTMENT			
Estimated First Cost	**$255,275,000**	**$6,736,000**	**$65,000,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36

Interest During Construction	$12,040,000	$318,000	$3,066,000
Investment Cost	$267,315,000	$7,054,000	$68,066,000
Interest	$8,354,000	$220,000	$2,127,000
Amortization	$2,284,000	$60,000	$581,000
TOTAL ANNUAL COSTS	**$10,637,000**	**$281,000**	**$2,709,000**
Without Project EAD	$70,351,000	$4,149,000	$2,255,000
Residual EAD	$8,641,000	$0	$0
Storm Reduction Benefits	$61,711,000	$4,149,000	$2,255,000
TOTAL BENEFITS	**$61,711,000**	**$4,149,000**	**$2,255,000**
NET BENEFITS	**$51,073,000**	**$3,869,000**	**($453,000)**
BENEFIT-COST RATIO	**5.8**	**14.8**	**0.8**

Freeport and Vicinity CSRM

	No Fail	NF + 1 Foot	NF + 2 Foot
INVESTMENT			
Estimated First Cost	**$261,391,000**	**$43,110,000**	**$244,319,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,328,000	$2,033,000	$11,523,000
Investment Cost	$273,719,000	$45,143,000	$255,841,000
Interest	$8,554,000	$1,411,000	$7,995,000
Amortization	$2,338,000	$386,000	$2,186,000
TOTAL ANNUAL COSTS	**$10,892,000**	**$1,796,000**	**$10,181,000**
Without Project EAD	$233,118,000	$14,171,000	$11,243,000
Residual EAD	$63,212,000	$0	$0
Storm Reduction Benefits	$169,906,000	$14,171,000	$11,243,000
TOTAL BENEFITS	**$169,906,000**	**$14,171,000**	**$11,243,000**
NET BENEFITS	**$159,014,000**	**$12,374,000**	**$1,063,000**
BENEFIT-COST RATIO	**15.6**	**7.9**	**1.1**

The following table depicts the benefits generated by the re-optimized plan for each of the aforementioned RSLC epochs and scenarios. As stated previously, the initially identified TSP was re-optimized under the 50-year intermediate USACE RSLC scenario. The numbers depicted below represent the "gross" benefits generated by taking the re-optimized alternatives evaluated for the TSP and subtracting the annual residual damages of each alternative from the without-project

benefits for each CSRM. Annual costs for each alternative are not taken into account since reformulation was done under 50-year epoch and intermediate RSLC scenario. For each CSRM, using the 50-year epoch as the "base," average annual benefits for the 20- and 100-year epochs are then compared in percentage terms. These changes are displayed in Table 2-26.

As would be expected, benefits for the re-optimized TSP are somewhat reduced under the 20-year epoch as compared to the 50-year epoch. Depending on the scenario, benefits may be reduced from 12 to 19 percent under the low RSLC scenario and increase from 50 to 52 percent under the high scenario for the Orange CSRM. For the existing CSRMs, changes in benefits stay relatively constant across the varying scales of alternatives. Under the 20-year epoch, benefits decrease around five percent at the Freeport CSRM and around ten percent at Freeport. Under the 100-year epoch, benefits increase around 22 to 23 percent for the Port Arthur CSRM under the low RSLC scenario and increase by over 600 percent under the high scenario. At Freeport, benefits decrease five percent under the 20-year low RSLC scenario and all alternatives increase by an average of 189 percent under the 100-year high scenario relative to the 50-year epoch. The bottom line from this analysis is that under these various epochs and RSLC scenarios, there is little variation in benefits in the array of alternative scales. In this regard, there is no compelling case to deviate from the NED in identifying the recommended plan.

Table 2-26. Benefit Sensitivities by CSRM System

	20-Year	50-Year	100-Year	% ch. 20-yr./50-yr.	% ch. 100-yr./50-yr.
Orange					
Low					
11 - Foot	$48,048,000	$54,648,000	$70,511,000	-12.1%	29.0%
12 - Foot	$49,507,000	$60,824,000	$78,093,000	-18.6%	28.4%
13 - Foot	$55,139,000	$66,816,000	$83,988,000	-17.5%	25.7%
Intermediate					
11 - Foot	$53,427,000	$77,070,000	$131,904,000	-30.7%	71.1%
12 - Foot	$59,479,000	$85,246,000	$143,294,000	-30.2%	68.1%
13 - Foot	$64,049,000	$91,412,000	$152,124,000	-29.9%	66.4%
High					
11 - Foot	$75,806,000	$157,082,000	$327,486,000	-51.7%	108.5%
12 - Foot	$83,663,000	$170,341,000	$563,628,000	-50.9%	230.9%
13 - Foot	$89,828,000	$180,418,000	$737,733,000	-50.2%	308.9%
Port Arthur					
Low					
No Fail	$46,324,000	$51,578,000	$63,153,000	-10.2%	22.4%
No Fail + 1	$49,370,000	$54,980,000	$67,538,000	-10.2%	22.8%
No Fail + 2	$50,997,000	$56,808,000	$69,877,000	-10.2%	23.0%
Intermediate					

No Fail	$50,582,000	$61,711,000	$102,307,000	-18.0%	65.8%
No Fail + 1	$53,910,000	$65,860,000	$109,926,000	-18.1%	66.9%
No Fail + 2	$55,699,000	$68,115,000	$114,285,000	-18.2%	67.8%
High					
No Fail	$67,447,000	$123,578,000	$875,555,000	-45.4%	608.5%
No Fail + 1	$71,982,000	$132,928,000	$942,822,000	-45.8%	609.3%
No Fail + 2	$74,454,000	$138,195,000	$986,739,000	-46.1%	614.0%
Freeport					
Low					
No Fail	$143,770,000	$151,311,000	$167,036,000	-5.0%	10.4%
No Fail + 1	$156,279,000	$164,314,000	$181,031,000	-4.9%	10.2%
No Fail + 2	$166,042,000	$174,603,000	$192,171,000	-4.9%	10.1%
Intermediate					
No Fail	$152,242,000	$169,906,000	$231,022,000	-10.4%	36.0%
No Fail + 1	$165,430,000	$184,077,000	$248,595,000	-10.1%	35.0%
No Fail + 2	$175,661,000	$195,320,000	$262,286,000	-10.1%	34.3%
High					
No Fail	$185,139,000	$270,916,000	$793,343,000	-31.7%	192.8%
No Fail + 1	$200,493,000	$290,612,000	$840,024,000	-31.0%	189.1%
No Fail + 2	$212,695,000	$306,323,000	$876,665,000	-30.6%	186.2%

Table 2-27. Economic Performance of Orange-Jefferson CSRM Under 50-Year Low RSLC Scenario
(FY 2016 Price Level/3.125 percent interest rate)

	Orange 3 New Levee		
	11 - Foot	12 - Foot	13 - Foot
INVESTMENT			
Estimated First Cost	**$1,087,799,000**	**$1,228,785,000**	**$1,439,239,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$51,304,000	$57,954,000	$67,879,000
Investment Cost	$1,139,103,000	$1,286,738,000	$1,507,118,000
Interest	$35,597,000	$40,211,000	$47,097,000
Amortization	$9,731,000	$10,993,000	$12,875,000
OMRR&R ($/year)	$4,084,000	$4,084,000	$4,084,000
TOTAL ANNUAL COSTS	**$49,412,000**	**$55,287,000**	**$64,057,000**
Without Project EAD	$73,565,000	$73,565,000	$73,565,000
Residual EAD	$18,917,000	$12,742,000	$6,749,000
Storm Reduction Benefits	$54,648,000	$60,824,000	$66,816,000
TOTAL BENEFITS	**$54,648,000**	**$60,824,000**	**$66,816,000**
NET BENEFITS	**$5,236,000**	**$5,537,000**	**$2,760,000**
BENEFIT-COST RATIO	**1.1**	**1.1**	**1.0**

Table 2-28. Economic Performance of Port Arthur and Vicinity CSRM Under 50-Year Low RSLC Scenario
(FY 2016 Price Level/3.125 percent interest rate)

	No Fail	NF + 1 Foot	NF + 2 Foot
INVESTMENT			
Estimated First Cost	**$255,275,000**	**$262,011,000**	**$327,011,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,040,000	$12,357,000	$15,423,000
Investment Cost	$267,315,000	$274,369,000	$342,434,000
Interest	$8,354,000	$8,574,000	$10,701,000
Amortization	$2,284,000	$2,344,000	$2,925,000
TOTAL ANNUAL COSTS	**$10,637,000**	**$10,918,000**	**$13,626,000**
Without Project EAD	$58,618,000	$58,618,000	$58,618,000
Residual EAD	$7,040,000	$3,638,000	$1,810,000

Storm Reduction Benefits	$51,578,000	$54,980,000	$56,808,000
TOTAL BENEFITS	**$51,578,000**	**$54,980,000**	**$56,808,000**
NET BENEFITS	**$40,941,000**	**$44,062,000**	**$43,182,000**
BENEFIT-COST RATIO	**4.8**	**5.0**	**4.2**

Table 2-29. Economic Performance of Freeport and Vicinity CSRM Under 50-Year Low RSLC Scenario
(FY 2016 Price Level/3.125 percent interest rate)

	No Fail	NF + 1 Foot	NF + 2 Foot
INVESTMENT			
Estimated First Cost	**$261,391,000**	**$304,501,000**	**$548,819,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,328,000	$14,361,000	$25,884,000
Investment Cost	$273,719,000	$318,862,000	$574,703,000
Interest	$8,554,000	$9,964,000	$17,959,000
Amortization	$2,338,000	$2,724,000	$4,910,000
TOTAL ANNUAL COSTS	**$10,892,000**	**$12,688,000**	**$22,869,000**
Without Project EAD	$209,064,000	$209,064,000	$209,064,000
Residual EAD	$57,753,000	$44,750,000	$34,461,000
Storm Reduction Benefits	$151,311,000	$164,314,000	$174,603,000
TOTAL BENEFITS	**$151,311,000**	**$164,314,000**	**$174,603,000**
NET BENEFITS	**$140,419,000**	**$151,625,000**	**$151,734,000**
BENEFIT-COST RATIO	**13.9**	**13.0**	**7.6**

Table 2-30. Economic Performance of Orange CSRM Under 50-Year High RSLC Scenario (FY 2016 Price Level/3.125 percent interest rate)

	Orange 3 New Levee		
	11 - Foot	12 - Foot	13 - Foot
INVESTMENT			
Estimated First Cost	**$1,087,799,000**	**$1,228,785,000**	**$1,439,239,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$51,304,000	$57,954,000	$67,879,000
Investment Cost	$1,139,103,000	$1,286,738,000	$1,507,118,000
Interest	$35,597,000	$40,211,000	$47,097,000
Amortization	$9,731,000	$10,993,000	$12,875,000
OMRR&R ($/year)*	$4,084,000	$4,084,000	$4,084,000
TOTAL ANNUAL COSTS	**$49,412,000**	**$55,287,000**	**$64,057,000**
Without Project EAD	$201,203,000	$201,203,000	$201,203,000
Residual EAD	$44,120,000	$30,862,000	$20,785,000
Storm Reduction Benefits	$157,082,000	$170,341,000	$180,418,000
TOTAL BENEFITS	**$157,082,000**	**$170,341,000**	**$180,418,000**
NET BENEFITS	**$107,670,000**	**$115,054,000**	**$116,361,000**
BENEFIT-COST RATIO	**3.18**	**3.08**	**2.82**

*For Mitigation

Table 2-31. Economic Performance of Port Arthur and Vicinity CSRM Under 50-Year High RSLC Scenario (FY 2016 Price Level/3.125 percent interest rate)

	No Fail	NF + 1 Foot	NF + 2 Foot
INVESTMENT			
Estimated First Cost	**$255,275,000**	**$262,011,000**	**$327,011,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,040,000	$12,357,000	$15,423,000
Investment Cost	$267,315,000	$274,369,000	$342,434,000
Interest	$8,354,000	$8,574,000	$10,701,000
Amortization	$2,284,000	$2,344,000	$2,925,000
TOTAL ANNUAL COSTS	**$10,637,000**	**$10,918,000**	**$13,626,000**
Without Project EAD	$137,926,000	$137,926,000	$137,926,000
Residual EAD	$19,391,000	$10,363,000	$5,331,000
Storm Reduction Benefits	$118,534,000	$127,563,000	$132,595,000
TOTAL BENEFITS	**$118,534,000**	**$127,563,000**	**$132,595,000**
NET BENEFITS	**$107,897,000**	**$116,645,000**	**$118,968,000**
BENEFIT-COST RATIO	**11.1**	**11.7**	**9.7**

Table 2-32. Economic Performance of Freeport and Vicinity CSRM Under 50-Year High RSLC Scenario
(FY 2016 Price Level/3.125 percent interest rate)

	No Fail	NF + 1 Foot	NF + 2 Foot
INVESTMENT			
Estimated First Cost	**$261,391,000**	**$304,501,000**	**$548,819,000**
Annual Interest Rate	3.125%	3.125%	3.125%
Project Life (years)	50	50	50
Construction Period (months)	36	36	36
Interest During Construction	$12,328,000	$14,361,000	$25,884,000
Investment Cost	$273,719,000	$318,862,000	$574,703,000
Interest	$8,554,000	$9,964,000	$17,959,000
Amortization	$2,338,000	$2,724,000	$4,910,000
TOTAL ANNUAL COSTS	**$10,892,000**	**$12,688,000**	**$22,869,000**
Without Project EAD	$358,388,000	$358,388,000	$358,388,000
Residual EAD	$87,473,000	$67,776,000	$52,065,000
Storm Reduction Benefits	$270,916,000	$290,612,000	$306,323,000
TOTAL BENEFITS	**$270,916,000**	**$290,612,000**	**$306,323,000**
NET BENEFITS	**$260,023,000**	**$277,924,000**	**$283,454,000**
BENEFIT-COST RATIO	**24.9**	**22.9**	**13.4**

The following figures recreate the information contained in Table 2-26 to display the annual benefits generated by the revised TSP for the 20-, 50-, and 100-year epochs and under each of the three RSCL scenarios.

Figure 2-12. Orange CSRM Benefits from RSLC Scenarios

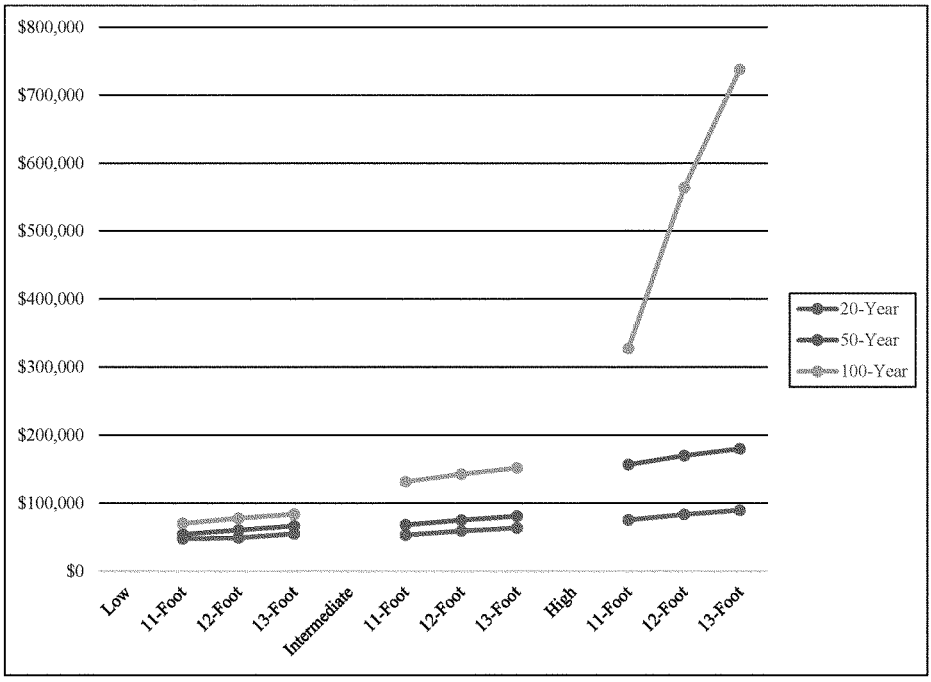


Figure 2-13. Port Arthur CSRM Benefits from RSLC Scenarios

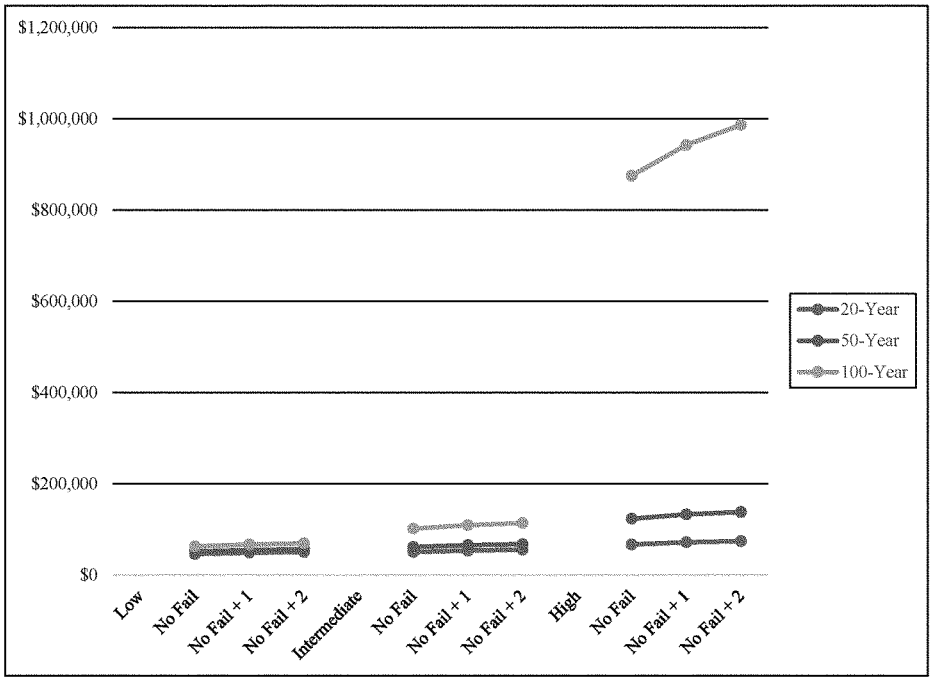
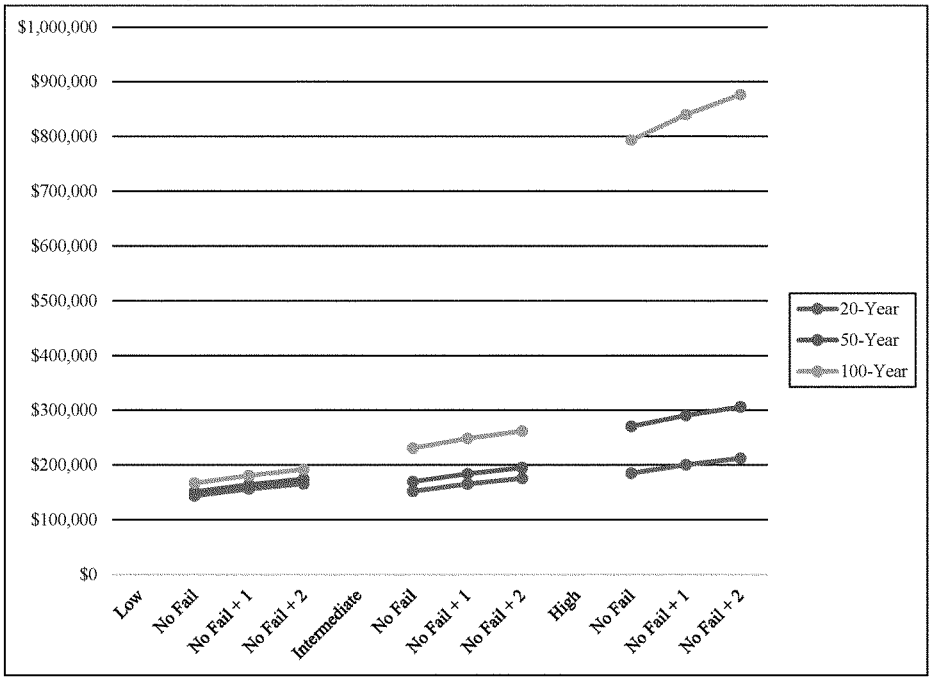


Figure 2-14. Freeport CSRM Benefits from RSLC Scenarios



2.9 RISK PERFORMANCE OF RSLC REVISED PROPOSED ACTIONS

The following table show the risk performance of the revised TSP under the 20-, 50-, and 100-year epochs and under the three RSLC scenarios.

Table 2-33. Project Performance for the Revised Tentatively Selected Plan – 20-Year Epoch

Low

			Long-Term Risk (years)	Assurance by Event					
Damage Reach	Plan Name	Expected AEP	10	10%	4%	2%	1%	0.4%	0.2%
Orange 3 CSRM									
	Without	0.1049	0.6700	0.6083	0.0655	0.0117	0.0023	0.0000	0.0000
	11-Foot	0.0048	0.0473	0.9997	0.9997	0.9953	0.8648	0.5264	0.3327
	12-Foot	0.0053	0.0516	0.9997	0.9997	0.9959	0.8553	0.4686	0.2590
Port Arthur CSRM									
	Without	0.0021	0.0208	1.0000	1.0000	0.9959	0.9460	0.7874	0.6460
	No Fail	0.0006	0.0062	0.9997	0.9997	0.9997	0.9996	0.9908	0.9653
	No Fail + 1	0.0006	0.0057	0.9997	0.9997	0.9997	0.9997	0.9970	0.9859
	No Fail + 2	0.0005	0.0052	0.9997	0.9997	0.9997	0.9997	0.9992	0.9949
Freeport CSRM									
	Without	0.0808	0.5693	0.7823	0.5401	0.3758	0.2203	0.0901	0.0480
	No Fail	0.0073	0.0709	0.9997	0.9995	0.9564	0.7328	0.3616	0.2021
	No Fail + 1	0.0056	0.0550	0.9997	0.9997	0.9826	0.8291	0.4698	0.2789
	No Fail + 2	0.0044	0.0428	0.9998	0.9998	0.9938	0.8994	0.5772	0.3674

Intermediate

			Long-Term Risk (years)	Assurance by Event					
Damage Reach	Plan Name	Expected AEP	10	10%	4%	2%	1%	0.4%	0.2%
Orange 3 CSRM									

	Without	0.1140	0.7019	0.5490	0.0500	0.0082	0.0017	0.0000	0.0000
	11-Foot	0.0055	0.0539	0.9997	0.9997	0.9923	0.8278	0.4633	0.2766
	12-Foot	0.0034	0.0335	0.9997	0.9997	0.9992	0.9422	0.6701	0.4590
Port Arthur CSRM									
	Without	0.0023	0.0233	1.0000	0.9997	0.9942	0.9320	0.7554	0.6065
	No Fail	0.0006	0.0061	0.9997	0.9997	0.9997	0.9995	0.9887	0.9586
	No Fail + 1	0.0006	0.0056	0.9997	0.9997	0.9997	0.9997	0.9963	0.9830
	No Fail + 2	0.0005	0.0052	0.9997	0.9997	0.9997	0.9997	0.9990	0.9939
Freeport CSRM									
	Without	0.0897	0.6094	0.7626	0.5202	0.3559	0.2022	0.0790	0.0408
	No Fail	0.0079	0.0763	0.9997	0.9993	0.9461	0.7013	0.3289	0.1782
	No Fail + 1	0.0061	0.0591	0.9997	0.9997	0.9780	0.8061	0.4351	0.2509
	No Fail + 2	0.0047	0.0457	0.9997	0.9997	0.9921	0.8840	0.5459	0.3372

High

			Long-Term Risk (years)	Assurance by Event					
Damage Reach	**Plan Name**	**Expected AEP**	**10**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Orange 3 CSRM									
	Without	0.1552	0.8148	0.3298	0.0163	0.0022	0.0000	0.0000	0.0000
	11-Foot	0.0084	0.0811	0.9996	0.9996	0.9678	0.6453	0.2489	0.1188
	12-Foot	0.0053	0.0515	0.9997	0.9997	0.9960	0.8571	0.4686	0.2590
Port Arthur CSRM									
	Without	0.0040	0.0396	1.0000	0.9992	0.9834	0.8710	0.6332	0.4686
	No Fail	0.0006	0.0063	0.9997	0.9997	0.9997	0.9988	0.9771	0.9268
	No Fail + 1	0.0005	0.0055	0.9997	0.9997	0.9997	0.9997	0.9926	0.9693
	No Fail + 2	0.0005	0.0050	0.9997	0.9997	0.9997	0.9997	0.9979	0.9887
Freeport CSRM									

	Without	0.1281	0.7460	0.7003	0.4590	0.2923	0.1479	0.0493	0.0232
	No Fail	0.0100	0.0954	0.9997	0.9975	0.8998	0.5868	0.2289	0.1123
	No Fail + 1	0.0077	0.0744	0.9997	0.9995	0.9551	0.7155	0.3259	0.1686
	No Fail + 2	0.0059	0.0574	0.9997	0.9997	0.9828	0.8212	0.4376	0.2437

Table 2-34. Project Performance for the Revised Tentatively Selected Plan – 50-Year Epoch

Low

			Long-Term Risk (years)			Assurance by Event					
Damage Reach	**Plan Name**	**Expected AEP**	**10**	**30**	**50**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Orange CSRM											
	Without	0.1208	0.7242	0.9790	0.9984	0.5088	0.0411	0.0064	0.0000	0.0000	0.0000
	11-Foot	0.0062	0.0605	0.1707	0.2679	0.9997	0.9997	0.9885	0.7861	0.4047	0.2281
	12-Foot	0.0038	0.0376	0.1087	0.1745	0.9997	0.9997	0.9988	0.9257	0.6227	0.4071
Port Arthur CSRM											
	Without	0.0029	0.0282	0.0821	0.1331	1.0000	0.9997	0.9922	0.9207	0.7254	0.5709
	No Fail	0.0006	0.0061	0.0182	0.0302	0.9997	0.9997	0.9997	0.9994	0.9862	0.9514
	No Fail + 1	0.0006	0.0056	0.0168	0.0278	0.9997	0.9997	0.9997	0.9997	0.9955	0.9799
	No Fail + 2	0.0005	0.0052	0.0047	0.0140	0.0232	0.9997	0.9997	0.9997	0.9997	0.9977
Freeport CSRM											
	Without	0.0939	0.6270	0.9481	0.9928	0.7542	0.5125	0.3473	0.1945	0.0745	0.0380
	No Fail	0.0081	0.0784	0.2173	0.3353	0.9997	0.9992	0.9413	0.6876	0.3155	0.0169
	No Fail + 1	0.0063	0.0609	0.1719	0.2698	0.9997	0.9997	0.9757	0.7954	0.4205	0.2398
	No Fail + 2	0.0048	0.0471	0.1348	0.2145	0.9997	0.9997	0.9913	0.8769	0.5322	0.3251

Intermediate

			Long-Term Risk (years)			Assurance by Event					
Damage Reach	**Plan Name**	**Expected AEP**	**10**	**30**	**50**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Orange CSRM											
	Without	0.1544	0.8131	0.9935	0.9998	0.3333	0.0165	0.0022	0.0000	0.0000	0.0000
	11-Foot	0.0084	0.0814	0.2248	0.3459	0.9996	0.9996	0.9670	0.6426	0.2489	0.1188
	12-Foot	0.0053	0.0516	0.1470	0.2327	0.9997	0.9997	0.9997	0.9625	0.7020	0.4675
Port Arthur CSRM											
	Without	0.0040	0.0397	0.1144	0.1833	1.0000	0.9992	0.9833	0.8709	0.6320	0.4687
	No Fail	0.0006	0.0063	0.0188	0.0312	0.9997	0.9997	0.9997	0.9987	0.9768	0.9267
	No Fail + 1	0.0005	0.0055	0.0164	0.0273	0.9997	0.9997	0.9997	0.9997	0.9925	0.9692
	No Fail + 2	0.0005	0.0050	0.0150	0.0249	0.9997	0.9997	0.9997	0.9997	0.9979	0.9887
Freeport CSRM											
	Without	0.1211	0.7248	0.9792	0.9984	0.7096	0.4681	0.3010	0.1556	0.0530	0.0253
	No Fail	0.0096	0.0923	0.2522	0.3840	0.9997	0.9980	0.9075	0.6051	0.2425	0.1209
	No Fail + 1	0.0074	0.0719	0.2006	0.3114	0.9997	0.9996	0.9591	0.7305	0.3411	0.1800
	No Fail + 2	0.0057	0.0555	0.1575	0.2485	0.9997	0.9997	0.9845	0.8321	0.4543	0.2575

High

			Long-Term Risk (years)			Assurance by Event					
Damage Reach	**Plan Name**	**Expected AEP**	**10**	**30**	**50**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Orange CSRM											
	Without	0.4229	0.9959	1.0000	1.0000	0.0082	0.0000	0.0000	0.0000	0.0000	0.0000
	11-Foot	0.0217	0.1967	0.4816	0.6654	0.9996	0.9468	0.5235	0.0872	0.0077	0.0019
	12-Foot	0.0139	0.1306	0.3430	0.5034	0.9996	0.9957	0.8478	0.2977	0.0436	0.0112
Port Arthur CSRM											
	Without	0.0110	0.1050	0.2831	0.4258	0.9996	0.9786	0.8605	0.5597	0.2683	0.1523
	No Fail	0.0016	0.0161	0.0477	0.0782	0.9998	0.9998	0.9997	0.9865	0.8820	0.7372
	No Fail + 1	0.0009	0.0089	0.0266	0.0439	0.9997	0.9997	0.9997	0.9971	0.9537	0.8663

	No Fail + 2	0.0006	0.0058	0.0172	0.0285	0.9997	0.9997	0.9997	0.9994	0.9854	0.9430
Freeport CSRM											
	Without	0.2474	0.9415	0.9998	1.0000	0.5665	0.3227	0.1556	0.0531	0.0109	0.0042
	No Fail	0.0167	0.1547	0.3960	0.5684	0.9997	0.9746	0.6854	0.2885	0.0632	0.0209
	No Fail + 1	0.0129	0.1214	0.3219	0.4766	0.9997	0.9935	0.8271	0.4350	0.1158	0.0425
	No Fail + 2	0.0098	0.0942	0.2567	0.3901	0.9997	0.9997	0.9693	0.7353	0.2972	0.1320

Table 2-35. Project Performance for the Revised Tentatively Selected Plan – 100-Year Epoch

Low

			Long-Term Risk (years)			Assurance by Event					
Damage Reach	**Plan Name**	**Expected AEP**	**10**	**30**	**50**	**10%**	**4%**	**2%**	**1%**	**0.4%**	**0.2%**
Orange CSRM											
	Without	0.1696	0.8442	0.9962	0.9999	0.2729	0.0116	0.0000	0.0000	0.0000	0.0000
	11-Foot	0.0093	0.0887	0.2432	0.3715	0.9996	0.9995	0.9548	0.5905	0.2063	0.0917
	12-Foot	0.0058	0.0566	0.1605	0.2529	0.9996	0.9996	0.9940	0.8256	0.4167	0.2179
Port Arthur CSRM											
	Without	0.0045	0.0439	0.1261	0.2012	1.0000	0.9988	0.9791	0.8515	0.6006	0.4357
	No Fail	0.0008	0.0076	0.0226	0.0374	0.9997	0.9997	0.9997	0.9984	0.9729	0.9169
	No Fail + 1	0.0005	0.0054	0.0163	0.0269	0.9997	0.9997	0.9997	0.9997	0.9912	0.9646
	No Fail + 2	0.0005	0.0050	0.0148	0.0246	0.9997	0.9997	0.9997	0.9997	0.9974	0.9868
Freeport CSRM											
	Without	0.1220	0.7278	0.9798	0.9985	0.7083	0.4668	0.2997	0.1545	0.0524	0.0250
	No Fail	0.0097	0.0928	0.2533	0.3854	0.9997	0.9979	0.9063	0.6026	0.2404	0.1197
	No Fail + 1	0.0075	0.0722	0.2015	0.3127	0.9997	0.9996	0.9585	0.7284	0.3388	0.1784
	No Fail + 2	0.0057	0.0558	0.1582	0.2496	0.9997	0.9997	0.9843	0.8306	0.4519	0.2556

Intermediate

			Long-Term Risk (years)			Assurance by Event					

Damage Reach	Plan Name	Expected AEP	10	30	50	10%	4%	2%	1%	0.4%	0.2%
Orange CSRM											
	Without	0.3673	0.9897	1.0000	1.0000	0.0186	0.0000	0.0000	0.0000	0.0000	0.0000
	11-Foot	0.0189	0.1736	0.4356	0.6146	0.9996	0.9734	0.6352	0.1415	0.0164	0.0038
	12-Foot	0.0122	0.1156	0.3083	0.4589	0.9996	0.9982	0.9009	0.3953	0.0763	0.0211
Port Arthur CSRM											
	Without	0.0096	0.0924	0.0252	0.3840	1.0000	0.9859	0.8928	0.6186	0.3195	0.1904
	No Fail	0.0014	0.0139	0.0411	0.0675	0.9997	0.9997	0.9997	0.9903	0.9054	0.7789
	No Fail + 1	0.0008	0.0078	0.0232	0.0384	0.9997	0.9997	0.9997	0.9979	0.9643	0.8911
	No Fail + 2	0.0005	0.0051	0.0153	0.0253	0.9997	0.9997	0.9997	0.9996	0.9892	0.9550
Freeport CSRM											
	Without	0.2174	0.9138	0.9994	1.0000	0.6005	0.3580	0.1896	0.0729	0.0172	0.0067
	No Fail	0.0146	0.1369	0.3571	0.5211	0.9997	0.9854	0.7596	0.3657	0.0954	0.0356
	No Fail + 1	0.0112	0.1069	0.2876	0.4318	0.9997	0.9966	0.8742	0.5167	0.1606	0.0658
	No Fail + 2	0.0086	0.0830	0.2290	0.3518	0.9997	0.9993	0.9449	0.6633	0.2512	0.1119

High

			Long-Term Risk (years)			Assurance by Event					
Damage Reach	Plan Name	Expected AEP	10	30	50	10%	4%	2%	1%	0.4%	0.2%
Orange CSRM											
	Without	0.9019	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	11-Foot	0.4296	0.9964	1.0000	1.0000	0.0065	0.0000	0.0000	0.0000	0.0000	0.0000
	12-Foot	0.2343	0.9307	0.9997	1.0000	0.1270	0.0004	0.0000	0.0000	0.0000	0.0000
Port Arthur CSRM											
	Without	0.1135	0.7004	0.9731	0.9976	0.5145	0.1420	0.0417	0.0085	0.0022	0.0015
	No Fail	0.0196	0.1795	0.4476	0.6282	0.9985	0.9216	0.6472	0.2279	0.0396	0.0091
	No Fail + 1	0.0124	0.1176	0.3129	0.4650	0.9997	0.9838	0.8588	0.4665	0.1300	0.0420
	No Fail + 2	0.0078	0.0749	0.2084	0.3226	0.9997	0.9978	0.9627	0.7188	0.3087	0.1316
Freeport CSRM											
	Without	0.5167	0.9993	1.0000	1.0000	0.2454	0.0258	0.0028	0.0010	0.0000	0.0000
	No Fail	0.0594	0.4581	0.8408	0.9533	0.9709	0.1933	0.0149	0.0009	0.0000	0.0000
	No Fail + 1	0.0457	0.3735	0.7541	0.9035	0.9964	0.4097	0.0547	0.0036	0.0001	0.0000

	No Fail + 2	0.0355	0.3030	0.6613	0.8355	0.9997	0.6584	0.1486	0.0144	0.0005	0.0000

2.10 RECOMMENDED PLAN

The Jefferson Main New Levee (11-foot) was removed from the final Recommended Plan based on a lack of local sponsorship and due to the limited perceived benefits. During the concurrent review period, local entities suggested that the economic performance of Jefferson Main should be reevaluated because there was not a perceived need for this component of the TSP. There was limited life-safety risk due to the industrial makeup of the area. Based on results of these evaluation, the sponsor decided to not to pursue this component of the final Recommended Plan.

Following the refinement and update of costs to account for interior drainage and the requisite pumps, costs, particularly for the Orange component (Orange 3) increased significantly. Twelve new pump stations were initially proposed for the Orange 3 levee reach however, due to the high cost of construction and maintenance for these structures, the benefit-to-cost ratio fell to well below unity (<1.0) therefore, a reduction in the pump discharge and number of pump stations was analyzed. A more detailed analysis and changes to the analysis included Joint Probability Analysis (JPA) to estimate discharge rates along with the potential to combine pumps. Additionally, the initial assumption of designing pumps for a 0.04 ACE with an additional ten percent capacity for RSLC was scrubbed in favor of basing pump design on the 0.04 ACE alone. The number of pumps as also reduced to seven from the initial twelve.

On the benefits side, additional benefits for debris removal and potential damages to roads, highways, and railroads were calculated. Information obtained from the New Orleans District included access to the report, *Development of Depth-Emergency Cost and Infrastructure Damage Relationships for Selected South Louisiana Parishes* which developed values as well as depth/damage functions for a number potential damage categories including debris removal and cleanup as well as evacuation activities and damages to transportation and critical infrastructure. Economic assumptions for debris removal and cleanup assumed debris would consist of vegetative (trees, shrubs, etc.), white goods (refrigerators, washers, stoves, etc.), electronic goods (TVs, computers, microwaves), hazardous waste, vehicles, vessels, and tires. Appropriate destination facilities were also identified depending on the type of debris. Assumptions also included consideration for flood-related labor diversion and capital use along with travel cost and the necessity for temporary/rental structures. Roads were divided into two categories; 1) major and secondary highways (assumed to be of the four-laned variety) and 2) streets (those assumed to consist of two lanes). These, along with railroads, were assumed to have been built to completion and are in some stage of depreciation. Unit values for these two damage debris removal and cleanup and roads, highways, and railroads were estimated based on the type of structure (for debris removal and cleanup) and by mile (for roads, highways, and railroads). These values were then adjusted for inflation, based on ENR's Cost Construction Index, and locality, based on the

CPI between Houma, Louisiana and Houston, Texas, the two most appropriate respective areas of analysis. Values for debris removal and cleanup were assigned to structures based on type. To minimize the potential for overestimation of benefits, structures with values below $10,000 were not assigned values for debris removal and cleanup. Roads, highways, and railroads were identified using GIS and values for were assigned per mile for those transportation networks within the protected areas of the recommended plan in each of the three CSRMs. Values for these to benefit categories are shown in the tables below.

Table 2-36. Values for Debris Removal and Cleanup and Roads, Highways, and Railroads

Debris Removal and Cleanup	$ per structure, $000s
Mobile Home	$6.09
Single-Family Residence	$5.90
Multi-Family Residence	$10.68
Eating or Recreation Facility	$35.81
Professional Office	$37.04
Public or Semi-Public Facility	$37.04
Warehouse or Construction Facility	$65.69
Streets, Highways, and Railroads	**$ per mile, $000s**
Streets	$255.73
Major and Secondary Highways	$695.72
Railroad	$329.23

As a validity check for estimates to roads and highways, a comparison was done utilizing roads and highway constriction estimates from a report prepared for the Orange County Economic Development Corporation and the Texas Water Development Board titled *Flood Protection Planning Study, Hurricane Flood Protection System, Orange County, Texas* dated December 2012. Estimates were derived using the principle components of road construction, asphalt for minor roads, concrete for major roads such as interstate and state highways, converted into a common unit and then costs calculated per mile. These values are listed in the table below.

Table 2-37. Values for Major and Minor Roads and Highways Based Orange County EDC Report

Minor Roads		
Item Description	$ per SF	$ per Mile (000s)
Excavation	$0.03	$1.96
Embankment (minus Levee)	$0.06	$3.91

Lime Treatment (6" EXST Material)	$0.44	$28.16
Lime (6% volume)	$1.90	$120.30
8" Asphalt Base	$0.95	$60.15
3" Asphalt Surface	$1.27	$80.20
Swale*	$2.50	$13.20
Signing/Paving Marking*	$15.00	$79.20
Seeding/Sodding	$0.02	$1.02
Total		**$388.10**

Major Roads		
Excavation	$0.03	$2.93
Embankment (minus Levee)	$0.06	$5.87
Lime Treatment for Subgrade	$0.44	$42.24
Lime (6% volume)	$1.90	$180.46
10" Concrete Pavement	$7.22	$686.40
6" Concrete Curb*	$10.00	$52.80
Swale*	$2.50	$13.20
Signing/Paving Marking*	$15.00	$79.20
Seeding/Sodding	$0.02	$1.53
Total		**$1,064.62**

* priced per LF

While these values do not take into consideration depreciation, they are significantly higher than the estimates based on the Louisiana report. In this regard, the values used for the benefit estimation appear valid. Uncertainties for residential and commercial cleanup costs were estimated based on the same method utilizing coefficients of variation for the values themselves assuming a normal distribution while uncertainties for elevations were derived from those used for residential and averages of commercial structures. Uncertainties for highways, streets, and railroads were estimated only for elevation assuming a normal distribution and utilizing coefficients of variation. No uncertainties were estimated for the values themselves.

The following table displays the without and with- project EADs for the recommended plan.

Table 2-38. Without and With-Project Equivalent Annual Damages for the Recommended Plan
(FY 2017 Price Level/2.875 percent interest rate, $1,000)

Without Project

	Damage Categories									
Reach	**Commercial**	**Industrial**	**Multifamily**	**Mobile**	**Public**	**POV**	**SFR**	**Debris**	**Roads**	**Total**
Orange CSRM	5,108	105,374	457	306	1,758	3,367	24,479	1,665	20,229	162,742
Port Arthur CSRM	146,428	4,739	609	0	2,650	1,871	19,904	1,100	637	177,937
Freeport CSRM	5,142	268,742	1,436	3	8,143	4,843	14,238	2,318	2,806	307,670

With Project

	Damage Categories									
Reach	**Commercial**	**Industrial**	**Multifamily**	**Mobile**	**Public**	**POV**	**SFR**	**Debris**	**Roads**	**Total**
Orange CSRM	2,320	36,781	267	152	1,008	1,646	14,660	761	1,633	59,228
Port Arthur CSRM	33,923	1,325	0	161	622	438	4,816	258	149	41,692
Freeport CSRM	991	97,676	318	1	1,687	710	2,352	359	581	104,674

Without Project

	Damage Categories									
Reach	**Commercial**	**Industrial**	**Multifamily**	**Mobile**	**Public**	**POV**	**SFR**	**Debris**	**Roads**	**Total**
Orange CSRM	3%	65%	0%	0%	1%	2%	15%	1%	12%	100%
Port Arthur CSRM	82%	3%	0%	0%	1%	1%	11%	1%	0%	100%
Freeport CSRM	2%	87%	0%	0%	3%	2%	5%	1%	1%	100%

With Project

	Damage Categories									
Reach	**Commercial**	**Industrial**	**Multifamily**	**Mobile**	**Public**	**POV**	**SFR**	**Debris**	**Roads**	**Total**
Orange CSRM	4%	62%	0%	0%	2%	3%	25%	1%	3%	100%
Port Arthur CSRM	81%	3%	0%	0%	1%	1%	12%	1%	0%	100%
Freeport CSRM	1%	93%	0%	0%	2%	1%	2%	0%	1%	100%

707

Table 2-39. Economic Performance of Recommended Plan
(50-Year Intermediate RSLC Scenario)
(FY 2017 Price Level/2.875 percent interest rate)

	Orange 11 - Foot	Freeport NF + 1 Foot	Port Arthur NF + 1 Foot	Combined
INVESTMENT				
Estimated First Cost	**$1,926,224,000**	**$593,313,000**	**$729,069,000**	**$3,248,606,000**
Annual Interest Rate	2.875%	2.875%	2.875%	2.875%
Project Life (years)	50	50	50	50
Construction Period (months)	120	72	72	120
Interest During Construction	$269,306,000	$44,315,000	$54,454,000	$368,075,000
Investment Cost	$2,195,530,000	$637,628,000	$783,523,000	$3,616,681,000
Interest	$63,121,000	$18,332,000	$22,526,000	$103,980,000
Amortization	$20,195,000	$5,865,000	$7,207,000	$33,267,000
OMRR&R ($/year)	$4,565,000	$708,000	$195,000	$5,467,000
TOTAL ANNUAL COSTS	**$87,881,000**	**$24,904,000**	**$29,928,000**	**$142,713,000**
Without Project EAD	$162,742,000	$307,670,000	$177,937,000	$648,349,000
Residual EAD	$59,228,000	$104,674,000	$41,692,000	$205,594,000
Storm Reduction Benefits	$103,515,000	$202,995,000	$136,246,000	$442,756,000
TOTAL BENEFITS	**$103,515,000**	**$202,995,000**	**$136,246,000**	**$442,756,000**
NET BENEFITS	**$15,634,000**	**$178,091,000**	**$106,318,000**	**$300,043,000**
BENEFIT-COST RATIO	**1.2**	**8.2**	**4.6**	**3.1**

708

The Orange CSRM recommended plan is a combination of levees and floodwalls designed to reduce the flood-damage potential from storm surge to much of the southern half of Orange County along the Sabine River and Bessie Heights Marsh. The plan consists of 82,169 LF of earthen levee and 56,755 LF of floodwall. The plan also calls for the inclusion of seven pump stations, 56 drainage structures, and 32 closure gates. First costs for this plan at the Orange CSRM reach are $1,926.224 million which annualizes to $87.881 million and produces $103.515 million in benefits with $15.634 million in net benefits for a 1.2 benefit-to-cost ratio.

The recommended plan for the Freeport and Vicinity CSRM consists of the construction of floodwalls, raising of levees, replacement of vehicular closure structures, and constructing a navigable gate structure in an active barge canal. Several sections of floodwall and levee require raising due in order to increase system capacity to prevent system failure. The plan consists of 69,375 LF of earthen levee and 29,205 LF of floodwall. The plan also includes four drainage structures, and ten closure gates. First costs for this plan at this CSRM is $593.313 million which annualizes to $24.904 million and produces $202.995 million in benefits with $178.091 million in net benefits for an 8.2 benefit-to-cost ratio.

The recommended plan for the Port Arthur and Vicinity CSRM consists of the construction of floodwalls, raising of levees, and replacement of vehicular closure structures. Several sections of floodwall and levee require raising due in order to increase system capacity to prevent system failure. The plan consists of 31,030 LF of earthen levee and 30,090 LF of floodwall. The plan also includes 26 closure gates. First costs for this plan at this CSRM is $729.069 million which annualizes to $29.928 million and produces $136.246 million in benefits with $106.318 million in net benefits for a 4.6 benefit-to-cost ratio. The following summarizes each of the CSRMs with their respective alternatives with the highest net benefits to be included as the recommended plan.

Estimates for OMRR&R received from Cost Engineering generally reflects an even stream of expenditures over the life of the project. For each of the CSRMs grassed levees will have to be regularly mowed and the floodwalls and gate structures routinely maintained. Occasional maintenance and repairs of the roadway on the levee crown will also be required. Due to the gate structures at the Orange CSRM, annual expenditures for OMRR&R spike one year per decade due to significant replacements. OMRR&R expenditures for the existing CSRMs at Freeport and Port Arthur spike as well but at much smaller magnitudes. Annual OMRR&R expenditures are therefore averaged over for the life of the project. OMRR&R estimates for the existing Port Arthur and Freeport CSRMs reflect the additional costs necessary for any potential improvements to the systems above what is currently need to operate and maintain the systems. These costs are depicted in Table 2-39.

Orange CSRM

- Orange 3 New Levee – 11-Foot Levee/Floodwall

Port Arthur and Vicinity CSRM

- 8-10 ft I-Wall Raise (1-Foot)
- Closure Structure Raise (1-Foot)
- I-Wall Raise Near Valero (1-Foot)
- I-Wall Raise Near Tank Farm (1-Foot)

Freeport and Vicinity CSRM

- Dow Barge Canal Gate Structure
- Oyster Creek Levee Raise (1-Foot)
- East Storm Levee Raise (1-Foot)
- Freeport Dock No Fail
- Old River Levee Raise at Dow Thumb (1-Foot)
- Tide Gate I-Wall Raise (1-Foot)

Table 2-40. Interest During Construction for the Recommended Plan
(FY 2017 Price Level/2.875 percent interest rate)

		Orange			Freeport			Port Arthur		
	Calendar Year	Construction Total	Compounded Value	Compound Factor	Construction Total	Compounded Value	Compound Factor	Construction Total	Compounded Value	Compound Factor
Base Year	2030	$192,622,000	$248,597,000	1.2906	$98,886,000	$113,941,000	1.1523	$121,512,000	$140,012,000	1.1523
	2031	$192,622,000	$241,649,000	1.2545	$98,886,000	$110,757,000	1.1201	$121,512,000	$136,100,000	1.1201
	2032	$192,622,000	$234,896,000	1.2195	$98,886,000	$107,662,000	1.0888	$121,512,000	$132,296,000	1.0888
	2033	$192,622,000	$228,332,000	1.1854	$98,886,000	$104,653,000	1.0583	$121,512,000	$128,599,000	1.0583
	2034	$192,622,000	$221,950,000	1.1523	$98,886,000	$101,728,000	1.0288	$121,512,000	$125,005,000	1.0288
	2035	$192,622,000	$215,748,000	1.1201	$98,886,000	$98,886,000	1.0000	$121,512,000	$121,512,000	1.0000
	2036	$192,622,000	$209,718,000	1.0888	0	0	0	0	0	0
	2037	$192,622,000	$203,857,000	1.0583	0	0	0	0	0	0
	2038	$192,622,000	$198,160,000	1.0288	0	0	0	0	0	0
	2039	$192,622,000	$192,622,000	1.0000	0	0	0	0	0	0
Total		$1,926,224,000	$2,195,530,000		$593,313,000	$637,628,000		$729,069,000	$783,523,000	

Summary	Orange	Freeport	Port Arthur
Implementation Costs:	$1,926,224,000	$593,313,000	$729,069,000
Interest During Construction:	$269,306,000	$44,315,000	$54,454,000
Total Construction Costs:	$2,195,530,000	$637,628,000	$783,523,000

Table 2-41. Probability Distribution
(FY 2017 Price Level/2.875 percent interest rate)

		Probability Damage Reduced Exceeds Indicated Values		
CSRM	Equivalent Annual Damages Reduced (2017 prices)	0.75	0.50	0.25
Orange	$103,515,000	$43,339,000	$98,190,000	$142,736,000
Freeport	$202,995,000	$23,064,000	$116,158,000	$316,250,000
Port Arthur	$136,246,000	$21,931,000	$27,002,000	$193,941,000

The evaluation incorporated uncertainty surrounding the economic and engineering inputs to generate results that can be used to assess the performance of the Recommended Plan. The percentiles displayed in Table 2-41 reflect the percentage chance that benefits may be greater than or equal to the indicated values. The probability distribution for expected and equivalent annual damages would typically be expected to follow a generally normal bell-shaped distribution with minimal skewing particularly for non-structural or where new structural measures are being proposed. This is case when observing the distribution for damages reduced for the Orange CSRM. For areas that are protected by existing systems, damages will tend to start at much less frequent events and can therefore tend to skew the probability distributions. This is the case for both the Freeport and Port Arthur CSRMs. Significant without-project damages for the Orange CSRM begin at around the 0.075 ACE (13-year event) and do not begin again until the 0.01 ACE (100-year event) under the proposed with-project condition. The distribution is somewhat skewed for the Freeport CSRM No without-project damages occur until approximately the 0.1 ACE (10-year event) and do not begin until the 0.01 ACE (100-year event). The probability distribution is extremely skewed for the Port Arthur CSRM due to no without-project damages starting until the 0.007 ACE (143 year-event) and with-project damages not beginning until the highest model water surface elevation at 0.001 ACE (1,000-year event).

2.11 CRITICAL INFRASTRUCTURE

The following describes the existing critical infrastructure in each project area. Critical infrastructure listed here includes industrial and manufacturing facilities as well as public facilities. This is a qualitative discussion of the future without-project condition focused on the impacts associated with potential storm surge flooding. The inventory of critical infrastructure came from information derived from the Homeland Security Infrastructure Program (HSIP), an infrastructure geospatial data inventory. The critical infrastructure is reported for the project areas by type (school, chemical manufacturing, etc.). A North American Industry Classification System (NAICS) code is included in the full listing of the inventory is at the end of this appendix. The

project areas are listed by county; Orange-Jefferson CSRM includes Orange and Jefferson County; Port Arthur and Vicinity CSRM includes Jefferson County; Freeport includes Brazoria County.

Orange CSRM (Orange County)

Public Facilities – Orange County

- 20 Schools
- 14 Law enforcement
- 2 Hospitals/6 nursing homes
- 11 Fire stations

Industrial and Manufacturing – Orange County

- 20 Chemical manufacturing
- 5 Electric generation
- 0 Petroleum refining
- 1 Airport

Some of the significant industrial and manufacturing facilities located in Orange-Jefferson CSRM include Exxon Mobil, DuPont, Honeywell, Firestone, Petrochemical, Chevron, Phillips, Laxness, Solvay Solexis, and Entergy. Exxon Mobil, located in Beaumont, Texas, on the Neches River, processes 345,000 barrels of crude oil per day and produces 2.5 billion gallons of gasoline annually.

Port Arthur and Vicinity CSRM (Jefferson County)

Public Facilities – Jefferson County

- 42 Schools
- 19 Law enforcement
- 13 Hospitals/7 nursing homes
- 26 Fire stations

Industrial and Manufacturing – Jefferson County

- 54 Chemical manufacturing
- 1 Electric generation
- Petroleum refining
- 1 Airport

Significant industrial and manufacturing facilities located in the Port Arthur and Vicinity CSRM include Valero, Premcor, Total, Motiva Enterprises and Huntsman Petrochemical. Jack Brooks

Regional Airport is also in the project area. Motiva is the largest petroleum refinery in the United States, with a capacity of approximately 600,000 barrels of crude oil per day.

Freeport and Vicinity CSRM (Brazoria County)

Public Facilities – Brazoria County

- 6 Schools
- 3 Law enforcement
- 0 Hospitals/0 nursing homes
- 2 Fire stations

Industrial and Manufacturing – Brazoria County

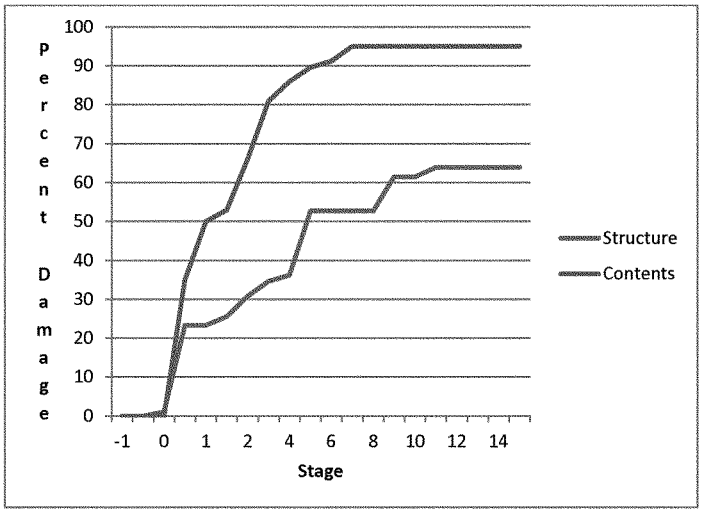
- 24 Chemical manufacturing
- 0 Electric generation
- 0 Petroleum refining

Significant industrial and manufacturing facilities located in the Freeport and Vicinity CSRM include Petroleum Reserve, Dow Chemical, Freeport LNG, Huntsman Gulf Chemicals, Phillips 66 Liquefied Petroleum Gas (LPG) Terminal, SI Group, and NALCO. A detailed description of each critical facility is not provided here; however, to explain one in some detail, Dow Chemical is the largest integrated chemical manufacturing complex in the western hemisphere. The Freeport site produces 44 percent of Dow's products sold in the U.S. and 20 percent of the company's products sold globally. A listing of these facilities is located at the end of this appendix.

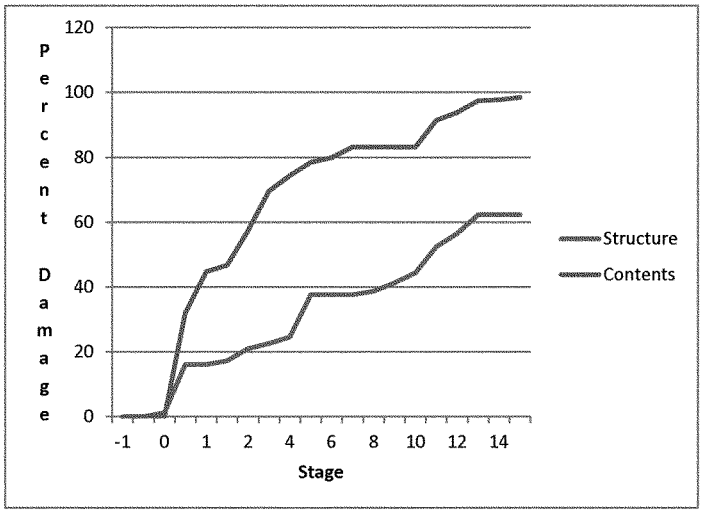
2.12 DEPTH DAMAGE FUNCTIONS

All depth-damage functions were obtained from the New Orleans District as part of their *Lower Atchafalaya and Morganza to the Gulf, Louisiana, Feasibility Study* with the exception of automobiles which are based on EGM, 09-04, *Generic Depth-Damage Relationships for Vehicles*.

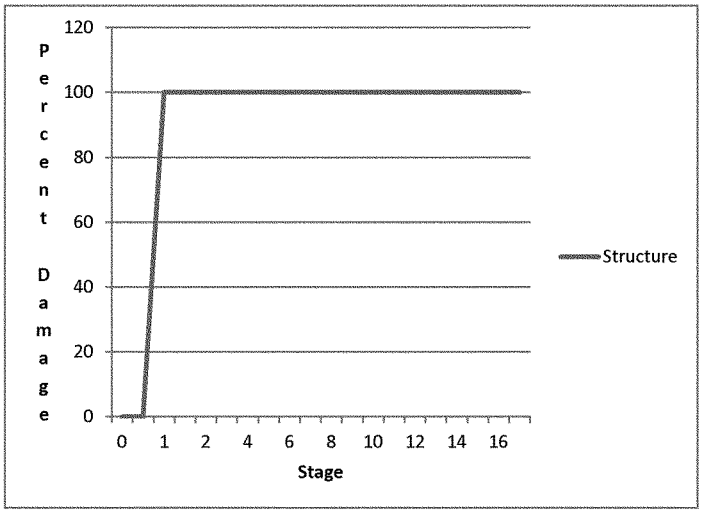
One Story Residence – Slab Foundation



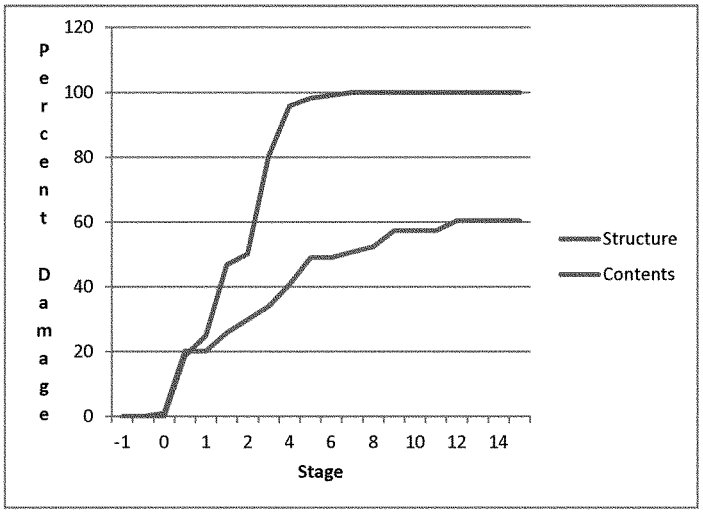
Two Story Residences – Slab Foundation



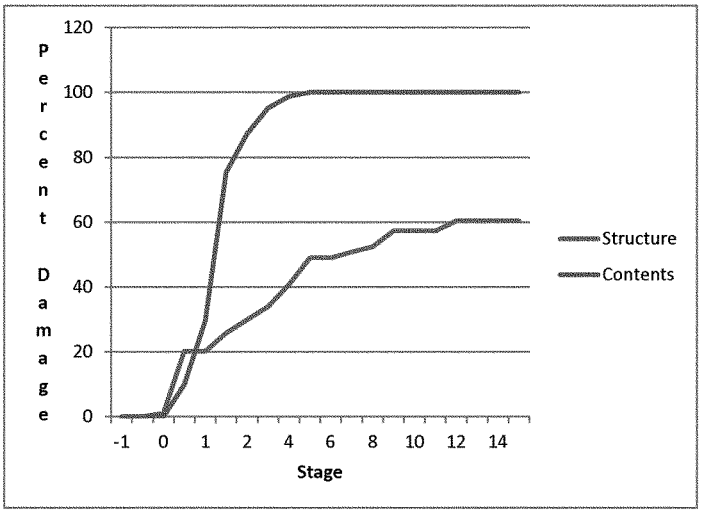
Autos



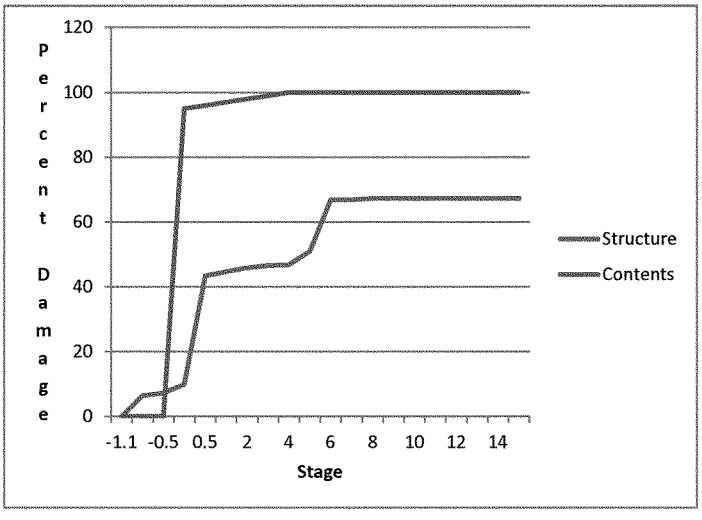
Eating Establishments



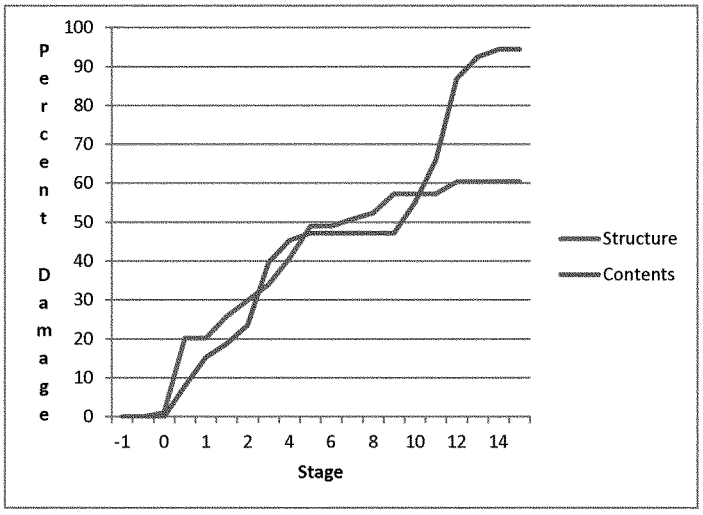
Grocery Stores



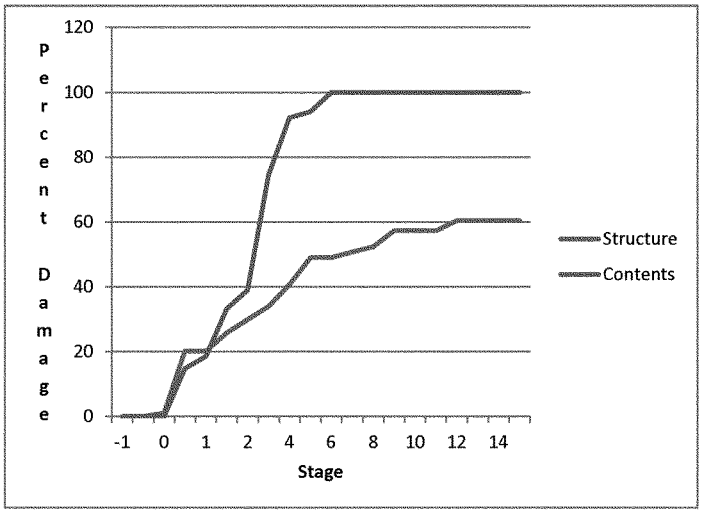
Mobile Residence



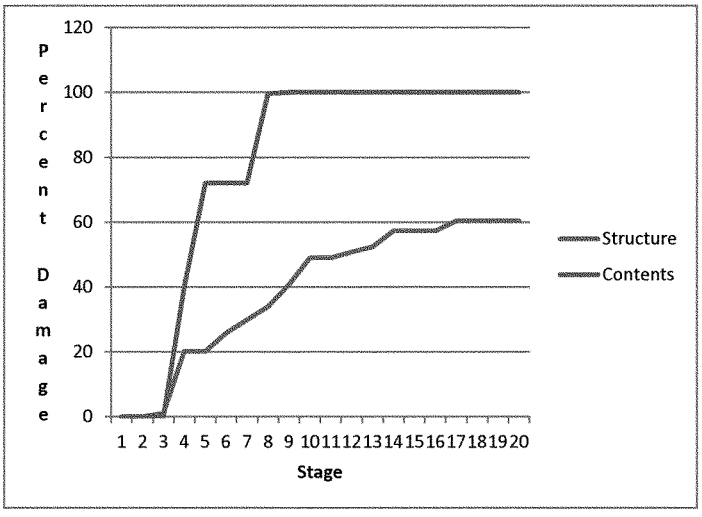
Multi-Family Residence



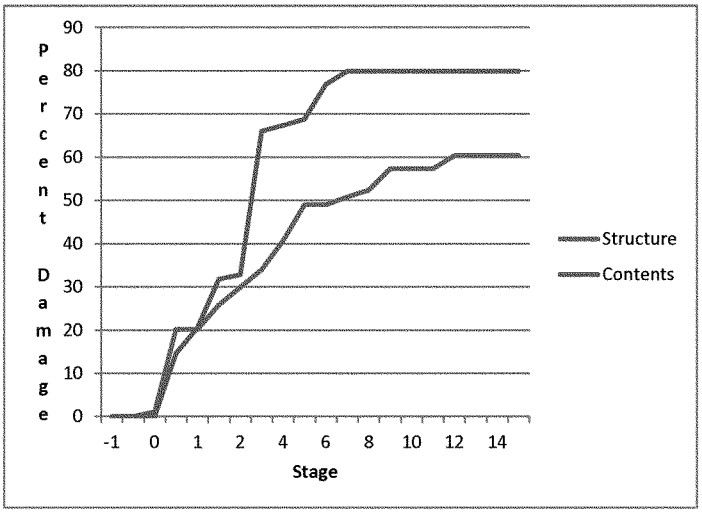
Professional Buildings



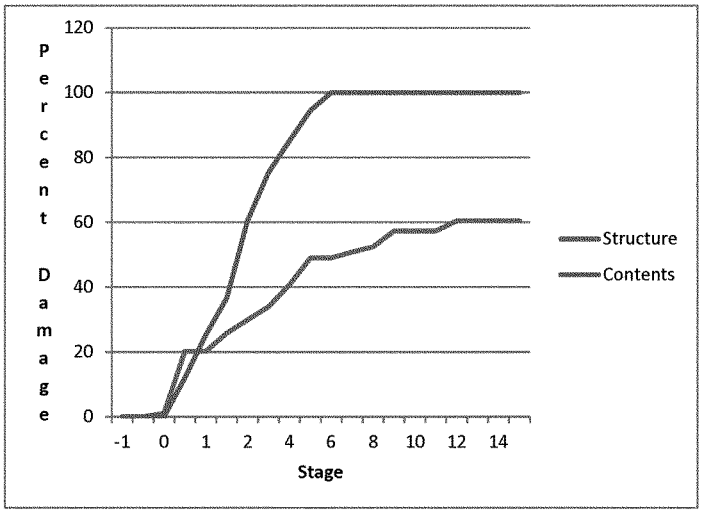
Public Buildings



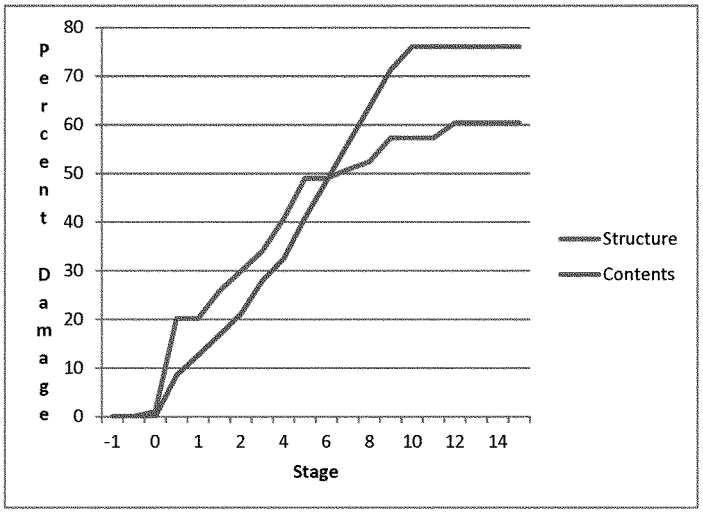
Repair



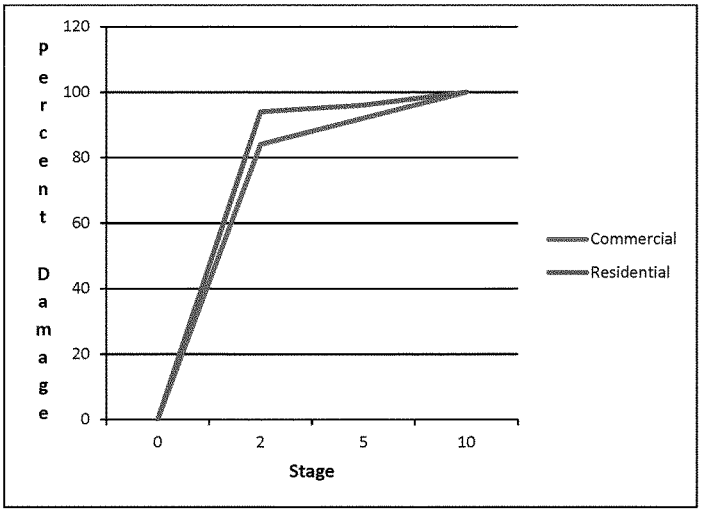
Retail



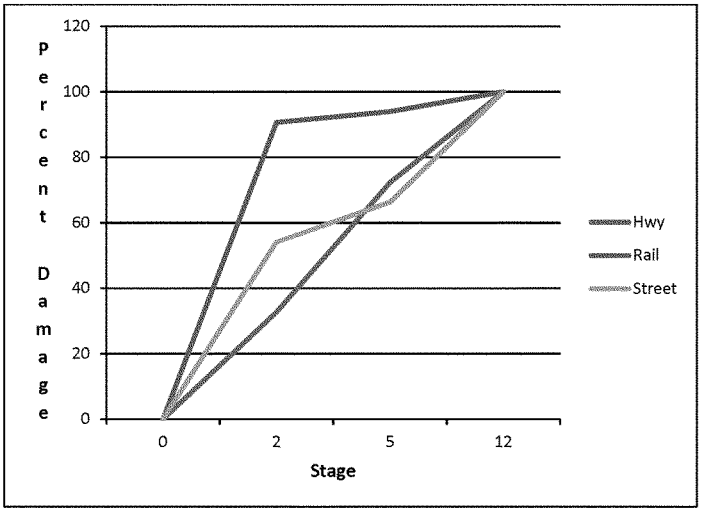
Warehouse



Debris Cleanup



Roads



2.13 LISTING OF CRITICAL INFRASTRUCTURE BY COUNTY

2.13.1 Orange

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
DuPont Sabine River Works	Orange	Pesticide and Other Agricultural Chemical Manufacturing
Solvay America Inc.	Orange	All Other Basic Inorganic Chemical Manufacturing
Latex Supply Inc.	Orange	All Other Basic Inorganic Chemical Manufacturing
Red Bird Supply, Inc.	Orange	Soap and Other Detergent Manufacturing
A Schulman Inc.	Orange	Plastics Material and Resin Manufacturing
Alloy Polymers, Inc.	Orange	Plastics Material and Resin Manufacturing
Clark & Company Inc.	Orange	All Other Basic Inorganic Chemical Manufacturing
Bourg Distributing Inc.	Bridge City	Polish and Other Sanitation Good Manufacturing
Hyett Manufacturing and Instrument Company, Inc.	Bridge City	All Other Basic Inorganic Chemical Manufacturing
Chevron Phillips Chemical Company LP	Orange	Plastics Material and Resin Manufacturing
Fine Line Colognes	Orange	Toilet Preparation Manufacturing
Lanxess Corporation Rubber Division	Orange	Synthetic Rubber Manufacturing
Invista S.A.R.L.	West Orange	Plastics Material and Resin Manufacturing
Chem32 LLC	West Orange	All Other Basic Inorganic Chemical Manufacturing
E. I. DuPont De Nemours and Company	Orange	Plastics Material and Resin Manufacturing
Nitrogen National	Orange	Industrial Gas Manufacturing
Lanxess Corp	Orange	All Other Basic Organic Chemical Manufacturing
Invista Capital Management, LLC	Orange	All Other Basic Organic Chemical Manufacturing
Invista S.A.R.L.	Orange	Plastics Material and Resin Manufacturing
Chevron Phillips Chemical Company LP	Orange	Plastics Material and Resin Manufacturing
Electric Generation		
Engineered Carbons Echo Cogeneration	Little Cypress	
Entergy Texas	Bridge City	
AirLiquide - Sabine Cogeneration LP	West Orange	
DuPont - Sabine River Works	West Orange	
SRW Cogeneration	West Orange	
Hospitals		
Harbor Hospital of Southeast Texas	Orange	

Memorial Hermann Baptist Orange Hospital	Orange
Nursing Homes	
Golden Years Assisted Living	Orange
Orange Villa Nursing and Rehabilitation	Orange
Pinehurst Nursing and Rehabilitation	Orange
Sabine House	Orange
The Meadows of Orange	Orange
Answered Prayer	Orange
Schools	
Little Cypress Jr. High	Orange
Bridge City High School	Bridge City
Bridge City Middle School	Bridge City
Little Cypress-Mauriceville High School	Orange
Little Cypress Elementary School	Orange
Little Cypress Intermediate	Orange
Oak Forest Elementary	Vidor
Vidor Middle School	Vidor
West Orange-Stark Elementary	Orange
West Orange-Stark Middle School	Orange
West Orange-Stark High School	Orange
North Early Learning Center	Orange
Orangefield Elementary	Orangefield
Orangefield High School	Orangefield
Orangefield Jr. High	Orangefield
Hatton Elementary	Bridge City
Bridge City Elementary	Bridge City
Bridge City Intermediate	Bridge City
OISD DAEP	Bridge City
Tekeo Academy of Accelerated Studies	Orange
Law Enforcement	
Orange County Sheriff Dept./Orange County Jail	Orange
Bridge City ISD Police Dept.	Bridge City
Orange Police Dept.	Orange
Rose City Police Dept.	Rose City
Vidor ISD Police Dept.	Vidor
Pine Forest Police Dept.	Vidor
Pinehurst Police Dept.	Orange
Vidor Police Dept.	Vidor
West Orange Police Dept.	Orange
Bridge City Police Dept.	Bridge City
Orange County Constable - Precinct 1	Orange
Orange County Constable - Precinct 2	Orange
Orange County Constable - Precinct 3	Orange

Orange County Constable - Precinct 4	Vidor
Fire Departments	
Bridge City Volunteer Fire and Rescue - Orangefield Station	Orange
Orange County Emergency Services District Station 1	Vidor
Orange County Emergency Services District Station 2	Vidor
Pinehurst Volunteer Fire Dept.	Orange
West Orange Volunteer Fire Dept.	West Orange
Little Cypress Fire and Rescue Station 1	Orange
Bridge City Volunteer Fire and Rescue	Bridge City
McLewis Volunteer Fire Dept.	Orange
City of Orange Fire Dept. Station 1	Orange
City of Orange Fire Dept. Station 2	Orange
City of Orange Fire Dept. Station 3	Orange
Airport	
Orange County Airport	Orange

2.13.2 Jefferson

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
Air Liquide America L.P.	Port Neches	Industrial Gas Manufacturing
Air Liquide America L.P.	Beaumont	Industrial Gas Manufacturing
Air Liquide Industrial U.S. LP	Nederland	Industrial Gas Manufacturing
Air Products and Chemicals, Inc.	Port Arthur	Industrial Gas Manufacturing
Arkema, Inc.	Beaumont	All Other Basic Inorganic Chemical Manufacturing
Ashland Elastomers LLC	Port Neches	Synthetic Rubber Manufacturing
Ashland Inc.	Port Neches	All Other Basic Organic Chemical Manufacturing
BASF Petro Chemicals	Port Arthur	All Other Miscellaneous Chemical Product and Preparation Manufacturing
BASF Petro Chemicals	Port Arthur	All Other Miscellaneous Chemical Product and Preparation Manufacturing
BASF Corporation	Beaumont	All Other Basic Organic Chemical Manufacturing
BASF Corporation	Port Arthur	All Other Basic Organic Chemical Manufacturing
Brock Specialty Services, Ltd.	Beaumont	All Other Basic Inorganic Chemical Manufacturing
Calabrian Corporation	Port Neches	All Other Basic Organic Chemical Manufacturing

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
Chemtrade Refinery Services Inc.	Beaumont	All Other Basic Inorganic Chemical Manufacturing
Chemtreat, Inc.	Nederland	All Other Miscellaneous Chemical Product and Preparation Manufacturing
Chevron Phillips Chemical Company LP	Port Arthur	All Other Miscellaneous Chemical Product and Preparation Manufacturing
DuPont Performance Elastomers L.L.C.	Nederland	Synthetic Rubber Manufacturing
Elegant Designer Essences	Port Arthur	Toilet Preparation Manufacturing
Elixir Incense	Port Arthur	All Other Miscellaneous Chemical Product and Preparation Manufacturing
Ethyl Additives Corporation	Port Arthur	All Other Basic Organic Chemical Manufacturing
Faubion Veterinary Clinic	Nederland	Pharmaceutical Preparation Manufacturing
Flint Hills Resources Port Arthur LLC	Port Arthur	All Other Basic Organic Chemical Manufacturing
G V C Holdings Inc.	Port Neches	Synthetic Rubber Manufacturing
Huntsman Corporation	Port Neches	Plastics Material and Resin Manufacturing
In Your Element Photography	Port Neches	All Other Basic Inorganic Chemical Manufacturing
Ineos Americas LLC	Port Arthur	All Other Miscellaneous Chemical Product and Preparation Manufacturing
J & M Resources	Port Arthur	Toilet Preparation Manufacturing
J F D Enterprises, Inc.	Groves	Toilet Preparation Manufacturing
Kbr Technical Services, Inc.	Beaumont	All Other Miscellaneous Chemical Product and Preparation Manufacturing
Kmtex	Port Arthur	All Other Basic Inorganic Chemical Manufacturing
La Designs	Port Arthur	Toilet Preparation Manufacturing
Nature's Secret	Port Arthur	Medicinal and Botanical Manufacturing
Neo Fuels	Port Arthur	Petrochemical Manufacturing
Oci Partners LP	Nederland	Cyclic Crude, Intermediate, and Gum and Wood Chemical Manufacturing
Pd Glycol LP	Beaumont	Plastics Material and Resin Manufacturing
Penny's Style	Port Arthur	Toilet Preparation Manufacturing
Perfume Palace	Port Arthur	Toilet Preparation Manufacturing
Praxair, Inc.	Groves	Industrial Gas Manufacturing
Pro Star Industries, Inc.	Port Arthur	Polish and Other Sanitation Good Manufacturing
Rbf Port Neches LLC	Port Neches	Petrochemical Manufacturing
Reliable Polymer Services, LP	Port Arthur	Synthetic Rubber Manufacturing
Sally Beauty Supply LLC	Port Arthur	Toilet Preparation Manufacturing
Savage Services Corporation	Port Arthur	All Other Basic Inorganic Chemical Manufacturing

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
Scan Tech, Inc.	Nederland	All Other Miscellaneous Chemical Product and Preparation Manufacturing
Service Offshore, Inc.	Beaumont	Paint and Coating Manufacturing
Smith and Thome Cardiovascular Consultants, L.L.P.	Port Arthur	Pharmaceutical Preparation Manufacturing
Sophia's International LLC	Port Neches	Toilet Preparation Manufacturing
Sunrose Scents	Nederland	Toilet Preparation Manufacturing
Texas Brine Company LLC	Beaumont	All Other Basic Inorganic Chemical Manufacturing
Texas Petrochemicals LP	Port Neches	All Other Basic Organic Chemical Manufacturing
Texas Petrochemicals LP	Port Neches	All Other Basic Organic Chemical Manufacturing
The Chemours Company Fc LLC	Beaumont	Synthetic Rubber Manufacturing
The Valspar Corporation	Beaumont	Paint and Coating Manufacturing
Worldwide Sorbent Products, Inc.	Port Arthur	Plastics Material and Resin Manufacturing
Petroleum Refining		
Exxon Mobil Refining & Supply Co.	Beaumont	
Total Petrochemicals Inc.	Port Arthur	
Motiva Enterprises LLC	Port Arthur	
Premcor Refining Group	Port Arthur	
Valero Refining Co.	Port Arthur	
Electric Generation	**City**	
JCO Oxides Olefins Plant	Port Neches	
Entergy Texas	Beaumont	
Public Schools	**City**	
Al Price State Juvenile Correctional Facility	Beaumont	
Jefferson County Youth Academy	Beaumont	
Preschool Center	Groves	
Groves Elementary	Groves	
Groves Middle School	Groves	
Van Buren Elementary	Groves	
Highland Park Elementary	Nederland	
Nederland High School	Nederland	
Alternative Education School	Nederland	
Helena Park Elementary	Nederland	
Hillcrest Elementary	Nederland	
Lanham Elementary	Nederland	
Central Middle School	Nederland	
Wilson Middle School	Nederland	
Dowling Elementary	Port Arthur	
Houston Elementary	Port Arthur	

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
Port Arthur Alternative Center	Port Arthur	
Stilwell Tech Center	Port Arthur	
Memorial High School	Port Arthur	
Tekeo Academy of Accelerated Studies	Port Arthur	
DeQueen Elementary	Port Arthur	
Jefferson Middle School	Port Arthur	
Lee Elementary	Port Arthur	
Travis Elementary	Port Arthur	
Tyrrell Elementary	Port Arthur	
Wheatley School Of Early Childhood Programs	Port Arthur	
Lincoln Middle School	Port Arthur	
Taft Elementary	Port Arthur	
Austin Middle School	Port Arthur	
Tekeo Academy of Accelerated Studies	Port Arthur	
Tekeo Academy of Accelerated Studies	Port Arthur	
Bob Hope School	Port Arthur	
Performing Arts School Of Technology	Port Arthur	
Staff Sergeant Lucien Adams Elementary	Port Arthur	
Washington Elementary	Port Arthur	
Memorial 9th Grade Academy at Austin	Port Arthur	
Woodcrest Elementary	Port Neches	
Port Neches Elementary	Port Neches	
Port Neches Middle School	Port Neches	
Port Neches-Groves High School	Port Neches	
Ridgewood Elementary	Port Neches	
Alter School	Port Neches	
Nursing Homes	**City**	
Gulf Healthcare Center	Port Arthur	
Magnolia Manor	Groves	
Oak Grove Nursing Home	Groves	
Senior Rehabilitation and Skilled Nursing Center	Port Arthur	
Cypress Glen East Nursing and Rehabilitation	Port Arthur	
Cypress Glen Nursing and Rehabilitation	Port Arthur	
Rose House	Port Arthur	
Hospitals	**City**	
Beaumont Bone and Joint Institute	Beaumont	
Christus Spohn Hospital - Saint Elizabeth	Beaumont	
Christus Spohn Hospital - Saint Mary	Port Arthur	
Dubuis Hospital of Beaumont	Beaumont	
Dubuis Hospital of Port Arthur	Port Arthur	

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
HealthSouth Rehabilitation Hospital - Beaumont	Beaumont	
Kate Dishman Rehabilitation Hospital	Beaumont	
Memorial Hermann Baptist Hospital	Beaumont	
Memorial Hermann Baptist Hospital - Behavioral Health Center	Beaumont	
Mid-Jefferson Extended Care Hospital	Nederland	
Promise Hospital of Southeast Texas	Nederland	
Renaissance Hospital - Groves	Groves	
The Medical Center of Southeast Texas	Port Arthur	
Law Enforcement	**City**	
Lamar University Police Dept.	Beaumont	
Beaumont Police Dept.	Beaumont	
Groves Police Dept.	Groves	
Port of Beaumont Port Authority Police Dept.	Beaumont	
Port Neches Police Department	Port Neches	
Bureau of Alcohol Tobacco & Firearms - Beaumont Field Office	Beaumont	
US Customs and Border Protection - Port of Entry - Port Arthur	Port Arthur	
Port Arthur Police Dept.	Port Arthur	
Jefferson County Sheriff's Office	Beaumont	
Beaumont ISD Police Dept.	Beaumont	
Nederland Police Department	Nederland	
Texas Dept. of Public Safety	Beaumont	
Jefferson County Constable - Precinct 1	Beaumont	
Jefferson County Constable - Precinct 2	Port Arthur	
Jefferson County Constable - Precinct 4	Beaumont	
Jefferson County Constable - Precinct 6	Beaumont	
Jefferson County Constable - Precinct 7	Beaumont	
Jefferson County Constable - Precinct 8	Port Arthur	
US Marshal's Service - Beaumont	Beaumont	
Fire Departments	**City**	
Port Arthur Fire Dept. Central Station	Port Arthur	
Beaumont Fire and Rescue Station 1	Beaumont	
Nederland Fire and Rescue	Nederland	
Beaumont Fire and Rescue Station 10	Beaumont	
Beaumont Fire and Rescue Station 11	Beaumont	
Beaumont Fire and Rescue Station 14	Beaumont	
Beaumont Fire and Rescue Station 2	Beaumont	
Beaumont Fire and Rescue Station 3	Beaumont	
Beaumont Fire and Rescue Station 4	Beaumont	

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
Beaumont Fire and Rescue Station 5	Beaumont	
Beaumont Fire and Rescue Station 6	Beaumont	
Beaumont Fire and Rescue Station 7	Beaumont	
Beaumont Fire and Rescue Station 7	Beaumont	
Beaumont Fire and Rescue Station 9	Beaumont	
Groves Fire Dept.	Groves	
Jefferson Volunteer Fire Dept.	Nederland	
LaBelle - Fannett Volunteer Fire/Emergency Medical Services - Substation	Beaumont	
Lamar Institute of Technology Regional Fire Academy	Beaumont	
Port Arthur Fire Dept. Station 1	Port Arthur	
Port Arthur Fire Dept. Station 2	Port Arthur	
Port Arthur Fire Dept. Station 3	Port Arthur	
Port Arthur Fire Dept. Station 4	Port Arthur	
Port Arthur Fire Dept. Station 5	Port Arthur	
Port Arthur Fire Dept. Station 6	Port Arthur	
Port Arthur Fire Dept. Station 8	Port Arthur	
Port Neches Fire Dept.	Port Arthur	

2.13.3 Brazoria

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
L C Huntsman-Cooper	Freeport	Plastics Material and Resin Manufacturing
Ineos Americas LLC	Freeport	All Other Basic Inorganic Chemical Manufacturing
K-Bin, Inc.	Freeport	Plastics Material and Resin Manufacturing
Air Liquide Large Industries U.S. LP	Freeport	Industrial Gas Manufacturing
Air Liquide Industrial U.S. LP	Freeport	Industrial Gas Manufacturing
S F Sulphur Company	Freeport	All Other Basic Inorganic Chemical Manufacturing
Nalco Energy Services L P	Freeport	All Other Miscellaneous Chemical Product and Preparation Manufacturing
Services Enterprise	Freeport	Polish and Other Sanitation Good Manufacturing
Air Liquide America L.P.	Freeport	Industrial Gas Manufacturing
Shintech Incorporated	Freeport	Plastics Material and Resin Manufacturing
Air Liquide Large Industries U.S. LP	Freeport	Industrial Gas Manufacturing
Air Liquide Large Industries U.S. LP	Freeport	Industrial Gas Manufacturing
Samdac Industries	Freeport	Plastics Material and Resin Manufacturing
Si Group, Inc.	Freeport	Petrochemical Manufacturing

Chemical Manufacturing		
Business Name	**City**	**NAICS Category**
The Dow Chemical Company	Freeport	All Other Basic Inorganic Chemical Manufacturing
Avon	Freeport	Toilet Preparation Manufacturing
Solvay USA, Inc.	Freeport	All Other Basic Inorganic Chemical Manufacturing
The Dow Chemical Company	Freeport	Plastics Material and Resin Manufacturing
Matheson Tri-Gas, Inc.	Freeport	Industrial Gas Manufacturing
Vencorex U.S., Inc.	Freeport	All Other Basic Organic Chemical Manufacturing
Vencorex U.S., Inc.	Freeport	All Other Basic Organic Chemical Manufacturing
BASF Corporation	Freeport	All Other Basic Organic Chemical Manufacturing
Ineos	Freeport	All Other Miscellaneous Chemical Product and Preparation Manufacturing
Americas Styrenics LLC	Freeport	Plastics Material and Resin Manufacturing

Schools	City
Brazosport High School	Freeport
OA Fleming Elementary	Freeport
Freeport Intermediate	Freeport
Jane Long Elementary	Freeport
Velasco Elementary	Freeport
O'Hara Lanier Middle School	Freeport

Fire Departments	City
Oyster Creek Volunteer Fire Dept.	Freeport
Freeport Fire and Emergency Medical Services Dept.	Freeport

Law Enforcement	City
Freeport City Marshals Office	Freeport
Freeport Police Dept.	Freeport
Brazoria County Constable - Precinct 1	Freeport

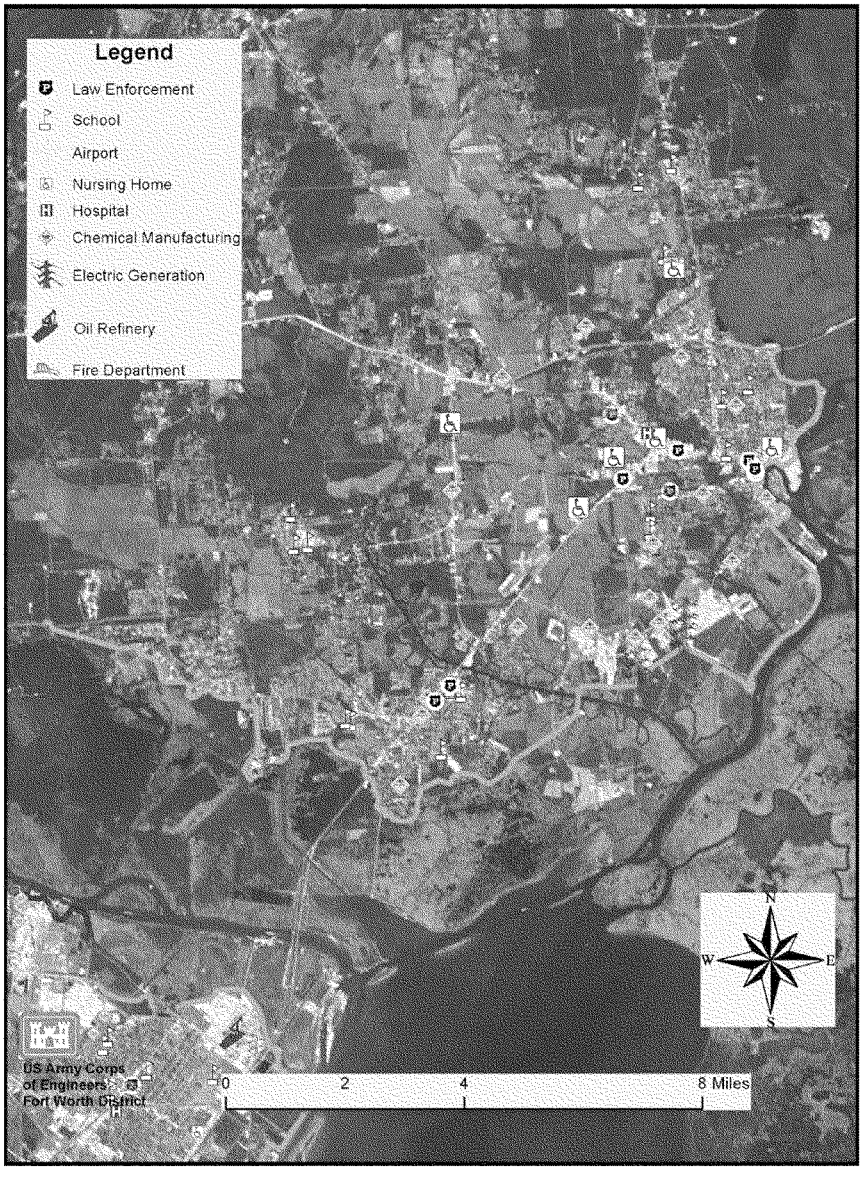


Figure 2-15. Orange County Critical Infrastructure

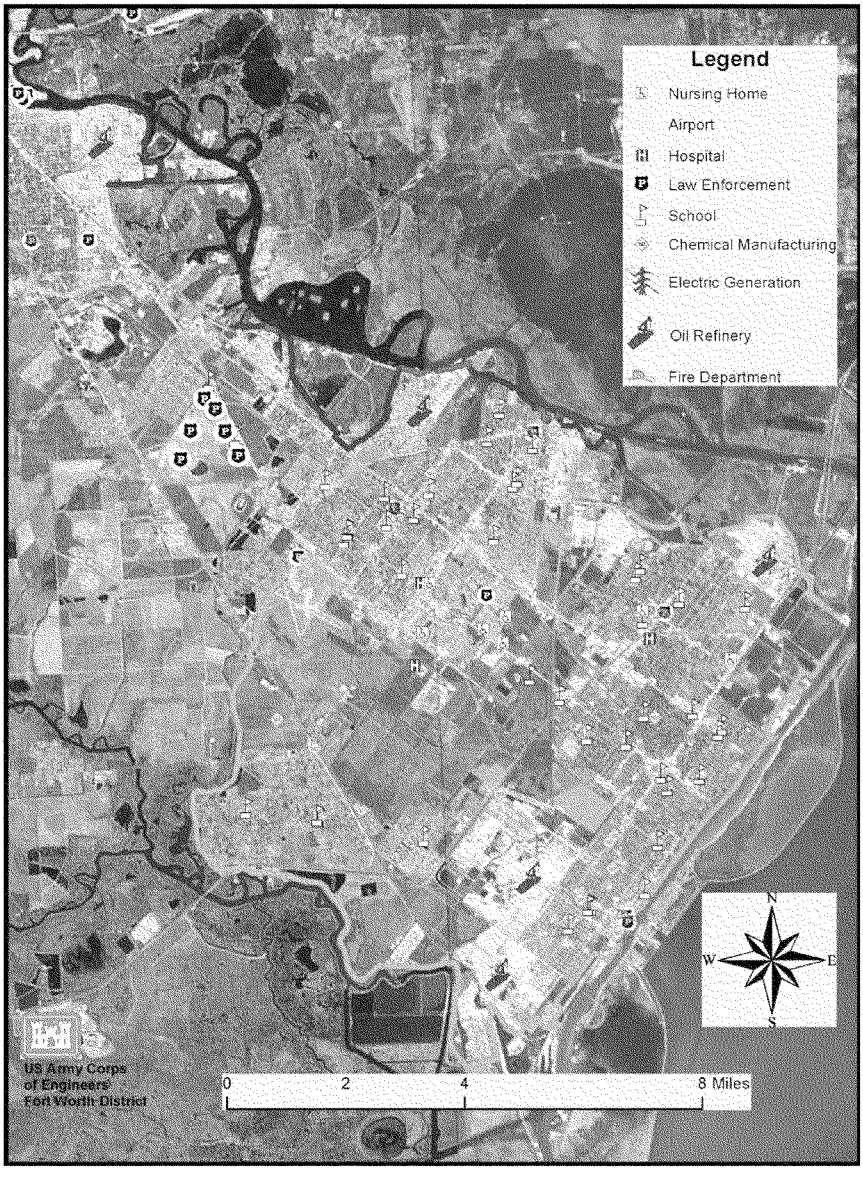


Figure 2-16. Jefferson County Critical Infrastructure

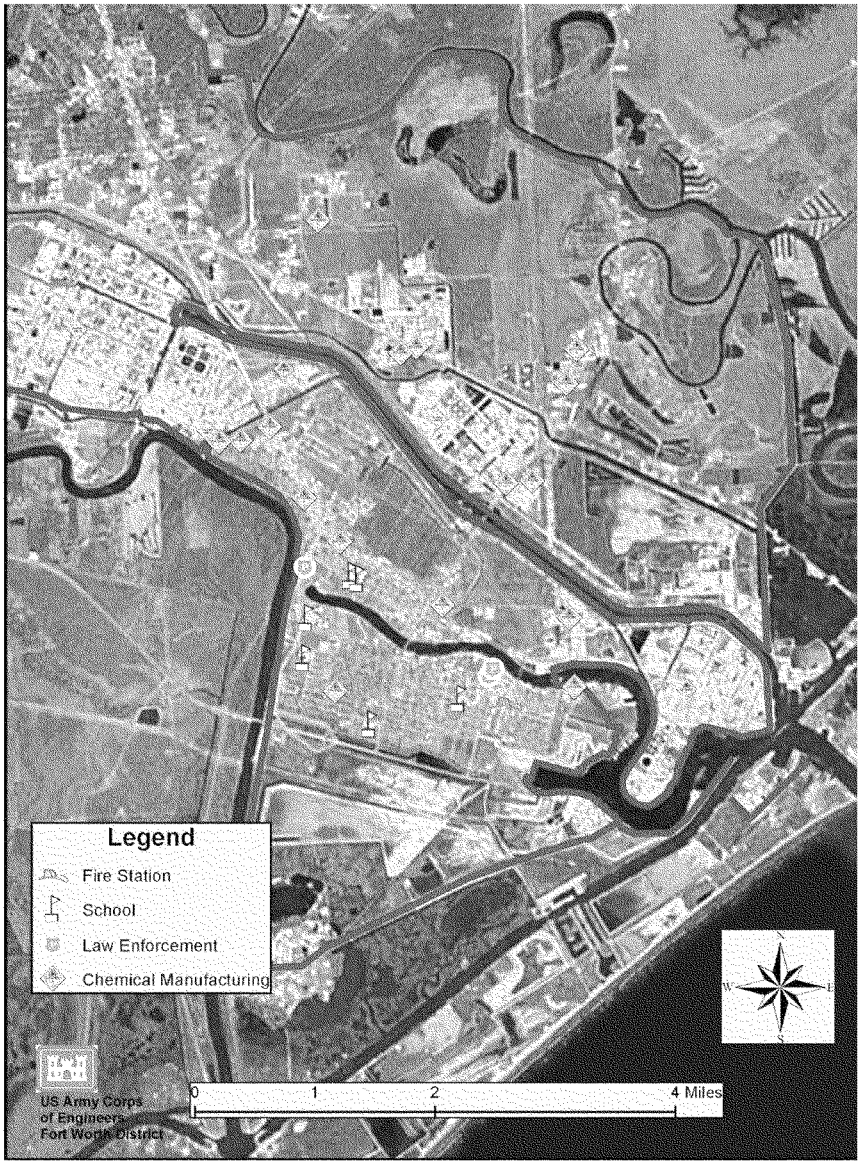


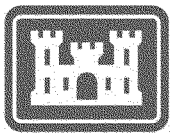
Figure 2-17. Brazoria County Critical Infrastructure

Sabine Pass to Galveston Bay, Texas
Coastal Storm Risk Management and Ecosystem Restoration
Final Integrated Feasibility Report And Environmental Impact Study

Appendix D

Engineering Design and Cost Estimates

May 2017



US Army Corps
of Engineers
Galveston District

Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration

Engineering Appendix

for

Final Integrated Feasibility Report – Environmental Impact Statement (FIFR-EIS)

May 2017

TABLE OF CONTENTS

FIGURES ..... **VIII**

TABLES ..... **XI**

ATTACHMENTS – ENGINEERING DESIGNS AND MAPS ..... **XIII**

LIST OF ACRONYMS ..... **XV**

1 GENERAL **18**

1.1 PURPOSE AND CONTEXT 18
1.2 SCOPE OF EFFORT 18
1.3 ENGINEERING DOCUMENTATION 19
1.4 PROJECT AREAS 19
1.5 PROJECT OVERVIEW 21
1.5.1 Project Need 21
1.5.2 Project Objective 21
1.5.3 Project Coordination 22
1.5.4 Project Background 22
1.5.5 Project Datum 22
1.6 GENERAL ASSUMPTIONS 23
1.6.1 Design Considerations 23
1.6.2 Relative Sea-Level Change 24
1.7 DESIGN ANALYSES PROCESS FOR THE RECOMMENDED PLAN 25
1.8 DESCRIPTION OF EXISTING PROJECT AREAS 26
1.8.1 Orange-Jefferson CSRM 26
1.8.2 Port Arthur and Vicinity CSRM 26
1.8.3 Freeport and Vicinity CSRM 29
1.9 PLAN EVALUATION, COMPARISON, AND SELECTION 30
1.9.1 Port Arthur and Vicinity CSRM Project 31
1.9.2 Freeport and Vicinity CSRM Project 32
1.10 DESCRIPTION OF RECOMMENDED PLAN 42
1.10.1 Orange-Jefferson CSRM Project 42
1.10.1.1 Orange 3 Reach 42
1.10.2 Port Arthur and Vicinity CSRM Project 44
1.10.2.1 Reach 1 47
1.10.2.2 Reach 2 47
1.10.2.3 Reach 3 48
1.10.2.4 Reach 4 48
1.10.2.5 Reach 5 49
1.10.2.6 Port Arthur Extension 49

1.10.3 Freeport and Vicinity CSRM Project 50
1.10.3.1 Oyster Creek and Oyster Creek Extension 54
1.10.3.2 East Storm 54
1.10.3.3 DOW Barge Canal 54
1.10.3.4 Old River North 55
1.10.3.5 Tide Gate 56
1.10.3.6 Old River South 56
1.10.3.7 South Storm 56
1.10.3.8 East Bank Brazos River 57
1.11 ADAPTABILITY 57
1.12 DEFERRED MAINTENANCE 58
2 HYDROLOGY AND HYDRAULICS 59
2.1 INTRODUCTION 59
2.1.1 Brazoria Region 59
2.1.2 Sabine Region 61
2.2 REGIONAL DATA 64
2.2.1 Units and Coordinate System 64
2.2.2 Gage Data 64
2.2.3 Datum and Tidal Information 65
2.3 EXISTING DATA COLLECTION 67
2.3.1 Data Collection Summary 67
2.3.2 Topographic, Bathymetric, and Survey Data 67
2.3.3 FEMA Data 67
2.3.4 Tropical Cyclones and Floods of Record 68
2.4 SUMMARY OF PROJECT AREAS AND H&H OBJECTIVE 69
2.5 ANALYSIS OF HYDRAULIC LOADING FOR FLOOD PROTECTION SYSTEMS 69
2.6 EXISTING DATA SUMMARY 71
2.6.1 Storm Surge and Adjacent Impact Analysis 71
2.6.2 Brazoria Region 71
2.6.3 Sabine Region 72
2.7 ANALYSIS OF STORM WATER LEVEL AND WAVES 73
2.7.1 Storm Modeling Approach 74
2.7.1.1 Brazoria Region 74
2.7.1.2 Sabine Region 77
2.8 LOCAL WAVE TRANSFORMATION AND CALCULATIONS 79
2.8.1 Software Description 79
2.8.2 Model Approach and Conventions 80
2.8.3 Direction Convention 80

2.8.4 Model Parameters 80
2.8.5 Calibration and Verification 80
2.9 MODEL RESULTS 80
2.9.1 Brazoria Region (Freeport) 80
2.9.2 Sabine Region 83
2.9.3 H&H Data for Levee NED Analysis 85
2.9.4 Wave Overtopping Analysis Methods 86
2.10 ADDITIONAL LEVEE ANALYSIS CONSIDERING FEMA AND USACE CRITERIA FOR REQUIRED LEVEE HEIGHTS 87
2.10.1 General Process 87
2.10.2 Recommended Elevations for Brazoria Region (Freeport) 88
2.10.3 Recommended Elevations for Sabine Region 89
2.11 ADJACENT IMPACTS 90
2.12 NED PLANS COMPARED TO RECOMMENDED FEMA CERTIFICATION AND USACE HEIGHTS 91
2.13 CLIMATE CHANGE 91
2.13.1 Relative Sea-Level Change 91
2.13.2 Historical RSLC 92
2.13.3 Predicted Future Rates of RSLC for 20-Year Period of Analysis 95
2.13.4 Predicted Future Rates of RSLC for 50-Year Period of Analysis 98
2.13.5 Predicted Future Rates of RSLC – 100-year Sea-Level Change 102
2.13.6 Total Water Level Approach 106
2.13.7 Additional Climate Change Considerations 109
2.13.8 Conclusions and Recommendations regarding Climate Change and RSLC 112
2.14 INTERIOR DRAINAGE 112
2.15 EXISTING LEVEE SYSTEMS INTERIOR DRAINAGE 113
2.15.1 Brazoria Region Data (Freeport and Vicinity) 113
2.15.2 Sabine Region Data (Port Arthur and Vicinity) 114
2.15.3 Preliminary Screening of Neches River Gate Alternative 115
2.15.4 Consideration of Storm Surge Damages in Port/City of Beaumont 118
2.15.5 Interior Drainage Analysis of Proposed Orange Levee System 120
2.15.6 Drainage Area Delineation 120
2.15.7 Drainage Area Discharge Estimates 121
2.15.8 Rational Method 121
2.15.9 Regression Method 123
2.15.10 Pumps 129
2.15.11 Gate Structures 130
2.16 LEVEE INTERIOR FLOODPLAIN IMPACT ANALYSIS 131

2.17 SEDIMENTATION AND SEDIMENT TRANSPORT 132
2.18 ENVIRONMENTAL IMPACTS OF PROPOSED DRAINAGE SYSTEM 135
2.18.1 Gate Structures on Cow and Adams Bayous 136
2.18.2 Cow Bayou Analysis 138
2.18.3 Adams Bayou Analysis 141
2.18.4 Neches River Gate 144
2.18.5 Discussion and Conclusions of Cow and Adams Proposed Gate Structures 144
2.18.6 Culverts and additional Interior Drainage Structures 145
2.18.7 Pumps 148
2.18.8 Drainage Environmental Impacts Summary and Conclusions 149
2.19 HYDROLOGIC AND HYDRAULIC REFERENCES 149
3 SURVEYING, MAPPING, AND OTHER GEOSPATIAL DATA REQUIREMENTS 154
4 GEOTECHNICAL 155
4.1 SUMMARY 155
4.2 INTRODUCTION 155
4.3 DESIGN CRITERIA 157
4.3.1 Selection of Design Criteria 157
4.3.2 Historical Documentation and Input Data 158
4.3.3 Survey Data 158
4.3.4 Reference Documents 159
4.3.4.1 USACE Engineer Manuals 159
4.3.4.2 USACE Engineer Technical Letters 159
4.3.4.3 USACE Engineering Regulations 159
4.3.4.4 Other USACE Engineering Guidelines 159
4.3.4.5 Drawings and Reports 159
4.3.5 Surficial Geology 159
4.3.6 Software 160
4.4 GEOTECHNICAL ANALYSIS 160
4.4.1 Foundation Conditions 160
4.4.2 Analysis Cross Section Selection and Soil Parameters 161
4.4.2.1 Orange 162
4.4.2.2 Freeport and Port Arthur 164
4.4.3 Geotechnical Design Assumptions 164
4.4.4 Material Properties 165
4.4.4.1 Saturated Unit Weights 165
4.4.5. Design Loads 165

4.4.5.1. Dead Load (D) 165
4.4.5.2 Hydraulic Load (H) 165
4.4.5.2.1. Hydrostatic Pressure (Ps) 165
4.4.5.3 Earthquake Loads (EQ) 166
4.4.6 Seepage Analysis 166
4.4.7 Slope Stability Analysis 167
4.4.8 Settlement Analysis and Results 167
4.5 RECOMMENDATIONS 167
4.5.1 Orange 167
4.5.2 Existing Systems – Port Arthur and Freeport 168
5 ENVIRONMENTAL IMPACTS AND ENGINEERING 170
5.1 USE OF ENVIRONMENTALLY RENEWABLE MATERIALS 170
5.2 DESIGN OF POSITIVE ENVIRONMENTAL ATTRIBUTES INTO THE PROJECT 170
5.3 INCLUSION OF ENVIRONMENTALLY BENEFICIAL OPERATIONS AND MANAGEMENT FOR THE PROJECT 171
5.4 BENEFICIAL USES OF SPOIL OR OTHER PROJECT REFUSE DURING CONSTRUCTION AND OPERATION 172
5.5 ENERGY SAVINGS FEATURES OF THE DESIGN 172
5.6 MAINTENANCE OF ECOLOGICAL CONTINUITY WITH THE SURROUNDING AREA AND WITHIN THE REGION 173
5.7 CONSIDERATION OF INDIRECT ENVIRONMENTAL COSTS AND BENEFITS 173
5.8 INTEGRATION OF ENVIRONMENTAL SENSITIVITY 174
5.9 CONSIDERATION OF ENVIRONMENTAL PROBLEMS ON SIMILAR PROJECTS WITH RESPECT TO THE ENVIRONMENTAL REVIEW GUIDE FOR OPERATIONS (ERGO) 174
5.10 INCORPORATION OF ENVIRONMENTAL COMPLIANCE MEASURES. 174
5.11 ENVIRONMENTAL IMPACTS 175
6 CIVIL DESIGN 176
6.1 SITE SELECTION AND PROJECT DEVELOPMENT 176
6.1.1 CSRM Alignments 176
6.1.1.1 Orange-Jefferson County Alignment 176
6.1.1.2 Port Arthur HFPP Alignment 178
6.1.1.3 Freeport HFPP Alignment 178
6.1.2 Site Development 179
6.1.2.1 Orange-Jefferson County HFPP 179
6.1.2.2 Port Arthur and Vicinity CSRM 179

6.1.2.3 Freeport and Vicinity CSRM 180
6.2 REAL ESTATE 181
6.2.1 General 181
6.2.2 Orange-Jefferson County CSRM 181
6.2.3 Port Arthur and Vicinity HFPP 182
6.2.4 Freeport and Vicinity HFPP 182
6.3 RELOCATIONS 182
6.3.1 Pipelines 182
6.3.1.1 Pipelines Crossing Orange-Jefferson County CSRM 184
6.3.1.2 Pipelines crossing Port Arthur and Vicinity and Freeport and Vicinity HFPPs 184
6.3.2 Pipeline Relocation Method 184
6.3.3 Road Crossings 185
7 STRUCTURAL 190
7.1 INTRODUCTION 190
7.2 FLOODWALL 193
7.2.1 Assumptions 193
7.2.2 Structural Analysis 194
7.2.2.2 Load Cases and Factors 195
7.2.2.3 Design 197
7.2.3 Conclusions 199
7.3 NAVIGABLE GATE STRUCTURES 202
7.3.1 Concept Design 202
7.3.1.1 Adams Bayou 205
7.3.1.2 Cow Bayou 206
7.3.1.3 DOW Barge Canal 206
7.3.2 Conclusions 207
7.4 EXISTING SYSTEMS 207
7.4.1 Port Arthur and Vicinity CSRM 208
7.4.1.1 Reach 1 (STA 0+00 to 381+30) 209
7.4.1.2 Reach 2 (STA 381+30 to 579+87) 210
7.4.1.3 Reach 3 (STA 579+87 to 733+41) 212
7.4.1.4 Reach 4 (STA 733+41 to 970+00) 214
7.4.1.5 Reach 5 (STA 970+00 to 1609+00) 216
7.4.2 Freeport and Vicinity CSRM 217
7.4.2.1 Oyster Creek and Oyster Creek Extension 218
7.4.2.2 East Storm 219
7.4.2.3 DOW Barge Canal 220
7.4.2.4 Old River North 222

7.4.2.5 Tide Gate 224
7.4.2.6 Old River South 225
7.4.2.7 East Bank Brazos River 226
7.4.3 Conclusions 227
7.5 OTHER STRUCTURAL COMPONENTS 228
7.6 REFERENCES 228
8 HAZARDOUS AND TOXIC MATERIALS 229
8.1 ORANGE-JEFFERSON COUNTY CSRM 229
8.2 PORT ARTHUR AND VICINITY CSRM 230
8.3 FREEPORT AND VICINITY CSRM 230
9 COST ESTIMATES 231
10 BACKGROUND INFORMATION 236
10.1 DESCRIPTION OF TSP PROJECTS 236
10.1.1 Orange-Jefferson CSRM Project 236
10.1.1.1 Orange 3 Reach 236
10.1.1.2 Jefferson Main Reach 237
10.1.1.3 Beaumont "A" Reach 237
10.1.2 Port Arthur and Vicinity CSRM Project 238
10.1.2.1 Port Arthur 8- to 10-foot I-Wall One-Foot Raise 238
10.1.2.2 Port Arthur Closure Structure 238
10.1.2.3 I-Wall near Valero 238
10.1.2.4 Port Arthur Tank Farm 239
10.1.3 Freeport and Vicinity CSRM Project 239
10.1.3.1 South Storm Levee Raise 239
10.1.3.2 Freeport Dock Floodwall Raise 239
10.1.3.3 Tide Gate One-Foot Raise 239
10.1.3.4 Old River at Dow Thumb 239
10.1.3.5 Dow Barge Canal Protection 240
10.1.3.6 East Storm Levee Raise 240
10.1.3.7 Oyster Creek Levee Raise 240

FIGURES

Page

Figure 1-1: Sabine and Brazoria Regions including Orange, Jefferson, and Brazoria Counties.. 20
Figure 1-2: Existing Levee System within Port Arthur and Vicinity CSRM Project Area 27
Figure 1-3: Existing Levee System within Freeport and Vicinity CSRM Project Area..... 29
Figure 1-4: Orange 3 CSRM – Recommended Plan..... 43
Figure 1-5: Orange 3 - Geo Point ID Locations 44
Figure 1-6: Port Arthur and Vicinity CSRM – Recommended Plan 45
Figure 1-7: Port Arthur - Geo Point ID Locations..... 46
Figure 1-8: Freeport and Vicinity CSRM – Recommended Plan 51
Figure 1-9: Freeport - Geo Point ID Locations..... 52
Figure 2-1: Existing Freeport and Vicinity HFPP 61
Figure 2-2: Existing Port Arthur and Vicinity HFPP..... 62
Figure 2-3: Original Extents of Proposed New Orange and Jefferson Counties Levee Systems Considered, later modified and optimized..... 63
Figure 2-4: NOAA Tidal Gage 8772440 in Brazoria Region..... 64
Figure 2-5: NOAA Tidal Gages 8770570 and 8770520, Sabine Region 65
Figure 2-6: Map of Freeport Area with Select Data Gathered..... 72
Figure 2-7: Map of Sabine Region with Select Data Gathered 73
Figure 2-8: Average 1.0% ACE Still-Water Level at Freeport 75
Figure 2-9: 90% Confidence Level for the 1.0% ACE Still-Water Level at Freeport..... 76
Figure 2-10: Example of Average Water-Level Return Periods at Freeport 76
Figure 2-11: Average 1 % ACE Still-Water Level in Sabine Region 78
Figure 2-12: 90 percent Confidence Level for the 1 % ACE Still-Water Levels in Sabine Region 78
Figure 2-13: Example of Average Water-Level Return Periods in Sabine Region..... 79
Figure 2-14: STWAVE Model Domains at Freeport..... 81
Figure 2-15: Freeport Local Wave Output Locations..... 82
Figure 2-16: STWAVE Model Domains in Sabine Region..... 83
Figure 2-17: Sabine Local Wave Output Locations 84
Figure 2-18: NOAA Gage Sea Level Trend 8770570 Vicinity Map..... 94
Figure 2-19: NOAA Sea Level Trend Gage 877150 Vicinity Map..... 94
Figure 2-20: NOAA Gage 8772440 Vicinity Map 95
Figure 2-21: RSLC at Sabine, Texas over 20-Year Period of Analysis 96
Figure 2-22: RSLC at Galveston, Texas over 20-Year Period of Analysis 97
Figure 2-23: RSLC at Freeport, Texas over 20-Year Period of Analysis..... 97
Figure 2-24: RSLC at Sabine Pass, Texas over 50-Year Period of Analysis 98
Figure 2-25: Extent of inundation at Sabine Pass, Texas with 2-foot sea level rise..... 99

Figure 2-26: RSLC at Galveston Bay, Texas over 50-Year Period of Analysis 100
Figure 2-27: Extent of inundation at Galveston, Texas with 2-foot sea level rise 101
Figure 2-28: RSLC at Freeport, Texas over 50-Year Period of Analysis 101
Figure 2-29: Extent of inundation at Freeport, Texas with 2-foot sea level rise 102
Figure 2-30: Predicted RSLC at Sabine, Texas over 100-Year Period of Analysis 105
Figure 2-31: Predicted RSLC at Galveston, Texas over 100-Year Period of Analysis 105
Figure 2-32: Predicted RSLC at Freeport, Texas over 100-Year Period of Analysis 106
Figure 2-33: RSLC and Total Water Level Plot for Brazoria Region 107
Figure 2-34: RSLC and Total Water Level Plot for Sabine Region 108
Figure 2-35: Bar Charts to Determine Total Water Level Forcing 109
Figure 2-36: Percent Change in Annual Precipitation for 1991-2012 Compared to 1901-1960 110
Figure 2-37: Port Arthur Pump Stations in Need of Rehabilitation 114
Figure 2-38: Location of Gages Used in this Analysis 116
Figure 2-39: Water Level and Discharge Data from 2003 to Present 116
Figure 2-40: Discharge and Water Level during Hurricane Rita 117
Figure 2-41: Joint Probability of Discharge (Q) and Water Level 118
Figure 2-42: 100-year Frequency Inundation in Beaumont Vicinity 120
Figure 2-43: Mean Annual Precipitation Values 2014 124
Figure 2-44: Omega Values Used for Regression Runoff Estimates 124
Figure 2-45: Region Map for the State of Texas 127
Figure 2-46: Cow and Adams Bayou Intersection with Gate Structures 137
Figure 2-47: Gage 9 Location 138
Figure 4-1: Sabine Pass to Galveston Bay – Orange 3 Vicinity Map 156
Figure 4-2: Sabine Pass to Galveston Bay – Freeport Vicinity Map 156
Figure 4-3: Sabine Pass to Galveston Bay – Port Arthur Vicinity Map 157
Figure 4-4: Core Boring Plan on Orange 160
Figure 4-5: CPT Plan on Orange 161
Figure 4-6: Orange Reach represented by shear strength plot IV (left) and its general location (right) 163
Figure 4-7: Typical proposed levee section. 168
Figure 4-8: Typical for proposed levee raise section. 168
Figure 4-9: Alternate typical for proposed levee raise section 169
Figure 6-1: Levee Alignment to Provide Full County Protection on East and West Bank of Neches River (ref: Orange County Report) 178
Figure 7-1: Orange-Jefferson CSRM – Overview Map 190
Figure 7-2: Port Arthur and Vicinity CSRM - Overview Map 191
Figure 7-3: Freeport and Vicinity CSRM - Overview Map 192
Figure 7-4: Floodwall - Conceptual Design Cross Section 198
Figure 7-5: Input for Floodwall Analysis 198

Figure 7-6: Floodwall - In Place of Earthen Levee Raise 199
Figure 7-7: Orange–Jefferson CSRM Gate Structures Overview Map 203
Figure 7-8: Freeport and Vicinity CSRM - Gate Structure Overview Map 204
Figure 7-9: Aerial Photograph of Navigation Sector Gates with Adjoining Vertical Lift Gates 205
Figure 7-10: Port Arthur and Vicinity CSRM – Reaches 208
Figure 7-11: Port Arthur and Vicinity: Reach 1 – Overview Map 210
Figure 7-12: Port Arthur and Vicinity CSRM: Reach 2 – Overview Map 211
Figure 7-13: Del Mar Pump Station – Floodwall Plan 212
Figure 7-14: Port Arthur and Vicinity CSRM: Reach 3 – Overview Map 213
Figure 7-15: STA 934+53 I-Wall – As-built Profile 214
Figure 7-16: Port Arthur and Vicinity CSRM: Reach 4 – Overview Map 215
Figure 7-17: Port Arthur and Vicinity CSRM: Reach 5 – Overview Map 216
Figure 7-18: Freeport and Vicinity CSRM - Reaches 217
Figure 7-19: Oyster Creek and Oyster Creek Extension – Overview Map 219
Figure 7-20: East Storm - Overview Map 220
Figure 7-21: DOW Barge Canal – Overview Map 221
Figure 7-22: DOW Barge Canal – South End Overview Map 222
Figure 7-23: Old River North – Overview Map 223
Figure 7-24: Tide Gate – Overview Map 224
Figure 7-25: Old River South – Overview Map 226
Figure 7-26: Pump Station – Overview Map 227

TABLES

Page

Table 1-1: Structural CSRM Alternatives Evaluated for Recommended Plan Selection 35
Table 1-2: Orange 3 Reach – Features of Work 42
Table 1-3: Orange 3 Levee and Floodwall Elevations 44
Table 1-4: Port Arthur and Vicinity CSRM – Features of Work 45
Table 1-5: Port Arthur Levee and Floodwall Elevations 47
Table 1-6: Freeport and Vicinity CSRM - Features of Work 50
Table 1-7: Freeport Levee and Floodwall Elevations 53
Table 2-1: Datum Conversion Summary Table for Brazoria and Sabine Region 66
Table 2-2: Tropical Cyclone Strikes by Decade since 1850 68
Table 2-3: Summary of Local Wave Output for Freeport 82
Table 2-4: Summary of Wave Output for Sabine Region 84
Table 2-5: H&H data for Freeport Region Economic Analysis 85
Table 2-6: H&H data for Port Arthur Economic Analysis 85
Table 2-7: H&H data for Orange Economic Analysis 86
Table 2-8: Recommended Levee/Floodwall Elevations for Freeport as a Function of RSLC 88
Table 2-9: Recommended Levee/Floodwall Elevations for Sabine as a Function of RSLC 89
Table 2-10: Estimated RSLC over the First 20 Years of the Project Life (2030 - 2050) 96
Table 2-11: Estimated RSLC over the First 50 Years of the Project Life (2030 - 2080) 98
Table 2-12: Predicted RSLC over the First 100 Years of the Project Life (2030 - 2130) 104
Table 2-13: Rational Method Calculated Discharges for the Sabine Region 122
Table 2-14: Regression Method Calculated Discharges using FHWA Methodology 125
Table 2-15: Regional Regression Equations Used in Second mthod for This Feasibility Analysis 125
Table 2-16: Region 11 Regression Coefficients for Orange and Jefferson County 128
Table 2-17: Regression Method Calculated Discharges using USGS/TxDOT Methodology 128
Table 2-18: Flows from Regression Calculations used for Sizing Structures 129
Table 2-19: Cow Bayou DOWSMM Model Parameters 138
Table 2-20: Cow Bayou Base Parameters: Low Flow, 120-foot Inlet Width 139
Table 2-21: Cow Bayou Base Parameters: Low Flow, 50-foot Inlet Width 140
Table 2-22: Cow Bayou Base Parameters: Median Flow, 120-foot Inlet Width 140
Table 2-23: Cow Bayou Base Parameters: Median Flow, 50-foot Inlet Wwidth 141

Table 2-24: Adams Bayou DOWSMM Model Parameters 142
Table 2-25: Adams Bayou Base Parameters: Low flow, 350-foot Inlet Width 142
Table 2-26: Adams Bayou Base Parameters: Low Flow, 100-foot Inlet Width 142
Table 2-27: Adams Bayou Base Parameters: Median Flow, 350-foot Inlet Width 143
Table 2-28: Adams Bayou Base Parameters: Median flow, 100-foot Inlet Width 143
Table 4-1: Approximate Lengths of Proposed Features per Area 157
Table 4-2: Approximate Lengths of Proposed Work on Existing Features 157
Table 4-3: Length of work on existing levee embankment at Freeport 164
Table 4-4: Length of work on existing levee embankment at Port Arthur 164
Table 4-5: Seepage Analysis Criteria 167
Table 4-6: Stability Analysis Criteria 167
Table 6-1: Orange 3 Road/Railroad Crossings 185
Table 6-2: Port Arthur Existing Road/Railroad Crossings 187
Table 6-3: Freeport Existing Road Crossings 188
Table 7-1: Approximate Lengths of Proposed Features per Area 192
Table 7-2: Floodwall Elevations for RSLC Scenarios - Orange 3 193
Table 7-3: Floodwall Load Cases 196
Table 7-4: Maximum Floodwall Elevations for RSLC Scenarios 201
Table 7-5: Port Arthur and Vicinity CSRM – Existing Floodwall 208
Table 7-6: Port Arthur and Vicinity CSRM – Proposed New Floodwall 209
Table 7-7: Freeport and Vicinity CSRM – Existing Floodwall 218
Table 7-8: Freeport and Vicinity CSRM – Proposed New Floodwall 218

ATTACHMENTS – ENGINEERING DESIGNS AND MAPS

C-01 to C-23 Orange-Jefferson CSRM Recommended Plan
C-24 to C-43 Port Arthur and Vicinity CSRM Recommended Plan
C-44 to C-62 Freeport and Vicinity CSRM Recommended Plan
C-63 Levee Details
C-64 Mitigation Plan Overview
C-65 Mitigation Area 11
C-66 Mitigation Area 28 & 29
C-67 Mitigation Area 31 & 161
C-68 Mitigation Area 52
C-69 to C-79 Orange-Jefferson CSRM Recommended Plan – Pipeline Crossings
C-80 to C-83 Port Arthur and Vicinity CSRM Recommended Plan – Pipeline Crossings
C-84 to C-87 Freeport and Vicinity CSRM Recommended Plan – Pipeline Crossings
B-01 Levee Typical Sections
S-01 Floodwall Typical Section
S-02 Adams Bayou Gate Structure Plan
S-03 Cow Bayou Gate Structure Plan
S-04 DOW Barge Canal Gate Structure Plan
S-05 Port Arthur Floodwall – Typical Sections
S-06 Freeport Floodwall – Typical Sections
D-00 Orange 3 Reach Drainage Area Overview
D-1 to D-10 Orange 3 Drainage Area Maps
D-11 Orange County Induced Impacts
D-12 Orange-Jefferson Inundation Change at 100-Year Flood Plain Level
D-13 Orange-Jefferson Inundation Change at 500-Year Flood Plain Level
D-14 Freeport Inundation Map at 100-Year Flood Plain Level
D-15 Freeport Inundation Map at 500-Year Flood Plain Level
D-16 Port Arthur Inundation Map at 100-Year Flood Plain Level
D-17 Port Arthur Inundation Map at 500-Year Flood Plain Level

COST ESTIMATE DOCUMENTS

MCASES Cost Estimate

Total Project Cost Summary (TPCS)

LIST OF ACRONYMS

ADCIRC	ADvanced CIRCulation (Model)
ADM	Agency Decision Milestone
AEP	Annual Exceedance Probability
ASTM	American Society for Testing and Materials
ATR	Agency Technical Review
CFR	Code of Federal Regulations
bpd	barrels per day
cfs	cubic feet per second
CPT	cone penetration test
CSRM	Coastal Storm Risk Management
DOWSMM	Desktop Off-Channel Wetland Salinity Mitigation Model
EC	Engineering Circular
EM	Engineering Manual
EoC	End of Construction
EPA	U.S. Environmental Protection Agency
ER	Engineering Regulation
ERDC-CHL	Engineer Research and Design Center - Coastal Hydraulics Laboratory
ETL	Engineering Technical Letter
FEMA	Federal Emergency Management Agency
FIFR-EIS	Final Integrated Feasibility Report – Environmental Impact Statement
FM	Farm-to-Market Road
FoS	Factor of Safety
FRP	Fiber-Reinforced Polymer
FWOP	Future Without-Project
GIWW	Gulf Intracoastal Waterway
GIS	Geographic Information System
GLO	General Land Office
gpm	gallons per minute
HEC	Hydrological Engineering Center
H&H	Hydraulics and Hydrology
HFPP	Hurricane Flood Protection Project
HH&C	Hydrologic, Hydraulic and Coastal
HPTRM	high performance turf-reinforcement mattress
HQ-USACE	Headquarters - United States Army Corps of Engineers

HSDRRSDG	Hurricane and Storm Damage Risk Reduction System Design Guidelines
IPET	Interagency Performance Evaluation Taskforce
ksf	kips per square foot
ksi	kips per square inch
lf	lineal or linear feet
LiDAR	Light Detection and Ranging
LSAC	Levee Safety Action Classification
MII	Micro-Computer Aided Cost Estimating Software, Second Generation
MLLW	Mean Lower Low Water
MLRA	Major Land Resource Area
NAD	North American Datum
NAVD	North American Vertical Datum
NED	National Economic Development
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
O&M	operations and maintenance
pcf	pounds per cubic foot
PDT	Project Delivery Team
PED	Preconstruction Engineering and Design
PI	Periodic Inspection
PL	Public Law
POR	Period of Record
RMC	Risk Management Center
ROW	Right-of-Way or Rights-of-Way
RP	Rehabilitation Program
RSLC	relative sea-level change
RTK	Real Time Kinematic
SLC	Sea Level Change
SMART	Specific, Measurable, Attainable, Risk-Informed, and Timely
SPF	Standard Project Flood
SQRA	Semi-Quantitative Risk Assessment
SWE	Still Water Elevation
SWG	Southwestern Division, Galveston District
SWIF	system-wide improvement framework
SWL	Still Water Level
TCOON	Texas Coastal Ocean Observation Network

TNRIS	Texas Natural Resources Information System
TRRC	Texas Railroad Commission
TSP	Tentatively Selected Plan
USACE	United States Army Corps of Engineers
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VE	Value Engineering
VT	Vertical Team
WPG	Water at Project Grade

1 GENERAL

1.1 PURPOSE AND CONTEXT

This Engineering Appendix documents the preliminary engineering analyses and concept designs for the coastal storm risk management (CSRM) projects comprising the Recommended Plan, specifically for implementation within the Sabine and Brazoria study regions along the upper Texas coast. It supports the viability of the proposed projects, which are developed in the "Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration" Final Integrated Feasibility Report – Environmental Impact Statement (FIFR-EIS).

The Sabine and Brazoria regions comprise a broader coastal study area in southeast Texas that encompasses six counties. These two sub-regions are the subject of the first interim study where CSRM opportunities were formulated. Additional interim studies are planned for the future to investigate other opportunities where structural alternatives could be implemented to lower the risk of storm surge flooding within the delineated Galveston region and throughout the entire study area. Assessments of the existing and predicted storm surge climate conditions for the Sabine and Brazoria regions, and the concept designs for the proposed project features that came out of these assessments, factor into the economic analyses and are the basis for the costs of the alternatives that were compared during plan formulation. Thus, the preliminary engineering analyses validate the technical and economic viability of the projects from an engineering standpoint.

1.2 SCOPE OF EFFORT

The engineering design work is premised on a feasibility level of detail and analysis, consistent with the SMART planning process that is necessary to substantiate the Recommended Plan baseline cost estimate. Thus, an appropriate level of engineering work was done in comparing alternatives during plan formulation. To the maximum extent possible, existing information that could be readily acquired was used to develop the plans and designs for the project features. Sources of available information included maps and imagery from the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), and Google; geospatial data; present and historical data from FEMA, the USGS, and the National Oceanic and Atmospheric Administration (NOAA); similar or related area studies; comparative studies; operations and maintenance (O&M) records; and damage risk assessment reports on existing systems. Limited core borings were taken to validate the existing data and to provide more localized site-specific data. Relevant technical references, empirical design guidance, and numerical modeling programs were used in the engineering analyses.

Engineering analysis completed during this study is adequate to assess project feasibility, but is

not complete or precise enough to design the project features; therefore, it should not be construed as such. Further investigation and engineering analyses to the feature designs will be completed in the Project Engineering and Design phase (PED) once the project is authorized.

1.3 ENGINEERING DOCUMENTATION

Narratives of the engineering analyses are broken out by discipline covering Hydrology and Hydraulics, Surveying and Mapping, Geotechnical engineering, Civil Design and Structural engineering. The engineering effort level of detail and report content and format are consistent with guidance provided in ER 1110-2-1150. In general, the objective of this appendix is to provide enough supporting documentation to enable reviewers to understand the assumptions and models used to evaluate project benefits and to develop the costs necessary to derive the Recommended Plan projects.

The technical sections discuss the development of the preliminary designs for the CSRM features evaluated in the Recommended Plan. They detail the engineering information that was collected, design references and guidance used, computer programs used, the design criteria assumed, design parameters, assumptions made, and methods of analyses.

1.4 PROJECT AREAS

The discrete projects making up this study for the Sabine and Brazoria sub-regions are located in Orange, Jefferson, and Brazoria Counties, Texas, along the upper Texas coast (Figure 1-1). These counties are constituent counties of the larger six-county study area between Sabine Pass and the City of Freeport, Texas, that also includes Galveston, Harris, and Chambers Counties.

This study specifically looks at CSRM opportunities within the following defined areas:

Orange-Jefferson County, Texas. Areas within the southern half of Orange County bounded by the Sabine and Neches Rivers and areas along the northeastern boundary of Jefferson County along the Neches River. Specific municipalities, industrial areas, and commercial facilities of interest within Orange County include the cities of Orange, West Orange, Pinehurst, Bridge City, Rose City, and Vidor, as well as surrounding unincorporated areas, an area known as "Chemical Row" along F.M. 1006, and Entergy Texas' Sabine Plant. In Jefferson County, specific areas include the cities of Port Neches and Nederland and industrial complexes along the west bank of the Neches River, which include the Du Pont Beaumont Works Industrial Park and ExxonMobil's Beaumont Chemical Plant.

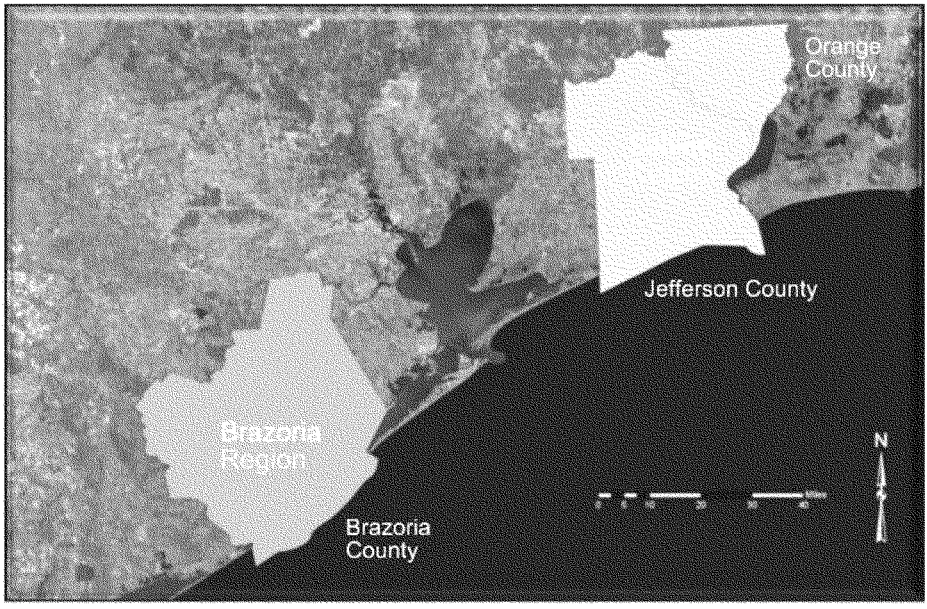


Figure 1-1: Sabine and Brazoria Regions including Orange, Jefferson, and Brazoria Counties

- Port Arthur and Vicinity, Jefferson County, Texas. An existing HFPP reduces the risk of flooding in the Port Arthur area from coastal storm surge events coming from the Gulf of Mexico. It also reduces flooding risk from the Sabine River. The levee system consists of 27.8 miles of earthen embankment and 5.3 miles of floodwall, including 2.9 miles of cantilever wall. There is also a wave barrier on Pleasure Island.

- Freeport and Vicinity, Brazoria County, Texas. An existing HFPP reduces the risk of flooding in the Freeport area from coastal storm surge events coming from the Gulf of Mexico. The line of protection includes multiple structures that also serve as control structures and docks for the Dow Chemical Company, BASF, Conoco Philips, ExxonMobil, and Port Freeport. The system consists of approximately 43 miles of levees, floodwalls, and wave barriers, pump stations, multiple gates, culverts, and related appurtenances.

1.5 PROJECT OVERVIEW

1.5.1 Project Need

A thorough discussion of the need for the CSRM projects is in Section 4 of the FIFR-EIS – Problems and Opportunities.

Approximately 5.57 million people reside within the six-county study area which is subject to flooding from storm surge. The population within the study area is currently projected to grow to over 9 million people within the next 50 years. The final study area, which includes the counties of Brazoria, Jefferson and Orange, contains approximately 676,000 people which are subject to flooding from storm surge. Industrially, the six-county study area encompasses three of the nine largest oil refineries in the world, 40 percent of the nation's petrochemical industry, 25 percent of the nation's petroleum-refining capacity, and three of the 10 largest U.S. seaports. The damages to the national economy that could be incurred from a one-month closure of the Houston Ship Channel alone are estimated to be upwards of $60 billion. It contains six major rivers and their watersheds, a nationally significant coastal estuary, a commercial fisheries industry, and tourism industry. Given the area's large population, nationally significant industries and facilities, and ecosystems that potentially could be harmed or damaged by storm surge flooding, governmental entities and interests over the years have identified and looked into possible CSRM opportunities in the context of local and regional strategies to address this.

Between 1900 and 2014, more hurricanes struck the upper Texas coast than along any other reach of the Texas coastline, which itself accounts for the second greatest total number of recorded hurricane strikes on the United States coastline, historically, behind only Florida. The probability that a hurricane will strike somewhere along the upper Texas coast in any given year ranges from 31 percent at Sabine Pass to 41 percent around Matagorda Bay. The frequency of hurricanes in along any fifty mile segment of the Texas coast is one about every six years (*source*: Texas Hurricane History, National Weather Service, David Roth, Updated Jan 2010).

1.5.2 Project Objective

The tentatively recommended plan seeks to reduce the risk of flood damage from coastal storm surge to large at-risk population areas, public and industrial facilities and infrastructure, critical industries in the energy sector having tremendous implications on the economy and national security, and sensitive ecosystems along the Orange, Jefferson, and Brazoria County coastlines. The risks to life safety and property damage associated with coastal storms can be reduced with engineered measures. Economically, the plan sought is that which optimizes the costs of project construction relative to the potential reduction in economic losses that could be incurred over a 50-year period of analysis to derive the greatest net economic benefit. To this end, the economic

damage assessments focus only on direct damages to structures. Incidental to reducing the life safety and property damage risks, opportunities were also looked into that preserve and enhance existing environmental habitats or reduce the damage potential to these habitats from storm surge flooding.

1.5.3 Project Coordination

The engineering assessments, analyses, and preliminary designs for the existing and proposed HFPPs were thoroughly coordinated and vetted with the entire project team, including Engineering Research and Development Center – Coastal Hydraulics Laboratory (ERDC-CHL), the Texas General Land Office (GLO), and other governmental agencies, such as FEMA, the EPA, representatives of Drainage District No. 7 (Port Arthur) and the Velasco Drainage District (Freeport), and county officials. Planning efforts were also coordinated with resource agencies and communities having an interest in the CSRM projects and with the Port of Orange. The interdisciplinary PDT collaborated with subject matter expert colleagues and seamlessly engaged the Vertical Team (VT - USACE District, Division, Headquarters, and Office of Water Project Review) in its efforts throughout the plan formulation process. Agency Technical Reviews (ATRs) and In-Progress Reviews were conducted at key development stages.

1.5.4 Project Background

The USACE, Galveston District (SWG), has been aware of the region's need to reduce the risk of flood damage from storm surge. There are opportunities available in addressing the flooding risk to the population at risk, the existing public and industrial infrastructure, and also critically important ecosystems. The SWG, with Congressional authorization, has explored possibilities of projects to benefit the region where there might also be a Federal interest. With this as the objective, the SWG collaborated with the State of Texas and local governmental entities to locate and implement opportunities for CSRM and ER. The SWG leveraged studies, data, and models that have already been produced or are under development.

The FIFR-EIS details the project background and describes the focus areas that were advanced from planning charrettes held to scope the feasibility study. The FIFR-EIS also discusses associated non-structural and structural measures that were considered to address CSRM. The focus areas for the Sabine and Brazoria regions and the structural features which comprise the Recommended Plan are summarized in section 1.7 below.

1.5.5 Project Datum

The horizontal and vertical datums used in the engineering analyses and models conform to the current Federal standard. Horizontal coordinates are referenced to North American Datum (NAD) of 1983. Elevations for upland areas and proposed upland features are referenced to the North

American Vertical Datum of 1988 (NAVD 88). Water depths are referenced to Mean Lower Low Water (MLLW), unless otherwise stated.

1.6 GENERAL ASSUMPTIONS

1.6.1 Design Considerations

Currently, there is no Federal standard to provide a specified minimum level of flood protection. Historically however, the USACE goal for the design of flood-damage reduction projects is to accommodate the Standard Project Flood (SPF) or other "design floods." The SPF is defined as those "discharges that may be expected from the most severe combination of meteorological and hydrologic conditions that are considered reasonably characteristic of the geographical region involved, excluding extremely rare combinations." This goal was rarely achievable though, because the projects had to be economically justified. Although the SPF may have a useful role for application in a risk analysis for evaluating flood damage reduction alternatives, it is no longer a valid design target per ER 1105-2-101 (dated 03 January 2006). Now, a full range of floods, including those that would exceed the SPF, are to be used in the formulation and evaluation of alternatives.

Since the early 1990s, USACE policy has mandated a balanced approach in planning flood-damage reduction projects in which the flood-damage reduction potential (i.e., physical performance), economic success, and residual risks associated with a particular alternative are assessed relative to its implementation cost. Accordingly, the total effect of uncertainty on the project's design and economic viability is examined and conscious decisions can be made that take into account risk and cost. Alternatives are evaluated and compared based on the scale of the flood damage reduction that reasonably maximizes the expected net benefits (expected benefits less expected costs). Those alternatives accomplishing this objective, with uncertainties in the key variables explicitly included, define the National Economic Development (NED) plans.

Increments in project scale beyond the NED plan can be considered to improve project performance and to manage residual risks to people and property, but existing policy governing such increments must be followed. For example, levee heights are often compared to that which would satisfy the FEMA National Flood Insurance Program (NFIP) base flood level for excluding the floodplain from mandatory flood insurance. In those urban settings where risk-based economics suggest a levee height less than the NFIP base flood protection, the heights are generally increased to that level so that the levees may be certified for NFIP purposes. The resulting project must still be economically justified and the non-Federal sponsor may be required to pay the cost for the increment of levee height between the NED plan project and the NFIP base flood protection project.

This study assessed the flood-damage reduction potential for the various alternatives based on damages that would be prevented under average still-water conditions, while also considering relative sea level change (RSLC), wave set-up and run-up. Storm surge modeling results combined with existing information collected identified the areas that would be inundated from storms with an annual chance exceedance varying from 0.1 to 0.001.

Evaluation of the existing HFPPs at Port Arthur and Freeport utilized the same design considerations. Design approach varied, in comparison to the proposed systems, due to the amount of raising that can be done practically is economically constrained by existing structures and facilities (e.g., floodwalls, gate structures, drainage structures, pipelines, utilities, pump stations), whose heights or capacities would have to be increased accordingly. Enlargement of the structures will increase the costs of the affected projects comprising the Recommended Plan.

1.6.2 Relative Sea-Level Change

RSLC is an important variable to consider in the design of HFPPs, so much so that USACE policy requires its consideration in every USACE coastal activity as far inland as the extent of estimated tidal influence. This is because sea-level change (SLC) can potentially affect project and system performance. Therefore, prospective projects need to consider how sensitive and adaptable human and engineered systems and ecosystems are to climate change and other related global changes, including SLC.

ER 1100-2-8162 requires that planning studies and engineering designs over the project life cycle, for both existing and proposed projects, consider a range of possible future rates of SLC when formulating and evaluating alternatives. This includes both structural and non-structural solutions. Future SLC was assumed to be the same across the system; therefore, it was not included or incorporated into the screening process for the structural alternatives of the project.

RSLC was a factor in deciding the Recommended Plan and the details are covered in the H&H section of this report. Recommendations made at earlier stages of the project were to consider a 50 year intermediate level as the design RSLC. An adaptive strategy will be employed to address higher change potential for sea-level rise over the project's service life, which is assumed to extend well beyond the 50-year period assumed for the economic analysis. Measures and design considerations can be adapted to a 50 year high or 100 intermediate RSLC. Project features will be optimally designed, during PED, based on the projected ranges of RSLC combined with CSRM objectives and economic considerations.

1.7 DESIGN ANALYSES PROCESS FOR THE RECOMMENDED PLAN

In order to obtain the alternatives that would yield the most benefits, several tasks were performed in succession and results were compared and analyzed. Storm and surge modeling was performed. Hydraulic data was applied to the alternative reaches, including estimated rates of RSLC and wave run-up values. The structural alternatives compared are proposed modifications to the existing Port Arthur and Freeport HFPP levees and floodwalls, as well as proposed new levees and floodwalls that would comprise the Orange-Jefferson County CSRM, which includes the "Port Arthur Extension" component. For each system, the principal emphasis regarding the economics of the structural alternatives, for the different still-water levels (SWLs) assumed, was on the reaches and heights of protection that would yield the greatest net excess benefits. The existing systems and proposed levee system alignments were broken out into separable elements allowing for the most efficient alignments possible. These separable elements constituted the structural alternatives that were evaluated to derive the Recommended Plan for the Orange, Port Arthur and Freeport CSRMs. The pertinent hydraulic data was gathered for a representative point of each separable element, that representative point was called an Index Point. Within each of the levee systems, Geo Points were used for simplification of the system and in subsequent stages of the feasibility process.

Economic analysis was performed at the designated Index point at varying heights, in one-foot intervals. The appropriate Geo point was chosen as the system Index point for which the most benefits would be achieved when compared to other Geo points. The alternative with the most benefits was identified and compared to preliminary estimates of the cost for construction of the project for each of the heights analyzed. The hydraulic condition was determined with the available storm and surge modeling, RSLC and wave run-up to obtain the design annual chance exceedance for the alternatives. Available data was gathered for the remaining Geo Points, at different locations throughout the system, using the annual chance exceedance as input to obtain appropriate values throughout the project alignment, which vary mainly due to the wave run-up component.

The design process utilizes calculation methods described in the respective technical discipline sections of this Appendix. The feature designs presented are schematic in nature and represent systems and components currently in use in the United States and/or other countries. The level of detail of the designs is sufficient to develop order of magnitude cost estimates suitable for the benefit-to-cost analysis in comparing the alternative plans. Primary features considered for the systems are:

- Earthen Levees

- Concrete Floodwall (T-Wall)
- Rights-of-Way Acquisitions
- Highway/Roadway Crossings - Non-Gated
- Pipeline and Major Utility Crossings
- Pump Stations
- Closure Gate Structures – Navigation
- Roadway and Railway Crossings – Gated
- Interior Drainage
- Resiliency Features

1.8 DESCRIPTION OF EXISTING PROJECT AREAS

1.8.1 Orange-Jefferson CSRM

The project areas in Orange and Jefferson Counties are characterized by nearly flat terrain that slightly dips towards the Gulf of Mexico, typical of the Gulf Coastal Plain in Texas. The general land slope is 0.05 percent and less with elevations ranging from 0 to 20 feet NAVD 88. Most of the area is less than 10 feet in elevation, with a great percentage being less than 5 feet. Much of the areas are fronted by coastal inland marshes. The major drainage systems in Orange County are the Neches River in the western part, the Sabine River in the eastern part, and two bayous in the central portion of the county, Adams and Cow. On the Jefferson County side, the major drainage system in the county is the Neches River. Both rivers, and other minor drainage systems, empty into the Gulf of Mexico at Sabine Lake. Noteworthy of the areas is that they are highly susceptible to rising sea level, with studies suggesting that regional relative sea-level rise rates, inferred from historical tide gauge data, have been significantly higher than presumed eustatic rise rates.

Most of the areas beyond the coastal marshes and river floodplains are highly developed, as evidenced by the cities, industrial plants, commercial facilities, residential areas, dock facilities, and agricultural-use areas that depict the area. These cities include Orange, West Orange, Pinehurst, Bridge City, and Port Neches. Currently, no flood damage reduction systems of significance are known to exist that would protect portions of Orange County and the northeastern part of Jefferson County from storm surge inundation.

1.8.2 Port Arthur and Vicinity CSRM

The Port Arthur and Vicinity Hurricane Protection Project (HFPP) reduces flood risk for the Port Arthur region from tropical storm events coming from the Gulf of Mexico. It is operated by Jefferson County Drainage District No. 7. This project was authorized by Flood Control Act of 1962, Public Law 87-874. Construction began in March 1966 and was completed in April 1982.

The levee system consists of 27.8 miles of earthen embankment and 5.3 miles of floodwall. This includes 2.9 miles of cantilever I-wall. The storm of record is Hurricane Ike (2008), which loaded several sections of I-wall to approximately 90% of its height. This storm produced wave action that overtopped sections of floodwall adjacent to the Sabine-Neches Waterway (a deep-draft navigation channel whose authorized depth is 40 feet) for approximately 30 minutes. Figure 1-2 shows the existing project area for the Port Arthur and Vicinity CSRM.

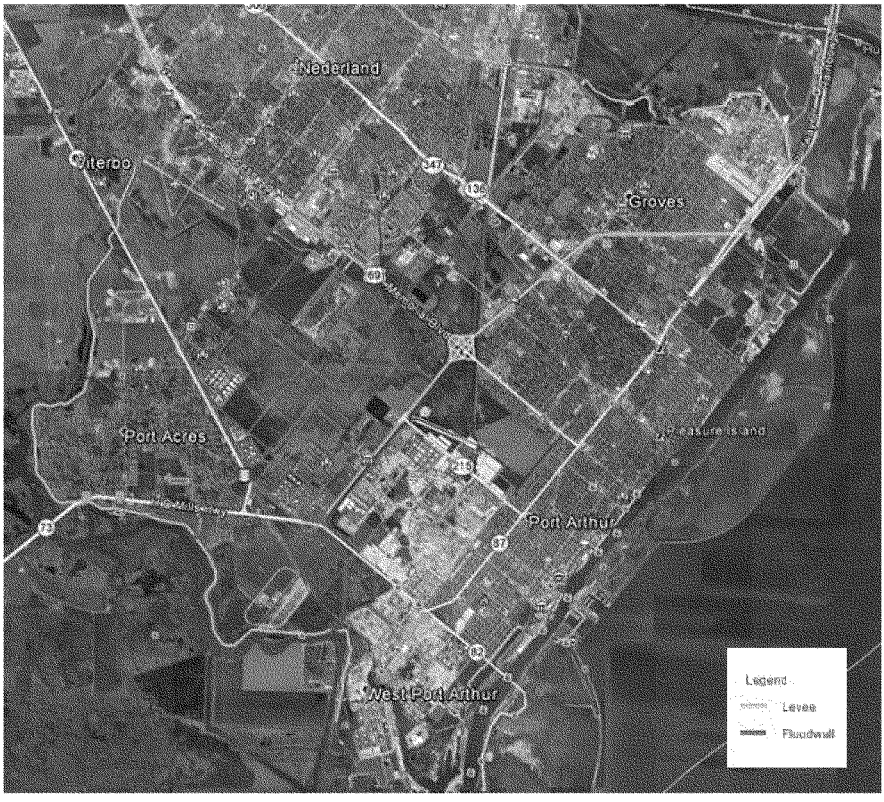


Figure 1-2: Existing Levee System within Port Arthur and Vicinity CSRM Project Area

The Port Arthur and Vicinity levee system has a Levee Safety Action Classification (LSAC) of 1, which resulted in the Risk Management Center (RMC) initiating a Semi-Quantitative Risk Assessment (SQRA) to better define the systems' risk. This classification was primarily driven by three main risk factors (probability of load, probability of failure, and nature of consequence). The following paragraphs detail the major engineering concerns for the Port Arthur and Vicinity Levee System.

I-wall stability analysis show concerns for performance during events that are at or above the top elevation of the floodwall. These concerns are due to marginal factors of safety for stability and excessive anticipated deflection in the steel sheet pile I-walls. Additional I-wall concerns are the lack of resiliency features for overtopping, no design considerations for vessel impact and embankment tie-ins that are susceptible to erosion during an overtopping event. Sections of T-wall type floodwall that were overtopped during Hurricane Ike experienced erosion and loss of supporting fill material due to as little as 30 minutes of overtopping. These T-wall sections are in the vicinity of the I-wall sections that are being evaluated under this study. It is expected that the foundation material at the I-walls could erode in a similar manner.

The Port Arthur system begins to experience overtopping at around a 300-year hydraulic loading event (0.67% ACE). This is a fairly infrequent event for still water overtopping, wave overtopping will occur at more frequent events as was observed during Hurricane Ike. The Port Arthur region has a population of around 90,000 in the leveed area along with a large refinery presence (over one million barrels per day (bpd) production). This includes Motiva's 600,000 bpd plant (2012) as well as 60 percent of the nation's jet-fuel production capacity. High economic consequences along with a large population, together with a high-return frequency for overtopping events that could lead to a catastrophic failure of the system, heavily influenced the LSAC rating.

The Port Arthur HFPP's storm of record is Hurricane Ike. High water marks from the storm surge were recorded at greater than 12 feet above mean sea level, approximately 75-90% of its height. Both levee and floodwall sections of the flood protection system, along the Sabine Neches Waterway, experienced wave overtopping. The damages from Hurricane Ike included erosion at the levee toe from Station 262+00 to 270+00, erosion behind the floodwall (due to wave overtopping) from Station 380+00 to 410+00 and 430+00 to 490+00, cover stone damage along the Sabine Neches waterway (Station 410+00 to 430+00 and 490+00 to 610+00), a slope failure on the interior of the levee from Station 1110+00 to 1120+00 and 1250+00 to 1260+00, and a slope failure on the exterior of the levee between Stations 1105+00 and 1140+00. All instances of damage from Hurricane Ike were repaired through the Rehabilitation Program under PL 84-99.

Currently the system is minimally acceptable in the Rehabilitation Program (RP) under PL 84-99 and certifiable for FEMA accreditation under CFR 65.10. A Periodic Inspection (PI) was completed for the Port Arthur system in 2012. The Non-Federal Sponsor was provided a list of items to correct and is currently in the process of correcting them. The future without project conditions would result in no action being undertaken to reduce the risk of the system.

1.8.3 Freeport and Vicinity CSRM

The Freeport and Vicinity HFPP is in the coastal plains in southern Brazoria County, about 48 miles southwest of Galveston, Texas. The Freeport and Vicinity levee system was authorized by the Flood Control Act of 23 October 1962, Public Law 87-874, substantially in accordance with House Document No. 495, 87th Congress, 2nd Session. The authorization provides for construction of improvements at Freeport and Vicinity, Texas, for risk reduction against storm tides caused by tropical cyclones along the Gulf Coast of magnitudes up to and including the standard project hurricane. The existing HFPP at Freeport consists of approximately 43 miles of levees, floodwalls, and wave barriers including pump stations, multiple gates, culverts, and related appurtenances. Additionally, in the alignment of the system, there are multiple structures that also serve as control structures and docks for the Dow Chemical Co., BASF, Conoco Philips, Exxon and Port Freeport. Figure 1-3 shows the existing project area for the Freeport and Vicinity CSRM.

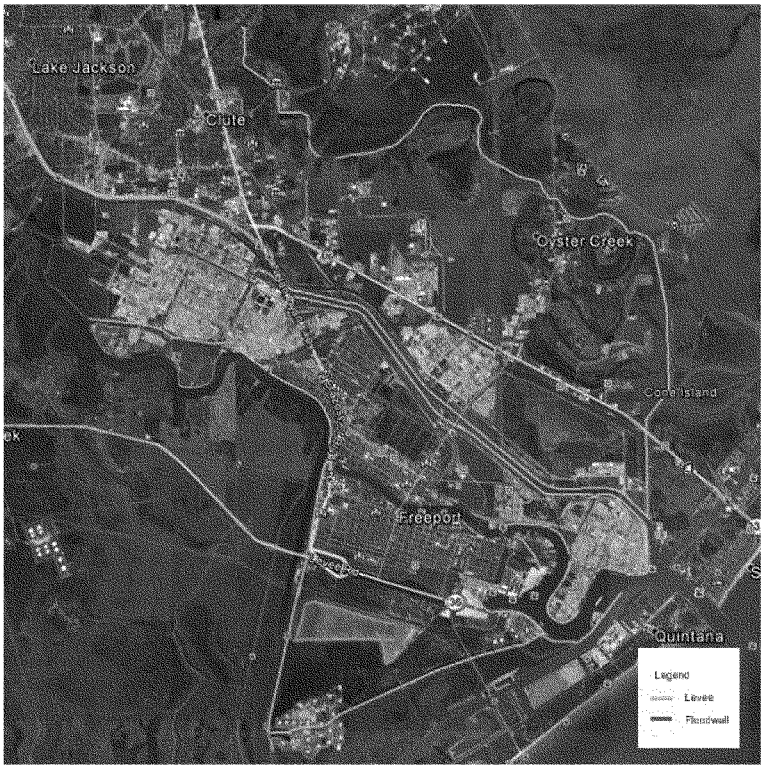


Figure 1-3: Existing Levee System within Freeport and Vicinity CSRM Project Area

The Freeport and Vicinity Levee system has a preliminarily LSAC of 1, which resulted in the RMC conducting an SQRA to better define the systems risk. The primary risk factors which attributed to the LSAC are both structural and economic. The structural factors include seepage considerations along with slope stability of sandy levees, I-wall stability, and a low level of protection. The leveed area of the Freeport system has very high economic consequences, which also drove the LSAC.

The Freeport HFPP's storm of record is Hurricane Ike. High water marks from the storm surge were recorded at greater than 10 feet above mean sea level, which loaded the system to approximately 50% of its height in some areas. Areas of damage included the Velasco Memorial Tide Gate and the panel closure system at the Port of Freeport. The damage to the Tide Gate structure was with the emergency electrical system. It was stated in the Project Information Report that the system was operational prior to Hurricane Ike landfall and inoperable after the storm. The damage in the Port of Freeport area was to the removable panel wall system from Station 197+00 to 224+24. The damage was caused by windblown debris striking the panels and the panel ties, which caused them to no longer function as designed. These two instances of damage from Hurricane Ike were repaired through the Rehabilitation Program under PL 84-99. Although, it has since been discovered that the re-designed panel system and additional concrete wall at the Port of Freeport is structurally deficient for hydraulic loading. More discussion of this is included in Chapter 7 of this appendix.

Currently the system is unacceptable in the Rehabilitation Program under PL 84-99 and not certifiable for FEMA accreditation under CFR 65.10. The Non-Federal Sponsor has a SWIF plan in place to address the deferred maintenance issues and issues impeding 65.10 accreditation. The Sponsor does not plan on addressing the structural risk drivers for the LSAC due to the performance concerns coming at a more significant hydraulic loading event than the requirements under 65.10. The FWOP conditions would result in no action being undertaken to reduce the risk that the system would suffer a catastrophic failure during a hydraulic loading roughly equivalent to or slightly before the 130-year event.

1.9 PLAN EVALUATION, COMPARISON, AND SELECTION

The evaluation and comparison of the various alternative plans considered is described in the FIFR-EIS. The actual plan selection process is undertaken as one of the final steps in the planning process and is performed in conjunction with sponsor input and HQ-USACE reviews and approval. The selected plan is held to stringent standards. Consequently, it must be technically viable, economically feasible, and environmentally acceptable, all in accordance with governing agency regulations and associated Federal statutes.

A preliminary array of conceptual structural alternatives was compiled by combining planning measures. Through the plan formulation process, this array was culled to an evaluation array of four (4) concept structural alternatives for the Orange-Jefferson CSRM project area that were carried forward for further development. These generalized alternatives were evaluated and refined accordingly to come up with the final array of structural alternatives summarized in Table 1-1 and shown on Plates C-01 to C-23. Alternatives for the existing systems, Port Arthur and Freeport, were conceptualized in a different manner and are discussed in this section.

These structural alternatives were then further evaluated at a preliminary level of design to determine the projects that would comprise the recommended plan. Incidental to this evaluation, alternative levee elevations were economically assessed to optimize the plans. Other alternatives screened in the preceding study phases are discussed in Appendix B, Plan Formulation. This section describes only the alternatives and each CSRM area's reaches. The Engineering appendix focuses on the final array evaluation and the recommended plan.

1.9.1 Port Arthur and Vicinity CSRM Project

The alternative selection process focused on selecting structural features that would significantly reduce the likelihood of a catastrophic failure of the Port Arthur HFPP under extreme hydraulic loading. Features that would allow for the levee system to provide a greater reduction in risk were also evaluated. These alternatives consisted of overtopping erosion protection along with additional structural features to increase stability along with entire reconstruction/reconfiguration of the I-walls to T-walls. Erosion control features would be constructed as needed to reduce the likelihood of significant erosion leading to system failure from an overtopping event.

Fragility curves were developed for specific locations along the Port Arthur system to account for the anticipated system performance at those locations and were used to scope the reconstruction and resiliency features for the existing system. These curves were developed using existing information. Existing data used included performance history based on previous hydraulic loadings for the system, draft findings of the Port Arthur SQRA, draft findings of the Texas Coastal I-wall study, FY12 periodic inspection and Arcadis I-wall analysis, USACE work on erosion for Herbert Hoover Dike, Interagency Performance Evaluation Taskforce (IPET) report, ETL 575 criteria, along with influence from the LSAC screenings, the Hydrologic Engineering Center (HEC) Risk Analysis for Flood-Damage Reduction Projects, and RMC Internal Erosion Workshop. The curves focused on anticipated structural performance of the I-walls along with erosion at floodwall to levee tie-in locations and reflect uncertainty in storm duration, size, landfall location, and wind-driven wave height. The flood wall fragility curves were developed off of the PFMA and elicitation from the Port Arthur SQRA. The fragility curves followed the factor of safety calculations computed for the SQRA.

Recommended plan implementation will require additional project scoping to ensure the CSRM project functions as a system. This additional work will include assessing the entire existing system to ensure that the system is able to perform under the anticipated hydraulic event while accommodating for relative sea-level change needs.

Risks associated with the recommended plan for the existing system are primarily due to the use of existing geotechnical and structural information. Given the extensive work for the initial construction, along with additional information obtained by the Non-Federal Sponsor for 65.10 work, this risk is considered to be manageable.

The draft findings of the SQRA for the Freeport levee system (discussed next in the section on Freeport) were applied to the plan formulation for the Port Arthur CSRM because the Port Arthur SQRA has not been completed. For the Port Arthur system, the detailed description of the needs is similar to what is presented in the Freeport HFPP section. However, the Port Arthur system is different because there are no known deferred maintenance issues related to this system at this time and general levee and foundation conditions at Port Arthur are less influenced by seepage concerns.

The formulation of alternatives for the Port Arthur and Vicinity CSRM began with defining reaches for the system. These were based on encompassing similar features of work and including the failure locations identified by the levee safety program in the absence of an SQRA. The following lists the reaches for the Port Arthur and Vicinity CSRM:

- Reach 1 (STA 0+00 to 381+30) – Encompasses the previously named "Closure Structure" alternative name
- Reach 2 (STA 381+30 to 579+87) – New work after ADM milestone
- Reach 3 (STA 579+87 to 733+41) – Encompasses "Tank Farm" and new work after ADM milestone
- Reach 4 (STA 733+41 to 970+00) – Encompasses "8- to 10-foot I-Wall" and "I-wall near Valero"
- Reach 5 (STA 970+00 to 1609+00) – New work after ADM milestone

1.9.2 Freeport and Vicinity CSRM Project

The alternative selection process focused on selecting structural features that would significantly reduce the likelihood of a catastrophic failure of the Freeport HFPP under extreme hydraulic loading. Features that would allow for the levee system to provide a greater reduction in risk were also evaluated. These alternatives consisted of overtopping erosion protection along with additional structural features to increase stability along with entire reconstruction/reconfiguration of the I-walls to T-walls. The additional structural features are a replacement of a wall/drop in

panel system at the Port Freeport and a closure of the Dow Barge Canal. Erosion control features would be constructed as needed to reduce the likelihood of significant erosion leading to system failure from an overtopping event.

Fragility curves were developed for specific locations along the existing systems in order to account for the anticipated system performance at those locations and were used to scope the reconstruction and resiliency features for the existing systems. Existing data used included performance history based on previous hydraulic loadings at each system, draft findings of the Freeport SQRA, draft findings of the Texas Coastal I-wall study, USACE work on erosion for Herbert Hoover Dike, IPET report, ETL 575 criteria, along with influence from the LSAC screenings and the HEC Risk Analysis for Flood Damage Reduction Projects and RMC Internal Erosion Workshop. The curves were focused on erodibility of "sandy" levees, steady state seepage concerns, saturated levee stability concerns, anticipated structural performance of the I-walls, and erosion at tie-in locations. These curves reflect uncertainty in storm duration, size, landfall location, and wind driven wave height. The flood wall fragility curves were developed off of the PFMA and elicitation from the Freeport SQRA. The fragility curves followed the factor of safety calculations computed for the SQRA. Earth embankment fragility curves were based on overtopping due to still water and wave action rates that were developed for the SQRA. Fragility curves were applied to areas where we had earth embankments that were susceptible to failure due to sandy embankment material. Recommended plan implementation will require additional project scoping to ensure the CSRM project functions as a system. This additional work will include assessing the entire existing system to ensure that the system is able to perform under the anticipated hydraulic event chosen for the recommended plan. Additionally the system will be evaluated and configured to accommodate relative sea-level rise.

Risks associated with the recommended plan for the existing system are primarily situated with the use of existing geotechnical and structural information. Given the extensive work for the initial construction, along with additional information obtained by the sponsor for 65.10 work, this risk should be manageable.

The draft findings of the SQRA for the Freeport system show vulnerabilities primarily associated with steady-state seepage issues and floodwall and levee overtopping. Other performance issues identified during the SQRA were the result of deferred Sponsor maintenance, or alterations that local industrial stakeholders have constructed over time, these are not being evaluated under this project. Floodwall performance issues, at locations where the originally constructed floodwall is still in place and has been operated and maintained in an acceptable manner, are being evaluated under this project to include stability and resiliency rehabilitation efforts. Levee reaches that are non-uniform in height or otherwise susceptible to concentrated overtopping erosion during an event are being evaluated for raising or armoring to reduce the likelihood of breach.

The formulation of alternatives for the Freeport and Vicinity CSRM began with defining reaches for the system. These locations were then narrowed during formulation to those locations where improvements would positively impact the system's capacity for avoiding redundancies and flood risk reduction. The following is the resulting list of reaches for the Freeport and Vicinity CSRM:

- Oyster Creek and Oyster Creek Extension
- East Storm
- DOW Barge Canal
- Old River North – Encompasses "Old River at Dow Thumb"
- Tide Gate
- Old River South – Encompasses "Freeport Dock"
- South Storm
- East Bank Brazos River

Table 1-1: Structural CSRM Alternatives Evaluated for Recommended Plan Selection

Project Area	Reach	Description of CSRM Reach	Optimization Alternatives
Orange-Jefferson CSRM	**Orange 3**	Orange 3 runs southeasterly from a high ground area south of highway 105 towards Bridge City. The alignment goes around the south side of the city and continues east-northeasterly to the Port of Orange. Along this segment, the alignment crosses Cow and Adams Bayous, both of which are used for navigation. From the port, the alignment runs northwesterly along the port's west property line (along Alabama Street) and to the north along much of the length of the Sabine River's west bank. The northeast terminus of the Orange 3 reach is at U.S. Interstate 10, on its south side, about 2/10ths of a mile east of the U.S. Highway 90 Business (Simmons Drive) intersection. The total length of this is 26.72 miles. A levee system consisting of earthen levee and floodwall was evaluated at four (4) incremental heights, in one-foot increments, that were correlated to corresponding reductions in the interior flood depths. Because the levee system alignment traverses several industrial areas, sensitive environmental habitat areas, places where the land area is insufficient for levee construction, or there are other real estate constraints, and wide floodplains subject to constant inundation with likely poor foundation, the system assumes 10.75 miles of concrete floodwall. The alignment crosses many pipelines and utilities, several roadways, including State Highway 87, and two navigation channels, all of which will have to be accommodated accordingly, relocated, or modified. Orange 3 reduces the surge flood-damage risk to the Cities of Orangefield, Bridge City, Pinehurst, West Orange, and Orange, which together represent a large population area and heavily industrialized area. It also protects Entergy Texas Inc.'s Sabine (Power) Plant, Bridge City.	All Alternatives Total new Levee length: 15.56 miles Total new Floodwall length: 10.75 miles Total new Reach length: 26.72 miles **Total length includes pump stations, road closure gates and navigation structures within the alignment --- Incremental Levee Heights • New levee/floodwall, 11 feet SWL (**Recommended Plan**) • New levee/floodwall, 12 feet SWL • New levee/floodwall, 13 feet SWL • New levee/floodwall, 14 feet SWL

Project Area	Reach	Description of CSRM Reach	Optimization Alternatives
Port Arthur and Vicinity CSRM	**Reach 1**	Reach 1 is a section of levee which to the eastern side of Port Arthur and runs along and then from the Sabine Neches Waterway to the north, ending to the southeast of Port Neches, tying into high ground. This reach encompasses the previously named 'Closure Structure' reach. Of the nearly 7.7 miles of existing levee system included in this reach; 359 LF of floodwall, 34,900 LF of levee and two sections of current high ground total approximately 4,760 LF in length. It also contains three gated closure structures, two pump stations and ten drainage structures within its alignment. The closure structures are currently designed to an elevation lower than the adjacent levee and are also not adaptable to RSLC, therefore all gated closure structures as well as their respective lengths of floodwall are recommended to be replaced in any considered alternatives. A slightly longer length of floodwall is required for construction due to providing additional space around one pump station for possible future expansion. No work is recommended on the pump stations themselves or the drainage structures in any of the proposed alternatives.	• No-Fail – Construct 690 LF of floodwall, replace 3 gated closure structures • No-Fail +1 - Construct 690 LF of floodwall, replace 3 gated closure structures (**Recommended Plan**) • No-Fail +2 - Construct 690 LF of floodwall, replace 3 gated closure structures, raise 6,500 LF of levee 1-foot ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.
	Reach 2	Reach 2 runs along the Sabine Neches Waterway from the end of Reach 1 to Augusta Ave of Port Arthur, Texas. The existing characteristics of this reach are approximately 3.8 miles, which consists of 10,737 LF of floodwall and 9,000 LF of levee. The floodwall is mostly made up of concrete T-wall with the exception of a short section of pre-stressed concrete piles. It also contains four pump stations and eleven drainage structures within its alignment. The floodwall of this reach is currently at a height which is several feet lower than predicted hydraulic loadings, as well as not currently designed for adaptability to RSLC. It is due to these issues that the recommended plan include replacement of all floodwall within this reach. A slightly longer length of floodwall is required for construction due to providing additional space around the pump stations for possible future expansion. No work is recommended on the pump stations themselves or the drainage structures in any of the proposed alternatives.	• No-Fail – Construct 10,940 LF of floodwall, raise 9,000 LF of levee 0.5-feet • No-Fail +1 - Construct 10,940 LF of floodwall, raise 9,000 LF of levee 1.5-feet (**Recommended Plan**) • No-Fail +2 - Construct 10,940 LF of floodwall, raise 9,000 LF of levee 2.5-feet ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.
	Reach 3	Reach 3 runs along the Sabine Neches Waterway from the end of Reach 2 to the Tank Farm at W 7th St and Texaco Island Rd, which encompasses the previously named "Tank Farm" reach of this project. The existing features of this reach consist of 5,605 LF of floodwall, 8,265 LF of levee and approximately 1,440 LF of current high ground. Approximately 5,134 LF of floodwall is steel sheet pile I-wall, which is along a deep draft navigation channel and is susceptible to vessel impacts. A 1,820 LF section of steel sheet pile I-wall is documented to have global stability issues because of insufficient embedment. This reach also contains one gated closure structure, six panel type closure structures, one drainage structure and three pump stations. The high ground area, which the current alignment passes through, is in a Port of Port Arthur facility and presents a difficult task in constructing an adaptable levee or floodwall. Several sections of floodwall require a raise due to predicted hydraulic loadings as well as all floodwall not currently adaptable to RSLC. This reach consists mostly of steel sheet pile I-wall, which has shown in other areas to be a major concern. It is recommended to replace all floodwall for this reach. The previously considered high ground area is recommended to be replaced with floodwall. No work is recommended on the pump stations themselves or the drainage structures in any of the proposed alternatives.	- No-Fail – Construct 7,030 LF of floodwall, raise 1,467 LF of levee 0.5-foot, 7 gated closure structures, add 3 gated closure structures - No-Fail +1 - Construct 7,030 LF of floodwall, raise 6,788 LF of levee 1-foot and 1,462 LF 1.5-feet, 7 gated closure structures, add 3 gated closure structures (**Recommended Plan**) - No-Fail +2 - Construct 7,030 LF of floodwall, raise 6,788 LF of levee 2-feet and 1,462 LF 2.5-feet, 7 gated closure structures, add 3 gated closure structures ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.

Project Area	Reach	Description of CSRM Reach	Optimization Alternatives
Port Arthur and Vicinity CSRM	**Reach 4**	Reach 4 runs along the Sabine Neches Waterway from the end of Reach 3 to the Taylors Bayou Turning Basin and then around the Tank Farm to the west of Port Arthur. The reach encompasses the previously named "I-wall Near Valero" and "8-10 foot I-wall" reaches of this project. This reach contains 9,404 LF of floodwall, 8,950 LF of levee, 12 gated closure structures and one drainage structure. The floodwall consists mostly of steel sheet pile I-wall with one area, approximately 1,160 LF of concrete piles (braced cantilever and cantilever). The I-wall has a stick height ranging from 6 to 12+ feet and no scour protection or protection from debris and vessel impacts. A section of steel sheet pile I-wall was added to an earthen embankment section where significant settlement had occurred post construction. This I-wall was left with excessive stick-up height (8-10 ft) to account for any future settlement, which is susceptible to failure for hydraulic loading events that exceed the systems' capacity. All floodwall of this reach requires a raise due to predicted hydraulic loadings and its current design is not adaptable to RSLC. This reach also consists mostly of steel sheet pile I-wall and when analyzed for stability shows marginal FOS for rotational stability as well as large deflections. The recommended plan for this reach is to replace all floodwall. No work is recommended on the drainage structure for any of the proposed alternatives.	- No-Fail – Construct 9,790 LF of floodwall, raise 1,450 LF of levee 0.5-feet and 7,500 LF 1-foot, replace 12 gated closure structures - No-Fail +1 - Construct 9,790 LF of floodwall, raise 1,450 LF of levee 1.5-feet and 7,500 LF 2-foot, replace 12 gated closure structures (**Recommended Plan**) - No-Fail +2 - Construct 9,790 LF of floodwall, raise 1,450 LF of levee 2.5-feet and 7,500 LF 3-foot, replace 12 gated closure structures ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.
	Reach 5	Reach 5 runs north from the end of Reach 4 adjacent to the Taylors Bayou Outfall Canal, then turns northwesterly until crossing Highway 73, where it turns to the north and runs into high ground near the Jack Brooks Regional Airport. The existing reach consists of 1,470 LF of floodwall, 62,400 LF of levee, one gated closure structure, three pump stations and seven drainage structures within the levee system alignment. Due to the floodwalls' current design not adaptable to RSLC, it is recommended to replace all floodwall for this reach. No work is recommended on the pump stations themselves or the drainage structures for any of the proposed alternatives.	- No-Fail – Construct 1,640 LF of floodwall, raise 3,000 LF of levee 0.5-feet, replace 1 gated closure structure - No-Fail +1 - Construct 1,640 LF of floodwall, raise 3,000 LF of levee 1.5-feet, replace 1 gated closure structure (**Recommended Plan**) - No-Fail +2 - Construct 1,640 LF of floodwall, raise 3,000 LF of levee 2.5-feet and 4,200 LF 1-foot, replace 1 gated closure structure ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.
	Port Arthur Extension	The 'Port Arthur Extension' is a new levee section on the northeastern end of the system. This extension of the Port Arthur HFPP would prevent storm surge from flanking the system by tying together two sections of high ground.	- No-Fail – Construct 1,830 LF of new levee 4-feet in height - No-Fail +1 - Construct 1,830 LF of new levee 5-feet in height (**Recommended Plan**) - No-Fail +2 - Construct 1,830 LF of new levee 6-feet in height

Project Area	Reach	Description of CSRM Reach	Optimization Alternatives
Freeport and Vicinity CSRM	**Oyster Creek and Oyster Creek Extension**	This reach consists of the Oyster Creek Extension and Oyster Creek levees. The Oyster Creek Extension begins north of the city of Clute and runs southeasterly along the western side of Oyster Creek. It then connects with the Oyster Creek levee, which continues along the bank of Oyster Creek until ending near county road 287. The Oyster Creek Extension consists of 235 LF of floodwall and 10,900 LF of levee. The Oyster Creek levee is comprised of 985 LF of floodwall and 28,380 LF of levee. The Oyster Creek levee was constructed at varying elevations to account for changes in hydraulic loadings. This levee reach also contains one pump station and ten gravity drainage structures. Due to a section of floodwall requiring a raise due to predicted hydraulic loadings and the floodwalls' current design not adaptable to RSLC, it is recommended to replace all floodwall for this reach in any of the considered alternatives. The areas of levee raise will bring the levee to a more uniform elevation throughout its length. No work on the pump station or the other drainage structures is recommended for any of the proposed alternatives.	• No-Fail – Construct 1,220 LF of floodwall, raise 4,700 LF of levee 2.0-feet • No-Fail +1 - Construct 1,220 LF of floodwall, raise 23,700 LF of levee 0.5-feet and 4,700 LF of levee 3.0-feet, replace 3 drainage structures (**Recommended Plan**) • No-Fail +2 - Construct 1,220 LF of floodwall, raise 23,700 LF of levee 1.5-feet and 4,700 LF of levee 4.0-feet, replace 3 drainage structures ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.
	East Storm	The East Storm reach runs south, from the end of Oyster Creek, on county road 690 eventually crossing Highway 332 and continuing south until reaching the DOW Barge Canal. This reach consists of 17,500 LF of levee, one gravity drainage structure and one pump station. The East Storm levee was constructed at varying elevations to account for changes in hydraulic loadings. The East pump station which pumps water from this wastewater canal would require an additional pump and all associated parts, to discharge the additional water from the DOW Barge Canal. The pump station currently contains available space for extra pumping equipment and therefore would not require any reconstruction or building expansion. The areas of levee raise are required due to predicted hydraulic loadings exceeding the systems' capacity along most of the length of this reach. The floodwall section is required due to space restrictions over an existing gravity drainage structure, of which the levee raise cannot be constructed.	• No-Fail – Construct 320 LF of new floodwall, raise 9,370 LF of levee 0.5-feet, 4,000 LF of levee 1.0-feet and 4,000 LF of levee 1.5-feet • No-Fail +1 - Construct 320 LF of new floodwall, additional pump in East pump station, raise 9,370 LF of levee 1.5-feet, 4,000 LF of levee 2.0-feet and 4,000 LF of levee 2.5-feet (**Recommended Plan**) • No-Fail +2 - Construct 4,320 LF of new floodwall, additional pump in East pump station, raise 9,370 LF of levee 2.5-feet, 4,000 LF of levee 3.0-feet, replacement of drainage structure near East pump station ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.

Project Area	Reach	Description of CSRM Reach	Optimization Alternatives
Freeport and Vicinity CSRM	**DOW Barge Canal**	The DOW Barge Canal North and South levees run on both sides of the DOW Barge Canal, from its entrance near the GIWW to the DOW Turning Basin to the northwest near the highway 332 and 288 interchange. These levees are approximately 12.5 miles in length and consist of mostly earthen embankment with 1,287 LF of floodwall (mostly steel sheet pile I-wall) in the DOW Turning Basin. This reach also contains two gravity drainage structures. There is significant risk associated with these levees' performance at and above the design event. This risk is primarily from seepage and instability caused by seepage through the "sandy" levee and foundation material. Significant risk also exists with numerous pipeline penetrations, I-wall instability, and non-uniform levee heights. Because of the significant existing infrastructure within the existing embankment and the uncertainty in the performance of seepage control measures installed in such a complex environment, the recommended plan is to utilize a navigable sector gate structure in the DOW Barge Canal. The structures' proposed location is approximately one mile into the canal from the juncture of the East Storm levee and the DOW Barge Canal North levee. Sections of floodwall will be on both sides of the gate structure, tying into the earthen embankment levees. A gravity drainage structure will be constructed at the northern end of the DOW Barge Canal to allow movement of water from the shipping canal to a nearby wastewater canal. The southern end of the DOW Barge Canal South Levee requires a significant levee raise, which cannot be accommodated with compacted earthen fill. To reach the required elevation, floodwall will be constructed through this area. No work on the gravity structures is recommended for any of the proposed alternatives.	• No-Fail – Construct navigable gate structure, new drainage structure near DBC Turning Basin, 3,190 LF of floodwall, raise 1,625 LF of levee 2-feet and 5,400 LF of levee 2.5-feet, add 2 gated closure structures • No-Fail +1 – Construct navigable gate structure, new drainage structure near DBC Turning Basin, 3,190 LF of floodwall, raise 4,600 LF of levee 3-feet and 4,550 LF of levee 3.5-feet, add 2 gated closure structures (**Recommended Plan**) • No-Fail +2 - Construct navigable gate structure, new drainage structure near DBC Turning Basin, replacement of Ethyl DOW water intake structure, 3,190 LF of floodwall, raise 4,600 LF of levee 4-feet and 4,550 LF of levee 4.5-feet, add 2 gated closure structures ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.
	Old River North	The Old River North levee reach runs along the eastern side of the Freeport Harbor Channel, which is a deep draft navigation channel. This reach encompasses the previously named "Old River at Dow Thumb" reach of this project. The Old River North levee consists of 4,990 LF of floodwall and 5,400 LF of earthen embankment. The floodwall is made up mostly of concrete wall incorporated into a dock face, with some panel walls for industry access, but does have sections of T-wall, steel sheet pile I-wall and concrete piles. An earthen embankment portion of this reach, which is referred to as the Dow Thumb, is not high enough to prevent overtopping by waves during extreme surge events. This section of levee has a very low FOS for global stability and is currently being evaluated under the General Re-evaluation Report for the navigation project. Due to sections of floodwall requiring a raise due to predicted hydraulic loadings and the floodwalls' current design not adaptable to RSLC, it is recommended to replace all floodwall for this reach in any of the considered alternatives. Also, for all alternatives, two new sections of floodwall will be added. One section for an area of levee with limited available space for the required raise. The other section is the Dow Thumb earthen embankment, which will require the levee to be degraded (due to stability issues) and floodwall constructed to achieve the required height. By degrading the levee, the required FOS for global stability can be achieved.	• No-Fail – Construct 15,660 LF of floodwall, raise 3,030 LF of levee 2-feet • No-Fail +1 - Construct 15,660 LF of floodwall, raise 3,030 LF of levee 3-feet (**Recommended Plan**) • No-Fail +2 - Construct 15,660 LF of floodwall, raise 3,030 LF of levee 4-feet, replacement of drainage structure ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.

Project Area	Reach	Description of CSRM Reach	Optimization Alternatives
Freeport and Vicinity CSRM	**Tide Gate**	The Tide Gate reach connects the Old River South and North reaches. It consists of 530 LF of floodwall and a vertical lift gate structure. The floodwall of this reach is composed of 362 LF of concrete capped steel sheet pile I-wall and 168 LF of concrete piles. The steel sheet pile I-wall was constructed as part of the original HFPP construction when the earth embankment section could not reach the design elevation. The very soft foundation materials present in the old river channel would not support the additional weight of the initially proposed embankment section. The stability concerns for this section of I-wall are at design exceedance events with water levels at or near the top of wall. Because of floodwall performance issues related to stability and resiliency, the I-wall at the Tide Gate is proposed to be reconstructed as a pile-founded T-wall.	- No-Fail – Construct 530 LF of floodwall - No-Fail +1 - Construct 530 LF of floodwall (**Recommended Plan**) - No-Fail +2 - Construct 530 LF of floodwall, replacement of Tide Gate Structure ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.
	Old River South	The Old River South reach runs along the western side of the Freeport Harbor channel. The reach consists of 10,500 LF of levee, 4,380 LF of floodwall, one pump station, and two gated closure structures. The floodwall is made up mostly of concrete wall incorporated into a dock face, with some panel walls for industry access, and a section of concrete capped steel sheet pile I-wall. The existing floodwall along the Port of Freeport dock (Berth 1, 2, 3 & 5) is not structurally adequate to handle the additional hydrostatic loading and overtopping from the assumed design storm event. Because of predicted hydraulic loadings exceeding existing floodwall design capacity and the floodwalls' current design not adaptable to RSLC, it is recommended to replace all floodwall for this reach in any of the considered alternatives. Also, for all alternatives, one new section of floodwall will be added. An area of existing levee with limited available space for the required raise will be recommended to have floodwall constructed in place of compacted earth fill. No work on the pump station is proposed for the recommended plan on any of the alternatives.	• No-Fail – Construct 7,855 LF of floodwall, raise 1,625 LF of levee 2-feet and 5,400 LF of levee 2.5-feet, replace two gated closure structures, add 6 gated closure structures • No-Fail +1 - Construct 7,855 LF of floodwall, raise 1,625 LF of levee 3-feet and 5,400 LF of levee 3.5-feet, replace two gated closure structures, add 6 gated closure structures (**Recommended Plan**) • No-Fail +2 - Construct 7,855 LF of floodwall, raise 1,625 LF of levee 4-feet and 5,400 LF of levee 4.5-feet, replace two gated closure structures, add 6 gated closure structures ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.
	South Storm	The South Storm Levee reach is on the south side of the Freeport and Vicinity Hurricane Flood Protection Project paralleling the Gulf Intracoastal Waterway. This reach consists of 18,795 LF of levee which is not uniform in height and is therefore susceptible to concentrated overtopping erosion for the assumed design storm event. Also within this reach is one gravity drainage structure. The area of levee raise will bring the levee reach to a more uniform elevation throughout its length. No work is proposed for the gravity drainage structure.	- No-Fail – No work - No-Fail +1 - Raise 4,400 LF of levee 1-foot (**Recommended Plan**) - No-Fail +2 - Raise 4,400 LF of levee 2-feet

Project Area	Reach	Description of CSRM Reach	Optimization Alternatives
Freeport and Vicinity CSRM	**East Bank Brazos River**	The East Bank Brazos River Levee Reach is on the western side of the Freeport levee system and runs north from the end of the South Storm Levee along the Brazos River until ending at the western edge of the DOW chemical plant. This reach consists of 396 LF of floodwall, 38,500 LF of levee, two pump stations, three water intake structures and two gravity drainage structures. Due to sections of floodwall not currently designed to be adaptable to RSLC, it is recommended to replace all floodwall for this reach in any of the considered alternatives. A slightly longer length of floodwall is required for construction due to providing additional space around the pump station for possible future expansion. No work is recommended for the pump stations, gravity drainage structures or water intake structures for any of the proposed alternatives.	- No-Fail – Construct 430 LF of new floodwall - No-Fail +1 - Construct 430 LF of new floodwall (**Recommended Plan**) - No-Fail +2 - Construct 430 LF of new floodwall, raise 21,720 LF of levee 1-foot ** Any recommended construction for this reach would include a scour pad behind all floodwall and erosion protection around all floodwall to levee tie-ins.

777

1.10 DESCRIPTION OF RECOMMENDED PLAN

1.10.1 Orange-Jefferson CSRM Project

1.10.1.1 Orange 3 Reach

The recommended plan of the Orange 3 reach is a levee/floodwall flood risk reduction system that will serve to reduce the flood-damage potential from storm surge to much of the southern half of Orange County along the Sabine River and Bessie Heights Marsh as shown in Figure 1-4 (see Plates C-01 to C-23). The features associated with the Orange 3 Reach are listed in Table 1-2. The floodwall length includes added footage for the closure gates at road crossings within levees and on each side of pump stations as well as the navigation gate structures. The borrow material for the levee and backfill of the floodwall is assumed to come from commercial sources. The pump stations range in size from 131 to 8,190 CFS for their respective discharge capacities. Where feasible, initial smaller pump station locations were combined into larger and more efficient pump stations. For purposes of this study an average size drainage structure (of the sizes calculated by Hydrology and Hydraulics) was assumed for quantities in the cost estimate. More information on the road and railroad closure gates can be found in 6.3.3 Road Crossings.

Table 1-2: Orange 3 Reach – Features of Work

Feature of Work	Length (ft)
Floodwall	56,755
Levee	82,169
	Each
Pump Stations	7
Drainage Structures	56
Closure Gates (Road/RailRoad Crossings)	32

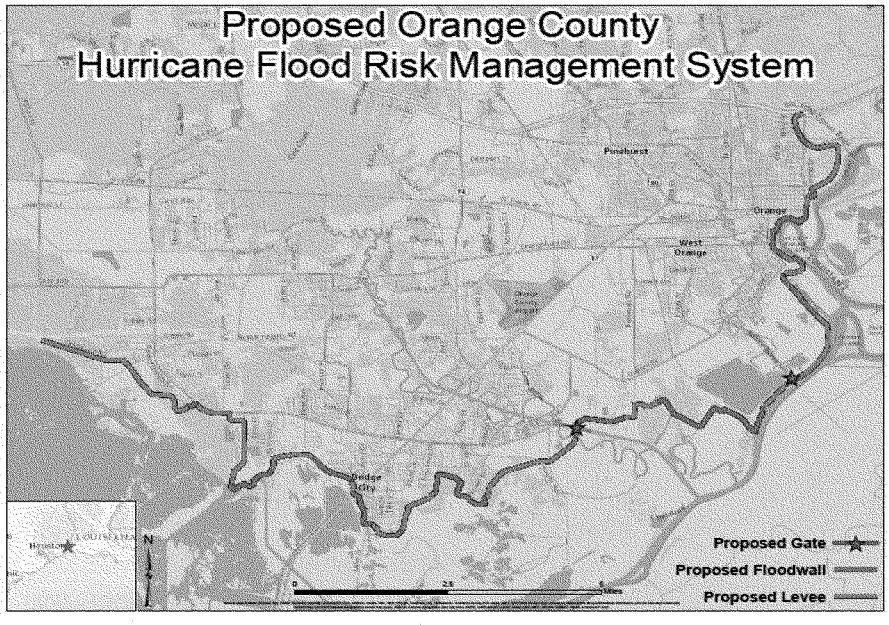


Figure 1-4: Orange 3 CSRM – Recommended Plan

The alignment of the Orange 3 reach crosses two shallow draft navigation channels. A sector gate structure which will allow vessel traffic through the gate is proposed at both of these locations. These structures will require construction from barges for certain aspects. A cofferdam will allow the construction to be mostly on land.

The performed optimization efforts for the Orange 3 reach found the 11-foot still water elevation alternative to be the most economically feasible and justifiable plan. This elevation was utilized to determine the appropriate levee and floodwall heights for the features of work listed in Table 1-2. The recommended levee and floodwall elevations, which were used for the quantity calculations, were determined from the heights listed in Table 2-9 for each of the Geo Point IDs. The location of the Geo Point IDs is shown in Figure 1-5. The heights from Section 2.10.3 were raised by a design offset, calculated from the Index Point, in order for the system to have a uniform annual chance exceedance throughout its length. The heights were then rounded up to 0.5 foot increments and are shown in Table 1-3.

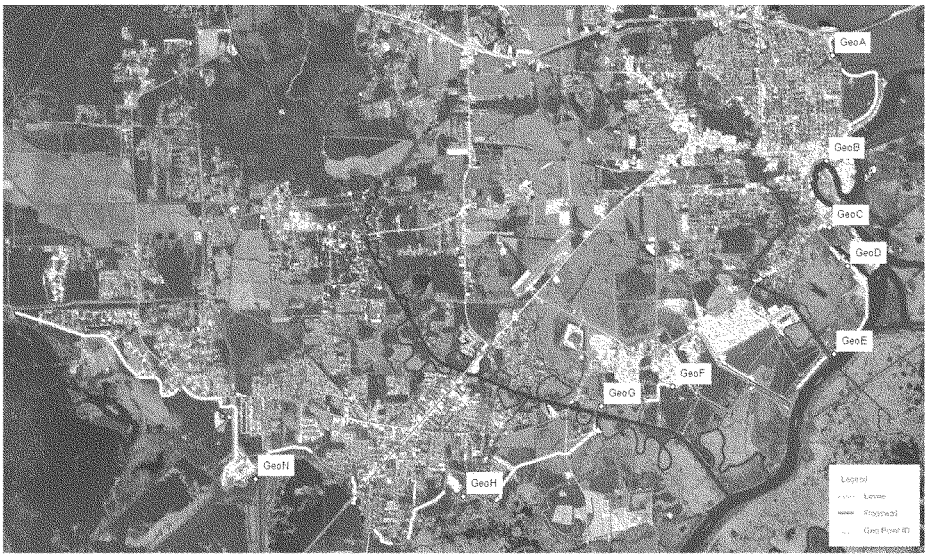


Figure 1-5: Orange 3 - Geo Point ID Locations

Table 1-3: Orange 3 Levee and Floodwall Elevations

	Recommended Elevation (NAVD88)	
Geo Point ID	Levee	Floodwall
A	14.00	14.00
B	12.00	14.50
C	15.50	16.00
D	14.00	13.00
E	14.00	
F	15.50	15.00
G		13.50
H	17.50	15.50
N	16.50	14.00

1.10.2 Port Arthur and Vicinity CSRM Project

The Port Arthur and Vicinity CSRM Project involves construction of floodwalls, raising of levees and replacement of vehicular closure structures, as shown in Figure 1-6. Several sections of floodwall and levee require raising due to a necessary increase in system capacity to further

reduce the likelihood of failure of the system. The borrow material for the levee and backfill of the floodwall is assumed to come from commercial sources. For resiliency of the levee system, erosion protection is recommended to be installed around all concrete structures which are part this plan. The No-Fail + 1 alternative was chosen as the most economically justifiable and feasible plan. The recommended plan is described in further detail under each of the reaches for the project. The values presented in Table 1-4 are the features of work for each reach and also the Addition to the levee system. A location plan of the recommended plan is shown in Figure 1-6 and is provided in the attached Plates, C-24 to C-43.

Table 1-4: Port Arthur and Vicinity CSRM – Features of Work

Reach	Floodwall (ft)	Levee (ft)	Closure Gates (Road/RailRoad Crossings)
1	690	0	3
2	10,940	9,000	0
3	7,030	8,250	10
4	9,790	8,950	12
5	1,640	3,000	1
Extension	0	1,830	0

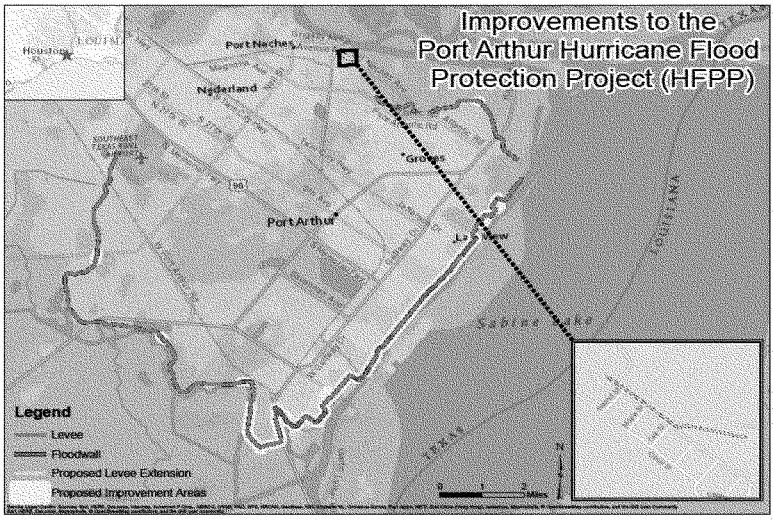


Figure 1-6: Port Arthur and Vicinity CSRM – Recommended Plan

The recommended levee and floodwall elevations, which were used for the quantity calculations, were determined from the heights listed in Table 2-9 for each of the Geo Point IDs. The location of the Geo Point IDs is shown in Figure 1-7. These heights were raised by a design offset, calculated from the chosen Index Point, in order for the system to have a uniform annual chance exceedance throughout its length. The heights then had an additional 1-foot added, which is the recommended plan (No-Fail + 1). The existing levee elevation throughout the system was taken from recent surveys completed by the local sponsor. For purposes of this study, an average elevation was used for the lengths of levee or floodwall within each reach, change in levee type and Geo Point area. The final recommended levee heights were then used against the existing surveyed elevations of the system to calculate the required raise of the existing levee and this raise amount was rounded up to 0.5 foot increments for the quantity calculations (for levee only: the heights shown in Table 1-5 are the surveyed elevation with the raise height rounded to 0.5 foot increments added). The same process was completed for the floodwall heights of the recommended plan, which are shown in Table 1-5. For the floodwall, if the calculated height was lower than the existing height for the same Geo Point ID location, the existing height (labeled with *) was used for the recommended plan.

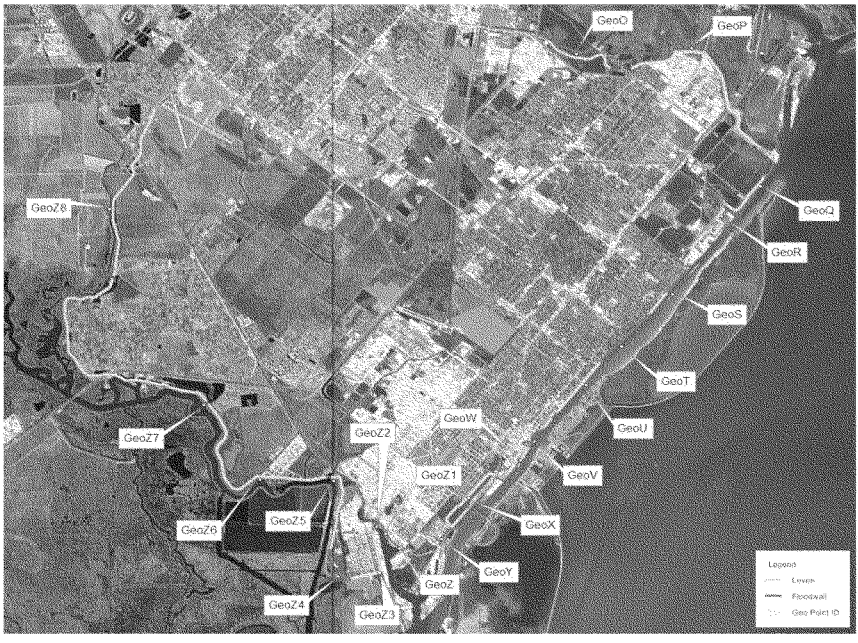


Figure 1-7: Port Arthur - Geo Point ID Locations

Table 1-5: Port Arthur Levee and Floodwall Elevations

	Recommended Elevation (NAVD88)	
Geo Point ID	Levee	Floodwall
O	14.39	14.50
P	14.40	17.00*
Q	14.93	
R	14.99	16.50*
S	16.41	19.50
T		19.50
U	16.31	17.00
V	16.60	17.50
W	16.30	17.50
X	16.60	
Y	17.10	19.00*
Z		18.00
Z1		19.50
Z2		19.50
Z3	17.20	
Z4	16.30	16.50*
Z5	15.91	18.00*
Z6	15.66	
Z7	15.21	15.50
Z8	14.70	16.00*

1.10.2.1 Reach 1

The recommended plan for construction and resiliency features of the existing HFPP in Reach 1 is construction of new floodwall. The floodwall reconstruction consists of 280 LF of existing steel sheet pile I-wall and concrete T-wall to be demolished and rebuilt as T-wall, which will provide an adaptable and more robust floodwall section. Three gated vehicular closure structures will be replaced. Approximately 410 LF of new floodwall will be placed to the flood side of the Crane Bayou Pump Station. For resiliency of this feature, a 15-foot wide scour pad will be placed behind the floodwall sections. All floodwall to levee tie-ins will have grouted in-place riprap as erosion protection.

1.10.2.2 Reach 2

The recommended plan for construction and resiliency features of the existing HFPP in Reach 2 is reconstruction of the existing floodwall throughout the reach, construction of three sections of

new floodwall and levee raise on all sections of embankment. The floodwall reconstruction consists of replacement of 10,737 LF of existing T-wall and concrete piles, which will provide an adaptable section of floodwall as well as an increase in system capacity. The sections of new floodwall total 203 LF and will be placed to the flood side of the Lakeview, Del Mar and Dequeen Pump Stations. This method will allow for an increase in pumping capacity if found to be required in the future. All floodwall sections are adjacent to a deep draft navigation channel and have large stones for erosion protection on their flood side. These stones will be required to be moved, stored and placed back in front of the new floodwall. For resiliency of this feature, a 15-foot wide scour pad will be placed behind the floodwall sections. The recommended plan for the levee of this reach entails 9,000 LF of 1.5-foot raise, with compacted earth fill. In addition to the raise, 5,200 LF of asphalt pavement will need to be replaced. All floodwall to levee tie-ins will have grouted in-place riprap as erosion protection.

1.10.2.3 Reach 3

The recommended plan for construction and resiliency features of the existing HFPP in Reach 3 is reconstruction of the existing floodwall throughout the reach, addition of a new section of floodwall and levee raise on all sections of embankment. The floodwall reconstruction consists of replacing 5,605 LF of steel sheet pile I-wall and concrete T-wall with reinforced concrete T-wall, which will provide an increase in system capacity as well as an adaptable section for RSLC. Construction of 1,425 LF of new floodwall, in front of the Shreveport Pump Station and over a section of current high ground. The high ground section of this reach runs through a Port of Port Arthur facility. Construction for this section will consist of a post and panel concrete floodwall. This reach of the system contains one gated vehicle closure structure and six panel closure structures which are for vehicle and rail use. The recommended plan for these structures is to replace all of the closures with swing gate structures. Two of the panel closures, which have larger width openings, will be replaced with two or three gated structures. The floodwall construction will require a 1,100 LF section of asphalt pavement to be demolished and replaced.

The recommended plan for levee of this reach entails 1,462 LF of 1.5-foot raise and 6,788 LF of 1-foot raise, with compacted earth fill. An 860 LF section of levee has a wooden plank deck on its crest. This deck would require removal, storage, and placing the deck in its previous location. All floodwall to levee tie-ins will have grouted in-place riprap as erosion protection.

1.10.2.4 Reach 4

The recommended plan for construction and resiliency features of the existing HFPP in Reach 4 is reconstruction of the existing floodwall throughout the reach, addition of a new section of floodwall and levee raise on all sections of embankment. The floodwall reconstruction consists of

replacing 9,404 LF of steel sheet pile and concrete pile I-wall with reinforced concrete T-wall, which will provide an increase in system capacity as well as an adaptable section for RSLC. A 4,600 foot floodwall section which is to be replaced will require the excavated material through this section to be environmentally tested to determine if contaminants are present. If the material contains contaminants, it will be hauled to a hazardous material disposal site. Construction of 386 LF of new floodwall will be placed over an existing earthen embankment section which is between two sections of steel sheet pile I-wall. These two sections of sheet pile I-wall and the new segment of floodwall total 3,540 LF and will be constructed on a levee section by degrading the levee and constructing a pile founded T-wall. For resiliency of this feature, a 15-foot wide scour pad will be placed behind the floodwall sections. The recommended plan also includes replacement of 12 gated closure structures within the floodwall sections of this reach.

The recommended plan for the levee of this reach entails 1,450 LF of 1.5-foot raise and 7,500 LF of 2-foot raise, with compacted earth fill. Approximately 6,500 LF of compacted gravel road will require replacement on the crest of the levee sections. All floodwall to levee tie-ins will have grouted in-place riprap as erosion protection.

1.10.2.5 Reach 5

The recommended plan for construction and resiliency features of the existing HFPP in Reach 5 is reconstruction of existing floodwall at a closure structure, addition of new sections of floodwall at pump stations and levee raise on one section of embankment. The floodwall reconstruction consists of replacing 115 LF of T-wall on the sides of a vehicular closure structure. The new T-wall will provide a floodwall section which is adaptable to RSLC. Construction of 1,525 LF of new floodwall, in front of Alligator Bayou, Lakeside and Port Acres Pump Stations, will allow these sections to be adapted to future RSLC. For resiliency of this feature, a 15-foot wide scour pad will be placed behind the floodwall sections. The recommended plan for the levee of this reach entails 3,000 LF of 1.5-foot raise with compacted earth fill. All floodwall to levee tie-ins will have grouted in-place riprap as erosion protection.

1.10.2.6 Port Arthur Extension

The recommended plan for the Port Arthur Extension is an addition to the existing Port Arthur and Vicinity HFPP. This extension entails construction of 1,830 LF of new levee, as compacted earth fill, on the northeastern end of the alignment.

1.10.3 Freeport and Vicinity CSRM Project

The Freeport and Vicinity CSRM Project involves construction of floodwalls, raising of levees, replacement of vehicular closure structures, and constructing a navigable gate structure in an active barge canal. Several sections of floodwall and levee require raising due to a necessary increase in system capacity to further reduce the likelihood of failure of the system. The borrow material for the levee and backfill of the floodwall is assumed to come from commercial sources. For resiliency of the levee system, erosion protection is recommended to be installed around all concrete structures which are part this plan. The No-Fail + 1 alternative was chosen as the most economically justifiable and feasible plan. The recommended plan is described in further detail under each of the reaches for the project. The values presented in Table 1-6 are the features of work for each reach. An overview map of the recommended plan is shown in Figure 1-8 and is provided in the attached Plates, C-44 to C-62.

Table 1-6: Freeport and Vicinity CSRM - Features of Work

Reach	Floodwall (ft)	Levee (ft)	Closure Gates (Road/RailRoad Crossings)	Drainage Structures (EA)
Oyster Creek & Oyster Creek Extension	1,220	28,400	0	3
East Storm	320	17,370	0	0
DOW Barge Canal	3,190	9,150	2	1
Old River North	15,660	3,030	0	0
Tide Gate	530	0	0	0
Old River South	7,855	7,025	8	0
South Storm	0	4,400	0	0
East Bank Brazos River	430	0	0	0

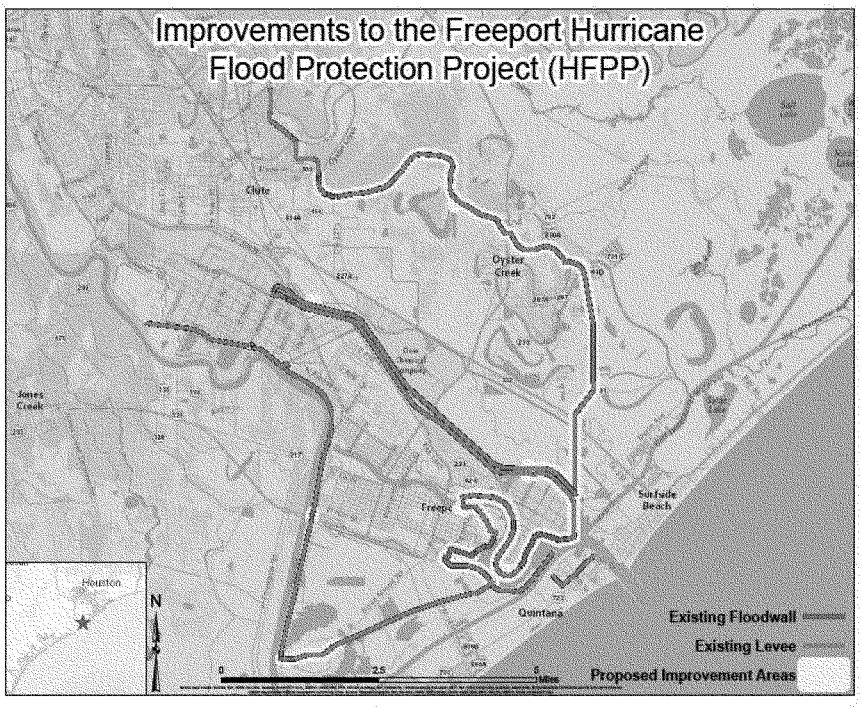


Figure 1-8: Freeport and Vicinity CSRM – Recommended Plan

The recommended levee and floodwall elevations, which were used for the quantity calculations, were determined from the heights listed in Table 2-8 under each of the Geo Point IDs. The location of the Geo Point IDs is shown in Figure 1-9. These heights were raised by a design offset, calculated from the chosen Index Point, in order for the system to have a uniform annual chance exceedance throughout its length. The heights then had an additional 1-foot added, which is the recommended plan (No-Fail + 1), and are shown in Table 1-7. The existing levee elevation throughout the system was taken from recent surveys completed by the local sponsor. For purposes of this study, an average elevation was used for the lengths of levee or floodwall within each reach, change in levee type and Geo ID area. The final recommended levee heights were then used against the existing surveyed elevations of the system to calculate the required raise of the existing levee and were rounded up to 0.5 foot increments for the quantity calculations (for levee only: the heights shown in Table 1-7 are the surveyed elevation with the raise height rounded to 0.5 foot increments added to them). The same process was completed for the floodwall heights of the recommended plan, which are shown in Table 1-6. For the floodwall, if the calculated height was

lower than the existing height for the same Geo ID location, the existing height (labeled with *) was used for the recommended plan.

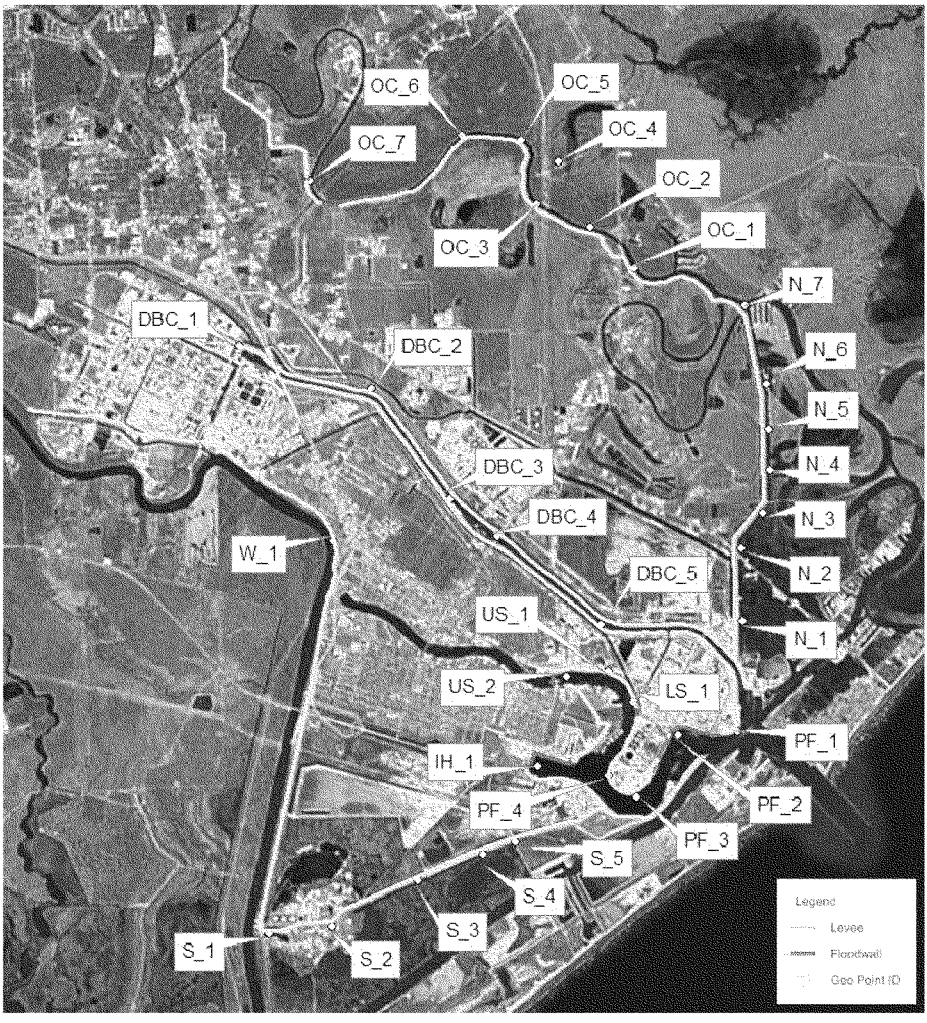


Figure 1-9: Freeport - Geo Point ID Locations

Table 1-7: Freeport Levee and Floodwall Elevations

	Recommended Elevation (NAVD88)	
Geo Point ID	Levee	Floodwall
OC_1	20.31	
OC_2	20.40	
OC_3	20.00	
OC_4	20.15	
OC_5	20.00	
OC_6	16.30	16.50
OC_7	13.40	16.00*
N_1	22.00	22.00
N_2	22.50	
N_3	23.50	
N_4	23.20	
N_5	23.00	
N_6	23.50	
N_7	23.16	
DBC_1	19.92	
DBC_2	19.27	
DBC_3	19.21	
DBC_4	19.18	
DBC_5	19.50	19.50
W_1	16.81	19.00*
S_1	17.85	
S_2	17.40	
S_3	18.83	
S_4	17.86	
S_5	17.32	
PF_1	25.85	26.00
PF_2	19.76	20.00
PF_3W	20.62	
PF_3T	19.28	19.50
PF_4T	18.96	19.00
PF_4P	17.17	
US_1	18.89	
US_2	20.04	20.50
IH_1	19.00	19.00
LS_1	18.82	19.00

1.10.3.1 Oyster Creek and Oyster Creek Extension

The recommended plan for construction and resiliency features of the existing HFPP in the Oyster Creek and Oyster Creek Extension reach is reconstruction of the existing floodwall and raise of levee. The floodwall reconstruction consists of 1,214 LF of existing floodwall which will be demolished and rebuilt as T-wall. For resiliency of this feature, a 15-foot wide scour pad will be placed behind the floodwall sections. The construction of the levee raise includes 4,700 LF of 3.0-foot raise and 23,700 LF of 0.5-foot raise of the Oyster Creek Levee with compacted earth fill. Approximately 8,620 LF of the Oyster Creek Levee will require replacement of the existing asphalt pavement. The other section of Oyster Creek, around 19,780 LF, will require replacement of the existing compacted gravel road on the levee crown. Also included in the construction is replacement of three drainage structures. Erosion protection (grouted in-place riprap) will be placed around the drainage structures and the floodwall to levee tie-ins.

1.10.3.2 East Storm

The recommended plan for construction of the existing HFPP in the East Storm reach is a raise of the levee and addition of one section of floodwall. The construction includes 9,370 LF of levee to be raised 1.5-feet, 4,000 LF of levee to be raised 2.0-feet and 4,000 LF of levee to be raised 2.5-feet, with compacted earth fill. The construction of 320 LF of new floodwall is required due to space restrictions over an existing gravity drainage structure, of which the levee raise cannot be constructed. For resiliency of the floodwall, a 15-foot wide scour pad will be placed behind the wall on the land side. The entire length of this levee reach will require the existing asphalt pavement to be replaced. Reconstruction and raising of the Highway 332 crossing will be required for this plan. This pump station would require additional capacity, due to the increased flow from the DOW Barge Canal, by means of adding a pump to this structure. The pump station currently has enough room to accommodate this feature and would not require any major construction activities. The pump and all of its appurtenances would be required. For erosion protection around the floodwall to levee tie-ins, grouted in-place riprap will be used.

1.10.3.3 DOW Barge Canal

The recommended plan for construction and resiliency features of the existing HFPP on the Dow Barge Canal levees is a gate structure, drainage structure, pump station addition, floodwall and levee raise. The gate structure will be constructed approximately one mile into the canal from its entrance. This structure will allow local industry barge traffic to pass during routine operations. The structure will have two (2) sector gates to provide for a 74-foot-wide navigable opening. This structure will require a temporary diversion channel due to the on-going use of the DOW Barge Canal. The USACE will limit, as much as possible, the interruption of the vessels utilizing the channel. A sheet pile cofferdam will be constructed to achieve dry working conditions and a

dewatering system will be required to attain a proper work area as well. The cofferdam will be constructed mostly from barges, while the gate construction will be within the cofferdam itself.

Approximately 330 LF of new floodwall will be constructed on the sides of the gate structure and tie into the DOW Barge Canal levees. A nearby water intake structure on the DOW Barge Canal South levee will require 730 LF of floodwall to be placed through it, due to the required levee raise in the area. A different section of the DOW Barge Canal South levee requires a large levee raise, approximately 7-feet, due to predicted hydraulic loadings. With the limited availability of space in the area, 2,130 LF of floodwall will be constructed in place of a levee raise. For resiliency of this feature, a 15-foot wide scour pad will be placed behind the floodwall sections. The drainage structure will be placed to the north, near the DOW Barge Canal Turning Basin, to allow water to flow from the DOW Barge Canal to a nearby wastewater canal; which flows to a pump station on the East Storm levee.

The construction includes 4,550 LF of the DOW Barge Canal North levee to be raised 3.5-feet, and 4,600 LF of the DOW Barge Canal South levee to be raised 3.0-feet, with compacted earth fill. With the sections of levee raise, around 7,200 LF of asphalt pavement will require replacement and 4,100 of compacted gravel road on the levee crown will need to be reconstructed. For resiliency of all construction features, erosion protection will be placed around the gate and drainage structures as well as the floodwall to levee tie-ins.

1.10.3.4 Old River North

The recommended plan for construction and resiliency features of the existing HFPP within the Old River North Levee reach is reconstruction of the existing floodwall, addition of new floodwall and levee raise. Construction will include reconstruction of 4,990 LF of existing floodwall and 10,670 LF of new floodwall constructed over levee. A portion of earthen levee will be degraded and the floodwall placed to the land side of the crest of the levee. The excavated material through this section will require environmental testing to determine if contaminants are present. If the material contains contaminants, it will be hauled to a hazardous material disposal site. A large portion of this proposed floodwall will require construction from barges due to it being adjacent to a deep draft navigation channel. Although some of the construction can be accomplished from the land, it is assumed that 3,200 LF will require most, if not all of its construction activities from barges. The other length of floodwall can be constructed mostly from land, but some barge construction is anticipated. Due to space restrictions, one section of levee will require new floodwall to meet calculated height requirements. For resiliency of the floodwall, a 15-foot wide scour pad will be placed behind the floodwall sections. The Old River North Levee will require 3,030 LF of levee to be raised 3.0-feet with compacted earth fill, as well as having the compacted gravel road replaced for this levee section. For additional resiliency of the levee and floodwall, erosion protection will be placed around the floodwall to levee tie-ins.

1.10.3.5 Tide Gate

The recommended plan for construction and resiliency features of the existing HFPP within the Tide gate reach is reconstruction of the existing floodwall. Currently the Tide Gate structure is flanked by two sections of floodwall. Construction will include replacement of 530 LF of floodwall. A portion of this floodwall will require construction from barges due to it being adjacent to a deep draft navigation channel. Resiliency features for this reach include a 15-foot wide scour pad which will be placed behind the floodwall sections. Erosion protection will be utilized around floodwall to levee tie-ins. The tide gate structure has existing riprap on each of its sides; erosion protection will be added to these areas to provide more resiliency.

1.10.3.6 Old River South

The recommended plan for construction and resiliency features of the existing HFPP in the Old River South reach is reconstruction of three sections of floodwall and raising all levee in this reach. The construction includes 7,855 LF of new floodwall, with some sections requiring drop-in panels for port facility access. The Port of Freeport Berth 1, 2, 3 and 5 dock is currently thought to be structurally deficient for hydraulic loading. Per the recommended plan, this section will require a raise in the floodwall elevation; therefore the plan is to construct new floodwall through this area. A large portion of this proposed floodwall will require construction from barges due to it being adjacent to a deep draft navigation channel and within the Port of Freeport facilities. Although some of the construction can be accomplished from the land, it is assumed that 4,300 LF will require most, if not all of its construction activities from barges. The other length of floodwall can be constructed from land. One section of the new floodwall will be constructed on existing levee due to limited available space for the required levee raise. The recommended plan for construction on the levee sections includes 1,625 LF of 3.0-foot raise and 5,400 LF of 3.5-foot raise, with compacted earth fill. The asphalt pavement for 3,580 LF of roadway will be replaced and 3,340 LF of compacted gravel road will be replaced. Resiliency features for this reach include a 15-foot wide scour pad which will be placed behind the floodwall sections and erosion protection around the floodwall to levee tie-ins.

1.10.3.7 South Storm

The recommended plan for construction of the existing HFPP in the South Storm reach is raising a section of the levee. This plan for construction entails raising 4,400 LF of levee 1.0-foot with compacted earth fill. The plan will require replacement of asphalt pavement for the entire length.

1.10.3.8 East Bank Brazos River

The recommended plan for construction and resiliency features of the existing HFPP in the East Bank Brazos River reach is the construction of a section of floodwall near the Freeport Pump Station. Approximately 430 LF of new floodwall will be placed to the flood side of the current floodwall and backfilled to equal existing grade around the pump station. Resiliency features for this reach include a 15-foot wide scour pad which will be placed behind the floodwall section and erosion protection around the floodwall to levee tie-ins.

1.11 ADAPTABILITY

In recognition of the uncertainty presented by climate change and the potential for directly proportionate impact in the design assumptions due to the coastal setting of the project, several measures have been incorporated at this stage of the project.

All proposed floodwall sections will be constructed to the 50-year intermediate RSLC and will be designed for the greatest hydraulic loading out of the 50-year intermediate, the 50-year high and the 100-year intermediate. These load cases will ensure that the wall will meet all design criteria for the 50-year intermediate and still survive and not suffer a brittle failure under hydraulic loading from the 50-year high or the 100-year intermediate RSLC. All levee sections will be designed and constructed to the 50-year intermediate RSLC, with the assumption that they can be more easily adapted to future SLC than the floodwall.

Drainage features will also be design with similar considerations to those implemented on the floodwalls, allowing them to withstand the additional loads that would result out of future potential modifications to the project.

Proposed pump stations will be provided with future expansion considerations in order to be able to handle potential increments in their capacity requirements while minimizing impacts to the structure or the need for an additional pump station.

This recommended approach allows the entire system to be adaptable to the 50-year high or the 100-year intermediate RSLC, which are the proposed performance limits of the systems. The limits of 50-year high or the 100-year intermediate RSLC were recognized due to the constraints of high ground tie in, levee footprint impacting ultimate levee height, and adaptability constraints on closure structures, navigation gates, and pump stations. The adaptability concept for the RSLC scenarios above the 50-year intermediate will allow for limited overtopping of wave and minor still water overtopping that would then be mitigated by using interior drainage features. This approach also minimizes the initial cost of the floodwall while still allowing for adaptation.

1.12 DEFERRED MAINTENANCE

Deferred maintenance issues have been identified for the existing system in Freeport, they are detailed in past USACE levee inspections and in a System Wide Improvement Framework (SWIF) plan.

Betterment of any of the existing issues noted on the before mentioned documents are not part of the scope of this ongoing feasibility study. Ongoing efforts are focused on the identification of additional capacity needs when assessing existing structures against current design criteria elements including climate change components. Proposed design is aimed towards addressing needs identified on such efforts while producing a cohesive system in an efficient and cost effective manner.

2 HYDROLOGY AND HYDRAULICS

2.1 INTRODUCTION

This section discusses the Hydrologic and Hydraulic (H&H) data gathering efforts and engineering analyses for the Sabine to Galveston FIFR-EIS. The H&H analysis was included as part of the information used to select the National Economic Development NED plans and final selected plan.

The focus areas of the study, the Brazoria and Sabine Regions, contain a complex system of floodwalls, earthen levees, pump stations, culverts, sluice gates, flap gates, sector gates, hazardous material sites, small local levees, large adjacent rivers and vertical lift gates. Two large sector gates are recommended as part of the tentatively selected plan on Cow and Adams Bayous in Orange County. A complete SMART (Specific, Measurable, Attainable, Risk Informed, Timely) planning feasibility level of analysis of the storm surge, waves, run-up, and interior drainage features including culverts and pumps was performed. Additionally, Relative Sea Level Change (RSLC, sometimes referred to as Relative Sea Level Rise (RSLR) and climate change were estimated and the impacts assessed in accordance with Engineering Regulation (ER) 1100-2-8162 and Engineering Technical Letter (ETL) 111-2-1. Levee height analyses were performed and overtopping rates calculated for all levee systems in the two study regions following guidance in planning guidance documents (as of 2015), Engineering Circular (EC) 1110-2-6067, ETL 1110-2-299, and Code of Federal Regulations (CFR) 44 and 45. The Brazoria Region contains Brazoria County and the Sabine Region contains Jefferson and Orange Counties. Some surrounding areas such as Southern Louisiana near the Sabine Region were also included in the current study to determine, assess, and minimize adjacent impacts.

An overall view showing the locations of the Brazoria and Sabine Regions is presented in Figures 2-1, 2-2, and 2-3. Three major rivers flow through these regions. The Neches River and Sabine River flow through the Sabine Region, with the Neches River delineating the county line between Jefferson and Orange Counties, and the Sabine River which marks the state line between the state of Texas and the state of Louisiana. In the Brazoria Region, the Brazos River flows along the west side of the existing Freeport and Vicinity Hurricane Flood Protection Project (HFPP). Additional important and also navigable waterways in the project study areas are discussed in further detail later in this section of the appendix.

2.1.1 Brazoria Region

The H&H analysis of Brazoria Region focused on detailed analysis of the existing Freeport levee system and its components, and how the existing system should be modified to prevent failure and increase the level of protection where needed. The Freeport levee footprint will change minimally

or not at all, with some exceptions, between the with-project and without-project conditions. The entire system was evaluated for an array of possible improvements and modifications. Improvements considered include raising the levees, changing the levee embankment geometry and height, acquiring rights-of-way (ROW), and constructing resiliency features (e.g., concrete scour pads on the interior side of the levee/floodwall and drainage features to manage overtopping flows). The study resulted in recommendation of a large closure structure with a navigable opening at the southern end of the DOW barge canal, this structure once constructed would recommended block one of the longest and weakest sections of the system along a barge canal from being impacted by surge. Some additional areas of this levee (lengths) are recommended for a height change, due to Surge and Wave, RSLC, Geotech and Structures Criteria, and economics. More information on Surge and Waves can be found in section 2.5 of this Appendix, information on RSLC in Section 2.4 of this Appendix, Geotech and Structures information can be found in Chapter 4 and 7 of the Engineering Appendix, and economic information can be found in the Economic and Plan Formulation Appendices. Detailed analysis of the Freeport levee system is discussed in Section 2.9. Improvements to or replacement of existing drainage features, such as pumping stations, to accommodate changes in flows due to improvements/modifications were preliminarily evaluated and were found to not be needed fir existing systems. Features needed to create a resilient and robust levee system were. An aerial view of the existing Freeport and Vicinity HFPP is shown in Figure 2-1.

Figure 2-1: Existing Freeport and Vicinity HFPP

2.1.2 Sabine Region

The Sabine Region contains an existing levee system – the Port Arthur and Vicinity HFPP (Figure 2-2), which was evaluated from an H&H perspective using the same procedures and methodology as the existing Freeport levee system. The City of Port Arthur is in Jefferson County on the west bank of Sabine Lake. A deep-draft navigation channel is immediately in front of the Port Arthur levee frontal wall facing Sabine Lake (mostly reinforced-concrete floodwall, 15+ feet high). The Sabine Region study area also contains proposed new levee systems in Orange and Jefferson Counties (Figure 2-3). The new levee systems studied included levees protecting the majority of Orange County south of Interstate 10, as well as additional components in Jefferson County along the west bank of the Neches River. An analysis was performed on the proposed Orange sy3stem to determine levee heights, required drainage features, and adjacent impacts. This included new storm surge and wave modeling. A preliminary analysis and design of an interior drainage system and levee components for the proposed Orange County system was completed, including drainage structures such as culverts, gates, and pump structures for Adams and Cow Bayous. These analysis

were later updated as needed for the final recommended plan selected, this is discussed in detail later in this section.

Figure 2-2: Existing Port Arthur and Vicinity HFPP

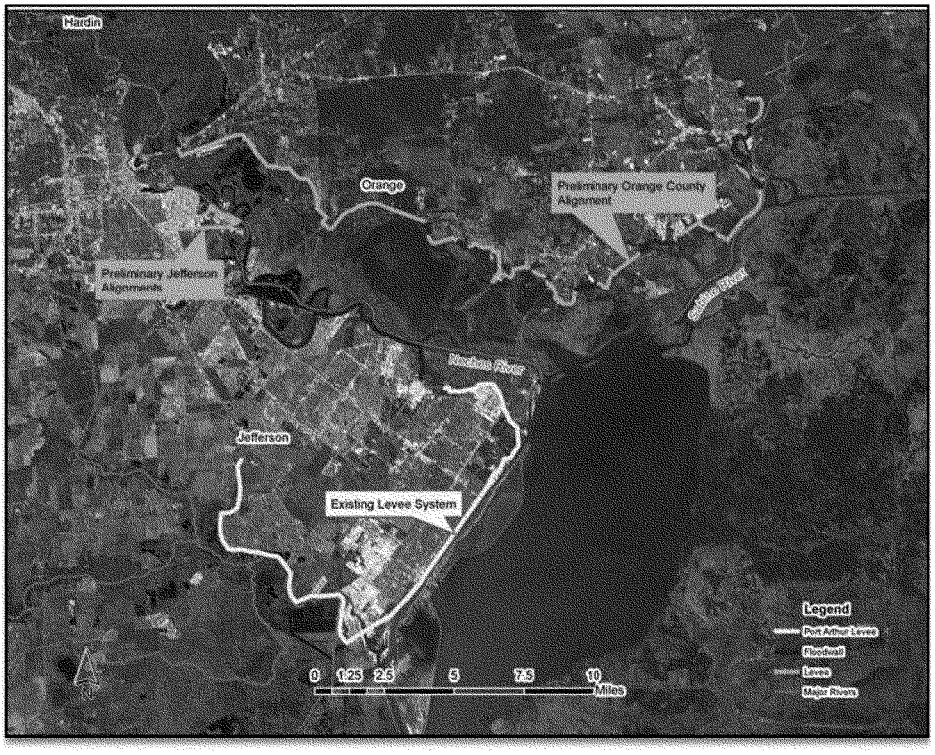


Figure 2-3: Original Extents of Proposed New Orange and Jefferson Counties Levee Systems Considered, later modified and optimized

New levee systems were also proposed and evaluated in Jefferson County across the Neches River from Orange County as shown in Figure 2-3. The evaluation included a gate across the Neches which is discussed in section 2-15 of the H&H analyses, as well as in the main report and other appendices. Impacts from the proposed levee were assessed and levee heights were recommended accordingly. The locations and configurations of interior-drainage features (such as culverts and pumps) were identified using existing plans, LiDAR, USGS topography maps, and aerial photography. Deficient pumps or pump stations requiring modification were identified utilizing levee periodic-inspection reports, information provided by Jefferson Drainage District #7, Orange County EDC, and several other entities to determine the final recommended levee configuration. The storm surge modeling is discussed in detail in Section 2.9. Interior drainage is discussed in Section 2.14.

2.2 REGIONAL DATA

2.2.1 Units and Coordinate System

All units are in International System (SI) of units unless stated otherwise. Vertical elevation data are in feet, referenced to NAVD 88 datum unless noted otherwise. Horizontal coordinates shown are in Universal Transverse Mercator (UTM) Zone 15. The project horizontal datum is NAD 83.

2.2.2 Gage Data

Measured gage data including water levels, discharge data, and velocities in the study area were obtained from NOAA. Local gages used to gather data include Gage 8772440 in the Brazoria Region and Gages 8770520 and 8770570 in the Sabine Region. Gage Locations are shown in Figure 2-4 and Figure 2-5. Additionally Discharge data available from the Neches River gage were utilized.

Figure 2-4: NOAA Tidal Gage 8772440 in Brazoria Region

Figure 2-5: NOAA Tidal Gages 8770570 and 8770520, Sabine Region

2.2.3 Datum and Tidal Information

Water levels used in design are a combination of hurricane surge, waves, tides, and sea-level rise. Stillwater levels used in the design were the product of a historical database of hundreds of hurricanes. Since so many hurricanes were used, it is reasonable to assume that hurricane arrival time was randomly distributed in the tidal cycle. However, the high-water marks (a combination of hurricane surge and normal tides) necessarily include high tide, since all hurricanes remained on the coast for at least a day. The final water levels used in design were a combination of this high-water mark distribution and the waves, performed with a Joint Probability Analysis (JPA) of waves and surge.

As previously mentioned all elevations in this report are referenced to NAVD 88 unless noted otherwise. Much of the data gathered used datums such as Mean Sea Level, Mean Low Tide, Mean Low Water, and Mean Lower Low Water. For easy reference, the conversion between

datums for the Freeport and Sabine regions is presented in the Table 2-1 on the next page. For additional information on datum conversion, reference EM 1110-2-6056.

Tidal information was obtained by NOAA gages. If the Earth were a perfect sphere without large continents, all areas on the planet would experience two equally proportioned high and low tides every lunar day. However, there are large continents on the planet blocking the westward passage of the tidal bulges as the Earth rotates. Unable to move freely around the globe, these tides establish complex patterns within each ocean basin. Tides can vary greatly depending on location.
Three basic tidal patterns occur along the Earths major shorelines. Most areas have two high tides and two low tides each day. When the two highs and the two lows are about the same height, the pattern is called a semi-daily or semidiurnal tide. If the high and low tides differ in height, the pattern is called a mixed semidiurnal tide. In the area of this study the Gulf of Mexico has only one high and one low tide each day. This is called a diurnal tide.

Diurnal tides in the Brazoria Region of the study area range from a low ebb tide of -0.28 feet (MLLW) to a high flood tide of 1.78 feet (MLLW). These elevations are based on NOAA Gage 8772440.

Diurnal Tides in the Sabine Region of the study area range from a low ebb tide of 0.62 feet (MLLW) to a high flood tide of 1.22 feet (MLLW). These elevations are based on NOAA Gage 8770520),

Table 2-1: Datum Conversion Summary Table for Brazoria and Sabine Region

Datum	Freeport Region	Sabine Region
	Gage 8772440	Gage 8770520 (Rainbow Bridge)
	Value (feet)	Value (feet)
MHHW*	5.61	4.96
MHW*	5.67	4.89
MTL*	5.00	4.45
MSL*	5.00	4.48
MLW*	4.32	4.00
MLLW*	4.05	3.90
NGVD29**	6.43	5.23
NAVD88**	3.41	3.72
Source - http://tidesandcurrents.noaa.gov/stations.html?type=Datums		
Conversion Source -USACE Survey, OPUS Control Monuments_Rizzo		

*Asterisk indicates water-based datum, **Asterisk indicates land-based datum

2.3 EXISTING DATA COLLECTION

2.3.1 Data Collection Summary

An extensive amount of existing data was gathered for both regions for use in this study. A wide variety of reports, models, design plans/as-built plans, feasibility studies, historical studies and books, watershed master plan studies, and multiple other various studies were obtained for use. The reference section of this document contains a list of data used for the H&H analysis. Additionally, the latest available tools including the Coastal Hazard System, IWR Suite, the latest ERDC storm modeling capabilities, and ERDC environmental modeling capabilities, among others, were used in this study to the extent possible. It is recommended that the modeling be revisited during PED when the project features are designed for construction as the models will be improved, and site conditions could change. Additional Surge modeling and tools will be available for use by this time and should be used to the extent practicable.

2.3.2 Topographic, Bathymetric, and Survey Data

Detailed terrain data were obtained for the study area in the form of LiDAR data obtained from the Texas Natural Resources Information System (TNRIS). LiDAR data for Brazoria/Orange/Jefferson County, dated 2010-2011, with 1-meter resolution were used. Additional terrain data were taken from existing surveys, USGS contour maps, and aerial photography. Historical reports, historical photography, and historical terrain maps were used where applicable. Bathymetry data for the study regions was obtained from the NOAA Geophysics Bathymetry and Global Relief World Data Services. Survey data in USACE's possession and ADCIRC mesh elevation data were also used. Recent survey data from other projects and construction plans were used to cross-reference the elevations in the data USACE is using. These data were also compared to the latest ADCIRC mesh data. In areas where the gathered topography, survey, and bathymetry data contained more recent and/or more accurate data, the ADCIRC mesh data were updated. Some previously used data, prior to USACE analysis, were found to be incorrect, and those errors were fixed before modeling began.

2.3.3 FEMA Data

The FEMA Coastal Counties Report (2011) and associated electronic files were obtained and used in this study. The Coastal Counties Study covered the entire Texas coast. USACE obtained flood inundation maps from FEMA for the 10-, 50-, 100-, and 500-year still-water levels (SWLs). These data were used in the screening for the Alternative Milestone Meeting (AMM) and Workshop (Reference Appendix B For information on screening). The data were later refined and stage-frequency data for the 10-, 20-, 50-, 100-, 200-, 500- and 1,000-year events were obtained utilizing ADCIRC modeling capabilities to determine the surge elevations for a range of different storms at points blanketing the area. ADCIRC coupled with STWAVE for the Brazoria Region was rerun.

Statistical analysis of the data generated was conducted using StormSim, a computer program recently developed by ERDC to produce results that are more accurate. ADCIRC was coupled with STWAVE for the Sabine Region for the without-project and with-project conditions. The statistical analysis, again, was performed using StormSim. The ADCIRC runs for the Sabine Region contained additional storms not modeled in the 2011 FEMA study. The surge modeling and data were provided to assist in selecting the final plan. Additional discussion regarding use of the FEMA data, storm-surge modeling, and accompanying analysis are discussed in Section 2.5.

2.3.4 Tropical Cyclones and Floods of Record

Both regions have a long history of being subjected to large topical events, including major hurricanes. The earliest documented hurricane in Texas made landfall at Matagorda Bay in 1527. For a complete list of documented hurricanes in Texas reference "Texas Hurricane History" authored by David Roth of the National Weather Service (at the time this Appendix document was last updated in 2010). The hurricane with the greatest known loss of life is the 1900 Galveston Storm with deaths estimated at between 6,000 and 12,000 people. The hurricane striking the Texas Gulf Coast with the greatest economic damages is Hurricane Ike, in 2008. Table 2-2 provides a list of major tropical events that have impacted Texas since the 1850s (Reference: David Roth, NWS, 2010).

Table 2-2: Tropical Cyclone Strikes by Decade since 1850

Tropical Cyclone Strikes By The Decade			
Decade	**Hurricanes**	**Tropical Storms**	**Total**
1850's	3	1	4
1860's	4	1	5
1870's	2	4	6
1880's	8	3	11
1890's	3	3	6
1900's	4	2	6
1910's	7	1	8
1920's	2	3	5
1930's	5	4	9
1940's	8	6	14
1950's	2	5	7
1960's	3	3	6
1970's	2	7	9
1980's	5	4	9
1990's	1	4	5
2000's	5	5	10
Total	64	56	120
Avg Per Decade	4	3.5	7.5

Tropical cyclones impacting the study area have included major hurricanes such as the Galveston storms of 1900 and 1915, the'unnamed' hurricane in 1943, Hurricane Carla in 1962, Hurricane Alicia in 1983, Hurricane Rita in 2005, and Hurricane Ike 2008. These storms have caused considerable loss of life and extensive economic damages. As evident in Table 2-2, tropical cyclones along the Texas Gulf Coast occur frequently, averaging approximately 7.5 per decade. This includes an average of four (4) hurricanes per decade over the last 150+ years. It is important to note that these are storms which made landfall in Texas. They do not include storms that made landfall in Louisiana or Mexico, but had significant impacts of surge and/or wind to the Texas coast, such as Hurricane Katrina in 2006.

2.4 SUMMARY OF PROJECT AREAS AND H&H OBJECTIVE

The coastal areas of Texas are low-lying and generally highly populated areas, and include a vast variety of recreation, population centers, residential areas, businesses, and industrial infrastructure. The area is subject to frequent tropical cyclones, which historically have caused great loss of life and high economic losses.

The objective of the CSRM study is to evaluate alternatives that would reduce coastal storm damages in the Brazoria and Sabine Regions. H&H analyses are key components in determining a plan to reduce damages from storms and associated storm surge. This section of the engineering appendix presents an overview of the H&H efforts performed to inform, evaluate, and provide support to USACE efforts in determining a final selected plan to reduce damages from storms along the Texas coast.

2.5 ANALYSIS OF HYDRAULIC LOADING FOR FLOOD PROTECTION SYSTEMS

The following documents the H&H data used to determine the NED, and analyses that were done to support a design of a proposed hurricane flood-protection system that would meet all FEMA and USACE requirements. Hydraulic analyses were conducted to inform flood-protection system design. Analyses were conducted to support design of the levees and floodwalls. The typical levee cross-section used in the design was the same as used in geotechnical analyses (Figure 4-7). The following parameters were evaluated for design:

- Levees
  - o Crest elevation
  - o Side slopes
  - o Overtopping rate

- Flood walls
  - o Crest elevation
  - o Side slopes
  - o Overtopping rate

In order to calculate design parameters, the following general process was applied:
-Gather existing data
-Perform Surge and Wave modeling of With-Project and Without Project conditions
-Use data to determine NED plan, and also a plan with levee heights that would meet FEMA accreditation and USACE design criteria. To complete this task the following activities were performed with some minor variations when needed.

1) Analyze storm surge and waves
   a. ADCIRC/STWAVE for large-scale storm surge and waves
   b. FEMA Coastal Counties Studies Data (FEMA, 20110 was used in the Brazoria Region, FEMA data as well as new ADCIRC/STWAVE model results were used in the Sabine Region to obtain surge results that include new proposed levees in the Sabine Region. This new modeling included storms that crossed onto land in Louisiana and impacted the Sabine Region.
   c. Output statistics for various return periods for waves and water levels along with quantification of uncertainty for surge and wave modeling results. New Statistical Analysis was done for both Regions as more advanced statistics methods were available
2) Local wave transformations using CMS-Wave, performed where required
3) Provide current SWLs, run-up/wave data, and RSLC data to economics to determine NED plan
4) Overtopping analysis
   a. Existing structures: run-up and overtopping were calculated for the 1 % ACE
   b. Proposed structures: acceptable overtopping limits were determined to calculate freeboard
5) Recommend levee crest elevations that would meet FEMA and USACE criteria based on hydraulic analyses presented
6) Assess any adjacent impacts due to new levee construction or modification to existing levees

2.6 EXISTING DATA SUMMARY

Existing data gathered and reviewed for each study region included:

- Previous surge and wave models and results
- Topographic and bathymetric data, aerial imagery, USGS maps, surveys
- Historical data including plans, modification studies, O&M manuals, and design memorandums, local hurricane flood protection plans, FEMA and other Texas coastal surge models and documentation
- Ongoing analysis and reports (for example, the Risk Management Center (RMC) report on the Freeport levee system)
- Existing levee alignment data and proposed modification from ports, districts, and cities

Data gathered were summarized using ArcMAP and Excel to simplify comparison and analysis.

2.6.1 Storm Surge and Adjacent Impact Analysis

2.6.2 Brazoria Region

Existing data were gathered for the Brazoria Region, focusing on data related to the existing Freeport and Vicinity HFPP, to enable hydraulic analyses. Figure 2-6 shows a map of some of the available data, including LiDAR data. Readily available data gathered included:

- FEMA DEM of LIDAR data collected in 2007
- Existing levee alignment and elevation data collected for the National Levee Database and periodic inspections
- 10-, 50-, 100-, and 500-year return period water levels calculated for the FEMA (2011) study
- STWAVE results from the FEMA (2011) study
- COULWAVE results from Lynett (2012)
- USACE channel survey data
- NOAA bathymetry surveys
- USGS, TCOON, and NOAA water data
- Aerial and topographic imagery from various sources
- USACE RMC Freeport Semi-Quantitative Risk Assessment (SQRA)
- Various other reports as referenced in this document

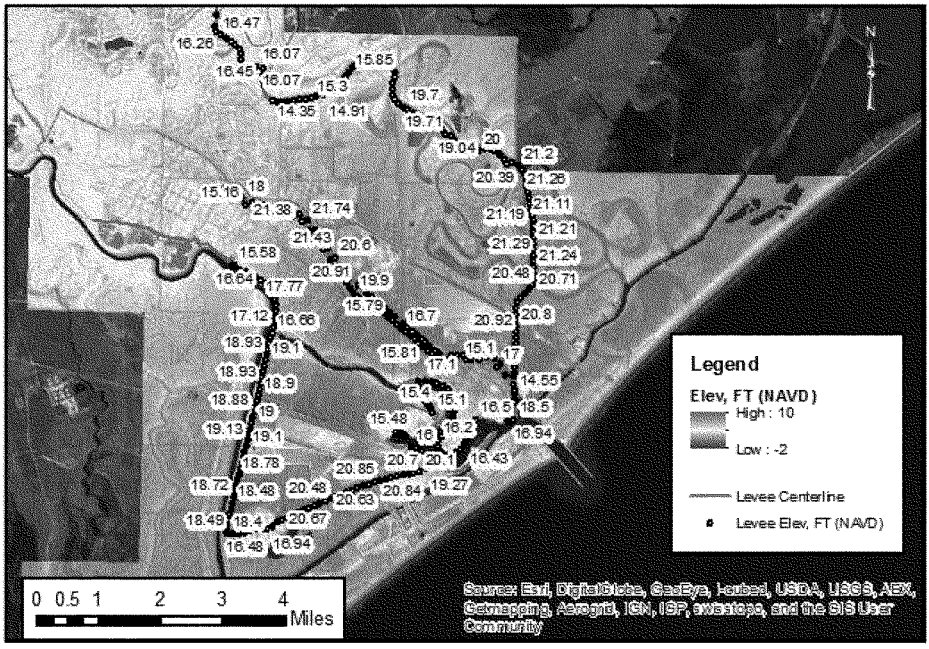


Figure 2-6: Map of Freeport Area with Select Data Gathered

2.6.3 Sabine Region

Existing data were gathered for the Sabine Region related to the storm-protection system to enable hydraulic analyses. Figure 2-7 shows a map of some of the available data including LiDAR data. Readily available data included:

- FEMA Digital Elevation Model (DEM) of LiDAR data collected in 2007
- Existing levee alignment and elevation data collected for the National Levee Database
- 10-, 50-, 100-, and 500-year return period water levels calculated for the FEMA (2011) study
- STWAVE results from the FEMA (2011) study
- Flood Protection Planning Study, Hurricane Flood Protection System, Orange County, Texas report (Carroll & Blackman, Inc. 2012)
- Neches River Corps Water Management System (CWMS) and Modeling, Mapping, and Consequences (MMC) hydraulic models
- Adams Bayou Hydraulic Drainage Area Delineations and Preliminary H&H models for Cow and Adams Bayou (Carroll & Blackman, 2015)
- USGS, TCOON, and NOAA water level data

- USACE channel survey data
- NOAA bathymetric surveys
- Aerial imagery from various sources
- USGS topography maps
- Various other reports and data as referenced in this document

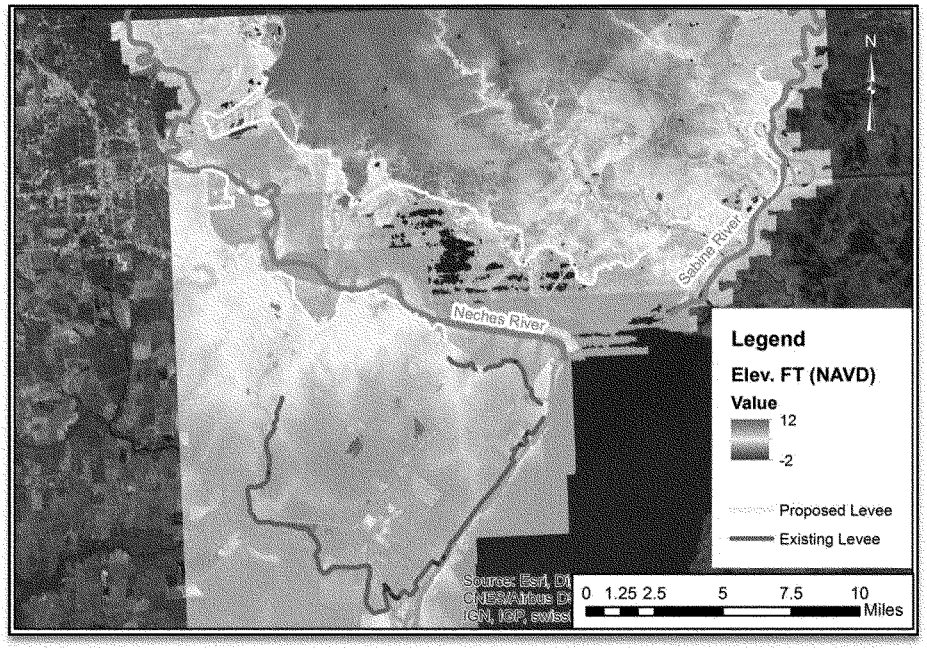


Figure 2-7: Map of Sabine Region with Select Data Gathered

2.7 ANALYSIS OF STORM WATER LEVEL AND WAVES

This section summarizes the modeling of storm surge and correlated waves for the with-project and without-project conditions.

2.7.1 Storm Modeling Approach

ERDC-CHL completed a storm modeling study of the Brazoria and Sabine Regions. The process applied and details of the model setup and accuracy are discussed in the ERDC report (Melby, et al 2015). The study took advantage of previous modeling efforts conducted for the FEMA Region VI NFIP Risk Mapping, Assessment and Planning (MAP) study reported in FEMA (2011). In general, hydrodynamic modeling of the offshore waves and coupled surge and nearshore waves that was conducted for the FEMA study was used for the current study. However, all storm statistics as well as response statistics were recomputed using new software developed at ERDC called StormSim. In addition to improved statistical analysis, new modeling was conducted to improve some of the prior modeling and to model the with-project alternatives for the Sabine Region (including the proposed new levee systems in Jefferson and Orange Counties). A joint probability model of tropical storm parameters was developed specifically for this study. Storm recurrence rates for the coastline were defined. Previously-defined synthetic tropical storms, as summarized in FEMA (2011), were mapped onto the new joint probability model. These storms had a frequency range of roughly 1 in 10 years to 1 in 1,000 years. For the FEMA study, 446 synthetic tropical storms were defined and modeled for the Texas coast. These included 152 low-frequency storms and 71 high-frequency storms for both the Brazoria and Sabine Regions. In addition, 152 Louisiana west low-frequency and 71 high-frequency storms defined in FEMA (2008) were used for the FEMA study.

2.7.1.1 Brazoria Region

For the Brazoria Region, nearshore waves and water levels modeled during the FEMA (2011) study were used to compute statistics for the Freeport area. There was no change in levee alignment for the with-project condition, so no additional with-project modeling was conducted for this area.

Extremal statistics for waves and water levels were computed using StormSim and the joint probability method. In addition, confidence levels were computed. Mean water level, wave height, and wave period responses were defined for return periods of 10, 20, 50, 100, 200, 500, and 1,000 years at save points in the Freeport area, including points surrounding and within the Freeport levee system. The average, standard deviation and 90, 95, and 98 percent levels of assurance were also calculated. Finally, the integrated uncertainty as used in the FEMA study was computed for comparison to the FEMA (2011) results to help verify quality. Figure 2-8 shows the 1 % ACE average water level at Freeport. Figure 2-9 shows the 1 % ACE upper 90 percent level of assurance at Freeport. Figure 2-10 shows plots of the return period of water level for some key locations around Freeport.

Inundation maps comparing the with-project and without-project conditions based on the FEMA (2011) 100-year storm level are presented in Plate H-01 which is included as part of this Engineering Appendix - H&H Support Documentation.

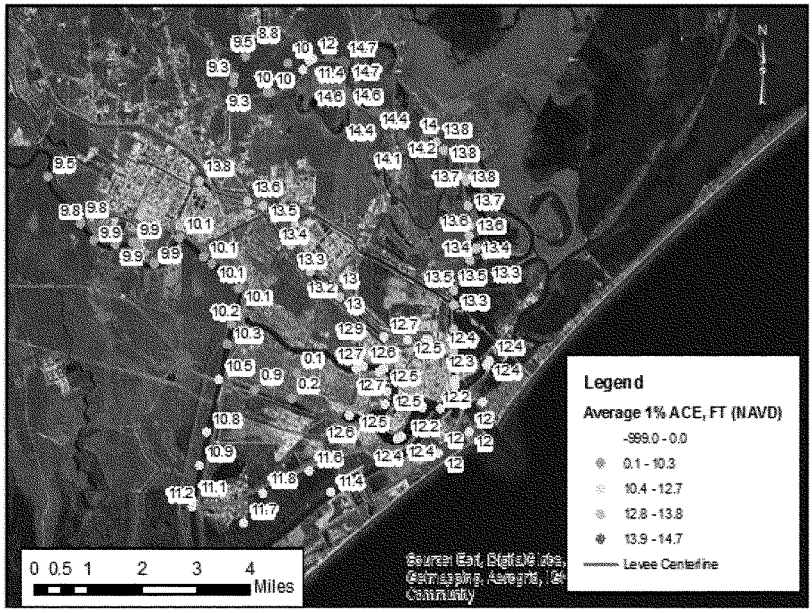


Figure 2-8: Average 1.0% ACE Still-Water Level at Freeport

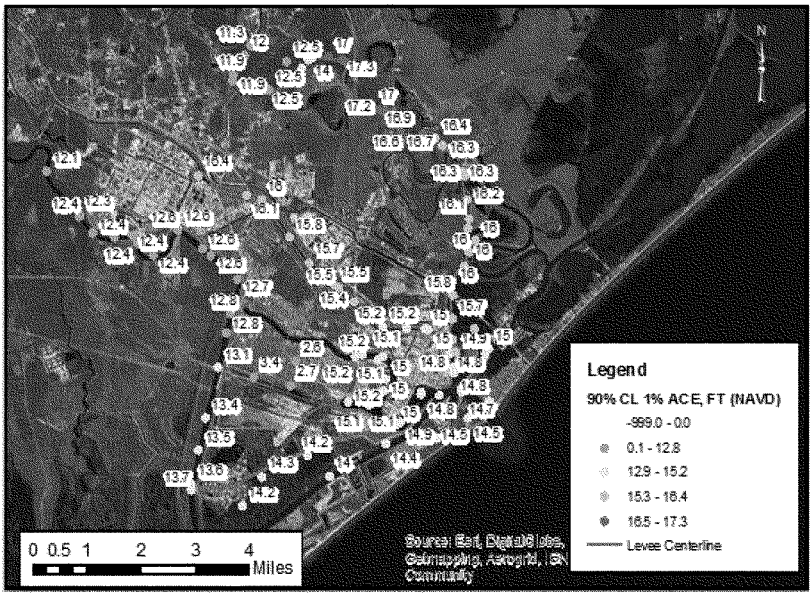


Figure 2-9: 90% Confidence Level for the 1.0% ACE Still-Water Level at Freeport

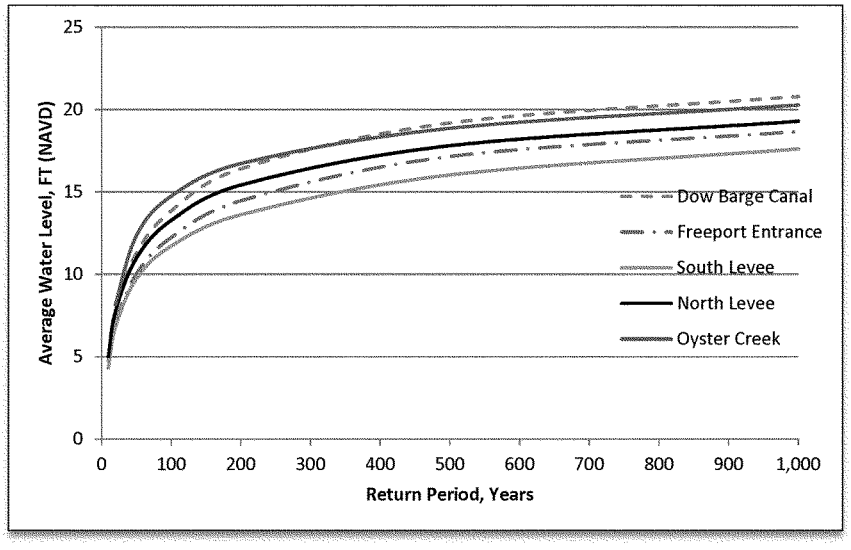


Figure 2-10: Example of Average Water-Level Return Periods at Freeport

2.7.1.2 Sabine Region

Nearshore waves and water levels modeled during the FEMA study were used to compute initial statistics. Comparison of the initial statistics with previous analyses indicated that some of the storms were previously run on the Louisiana grids only. Thus, there was concern that including these storms might dramatically increase the water levels for the Sabine Region projects. Additional model runs were conducted to include these storms and test this assumption. The results indicated that the additional storms did not increase the water levels.

New model grids were developed to include the proposed levee alignments. The same suite of storms was run on both grids, and the same statistical analysis was run on both sets of results. Extremal statistics for waves and water levels were computed using StormSim and the joint probability method. Confidence levels were also computed. Mean water level, wave height, and wave period responses were defined for return periods of 10, 20, 50, 100, 200, 500, and 1,000 years for save points in the Sabine Region, including points surrounding and within the Port Arthur and proposed Jefferson and Orange levee systems. The standard deviation and 90 and 95 percent levels of assurance were also calculated. Finally, the integrated uncertainty as used in the FEMA study was computed for comparison to the FEMA (2011) results to help verify results. Figure 2-11 shows the 1 % ACE average water level in the Sabine Region. Figure 2-12 shows the 1 % ACE upper 90 percent level of assurance in the Sabine Region. Figure 2-13 shows plots of the return period of water level for some key locations around the Sabine Region.

Inundation maps comparing the with-project and without-project conditions based on the FEMA (2011) 100-year and 500-year storm level are included later as Plates as part of this Engineering Appendix - H&H Support Documentation.

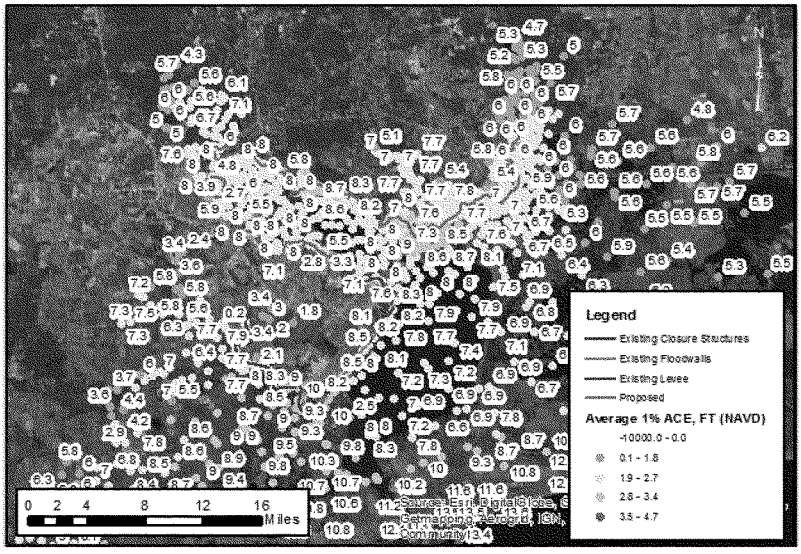


Figure 2-11: Average 1 % ACE Still-Water Level in Sabine Region

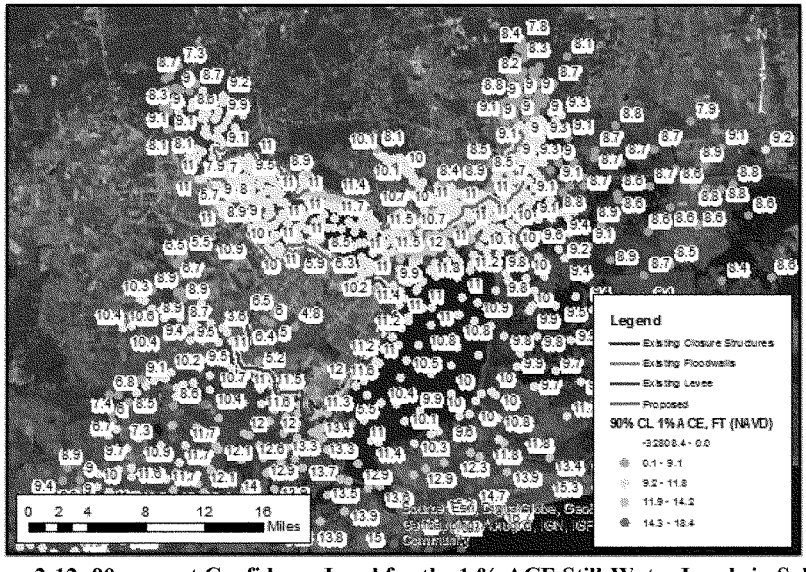


Figure 2-12: 90 percent Confidence Level for the 1 % ACE Still-Water Levels in Sabine Region

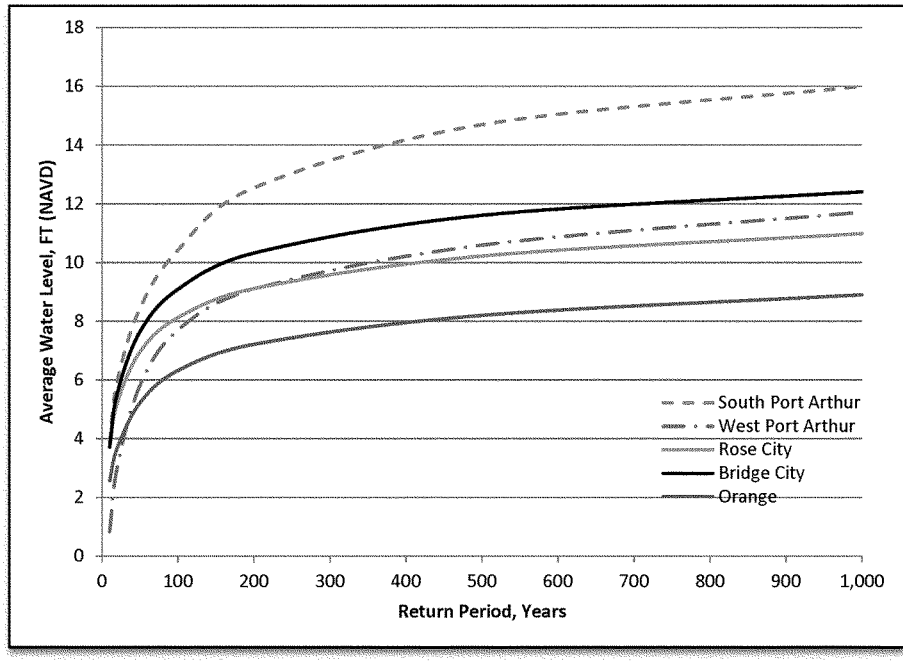


Figure 2-13: Example of Average Water-Level Return Periods in Sabine Region

2.8 LOCAL WAVE TRANSFORMATION AND CALCULATIONS

Local scale wave modeling was required to augment the WAM and STWAVE models run by ERDC. This section describes the local scale wave modeling.

2.8.1 Software Description

- STWAVE (STeady state spectral WAVE)
- STWAVE was applied to simulate wave propagation and generation from the larger scale STWAVE grid to the structure toe. STWAVE is a spectral wind-wave model capable of simulating growth, decay and transformation of wind generated waves, and swell in offshore and coastal areas (Massey, et al, 2011).
- Coastal Modeling System - Wave (CMS-Wave)
- CMS-Wave is a two-dimensional (2D) spectral wave model with energy dissipation and diffraction terms (Lin, et al 2011). The model was applied to help evaluate STWAVE results since no measured wave data was available.

2.8.2 Model Approach and Conventions

Numerical models were developed to simulate wave propagation and generation from the larger scale STWAVE grid to the structure toe.

2.8.3 Direction Convention

Wind and wave direction follow the meteorological convention for input and output, indicating direction of origin (direction from which it travels).

2.8.4 Model Parameters

The following model parameters were specified in the STWAVE model (CMS-Wave setup was similar):

- Depth type: Nontransient
- Source terms and propagation
- No current interaction
- Bottom friction: Manning's estimated and set at 0.03 based on known data
- Constant surge applied
  - Average 1 % ACE applied when waves on the boundary were known
  - 95 percent CL 1 % ACE applied when waves are generated by local winds only
- Winds
  - Based on ASCE (2010)
- 100-year return period
- 20-minute average
- Winds were applied in the several directions to determine the worst-case (highest) waves using CMS-Wave and STWAVE.

2.8.5 Calibration and Verification

Measured or observed wave data at the project site were not available for calibration or verification. Since appropriate data for calibration and verification were not available, the solution from STWAVE was compared to results from CMS-Wave and the Automated Coastal Engineering System (ACES).

2.9 MODEL RESULTS

2.9.1 Brazoria Region (Freeport)

Large-scale STWAVE models run as part of the storm simulations for FEMA (2011) were not well resolved near the Freeport levees, requiring transformation of waves from nearshore to the levee

toe. Waves inside the Freeport channels were also not resolved by the FEMA (2011) model runs, requiring calculation. Five (5) local grids were modeled with rectangular cells ranging in size from 2 to 20 meters (Figure 2-14). The figure shows the local model domains and the location of waves output from the large-scale storm model suite.

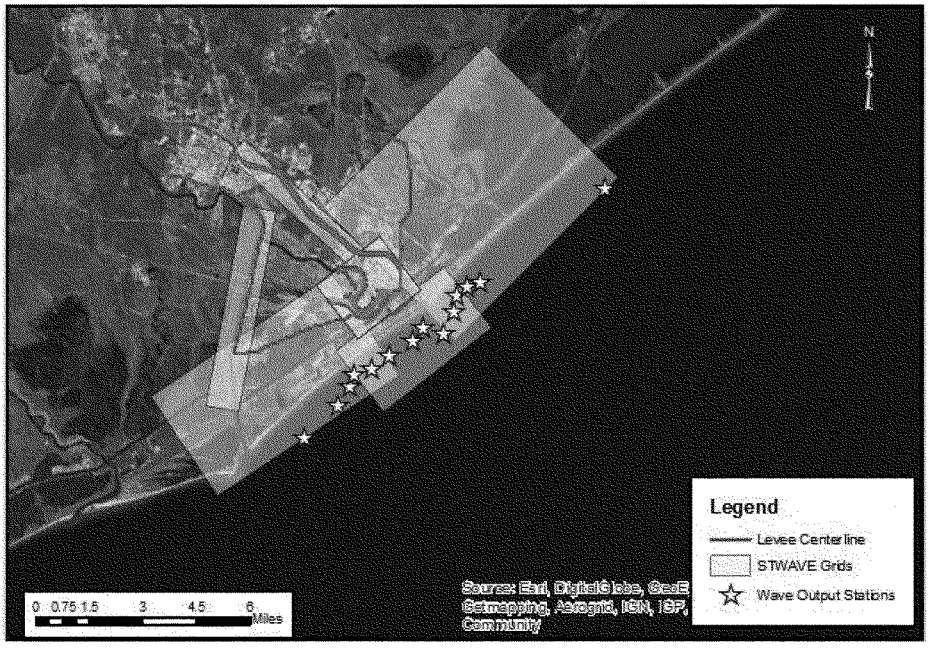


Figure 2-14: STWAVE Model Domains at Freeport

Each domain was forced with winds and offshore waves. The largest waves along each levee reach were summarized from all available runs. Figure 2-15 shows plots of the approximate locations of wave output used to inform the levee design. Table 2-3 lists the zero-moment spectral wave height (Hm0) and peak spectral wave period at each location (Figure 2-15).

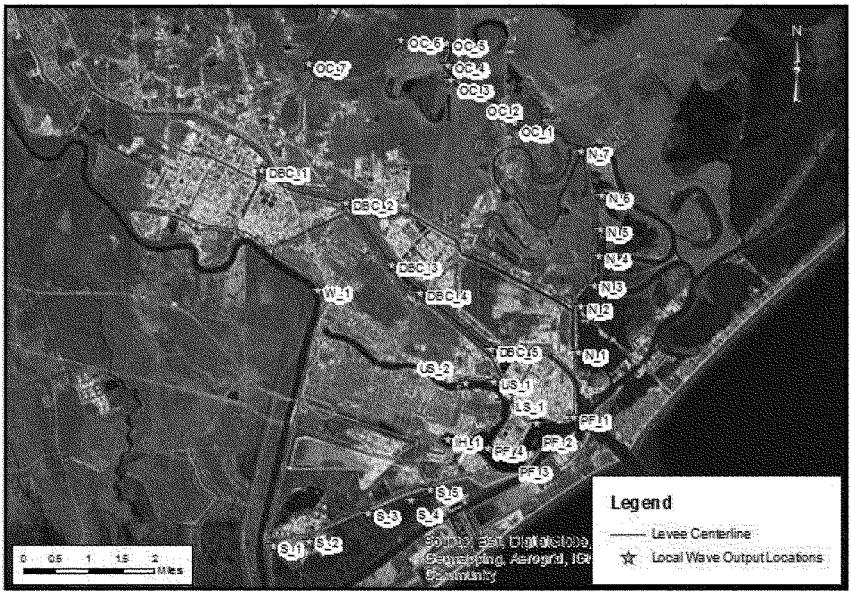


Figure 2-15: Freeport Local Wave Output Locations

Table 2-3: Summary of Local Wave Output for Freeport

Wave Output Station Name	H_{m0}, ft	T_p, s	Wave Output Station Name	H_{m0}, ft	T_p, s
DBC_1	1.28	2.8	PF_4 Phillips	2.23	2.80
DBC_2	1.38	2.8	PF_2	2.23	2.80
DBC_3	1.76	2.8	PF_1	2.53	8.57
DBC_3v2*	1.64	2.8	US_2	2.13	2.80
DBC_4	1.35	2.8	US_2v2*	0.69	2.80
DBC_4v2*	2.23	2.8	IH_1*	1.15	2.80
DBC_5	0.72	2.8	IH_1	2.36	2.80
DBC_5v2*	1.67	2.8	N_1	1.77	8.12
W_1	1.84	4.2	N_2	1.84	9.40
S_1	2.07	3.4	N_3	2.89	9.40
S_2	0.00		N_4	2.46	9.10
S_3	1.25	5.8	N_6	1.87	9.10
S_4	1.35	4.3	N_5	2.13	9.12
S_5	0.52	7	N_7	2.13	8.70
PF_3-wave barrier	2.79	3	LS_1	1.61	3.30
PF_3-thumb	1.51	2.8	US_1	2.33	2.80
PF_4 thumb*	2.00	2.8			

2.9.2 Sabine Region

Large-scale STWAVE models run as part of the storm simulations conducted in this study were not well resolved along all of the proposed and existing Port Arthur system along the Neches Rive, and along the east and west sides of the proposed Orange levee system, requiring wave generation and transformation of waves from nearshore to the levee toe in some locations. Two (2) local grids were modeled with rectangular cells ranging in size from 2 to 20 meters (Figure 2-16). The figure shows the local model domains and the location of waves output from the large-scale storm model suite.

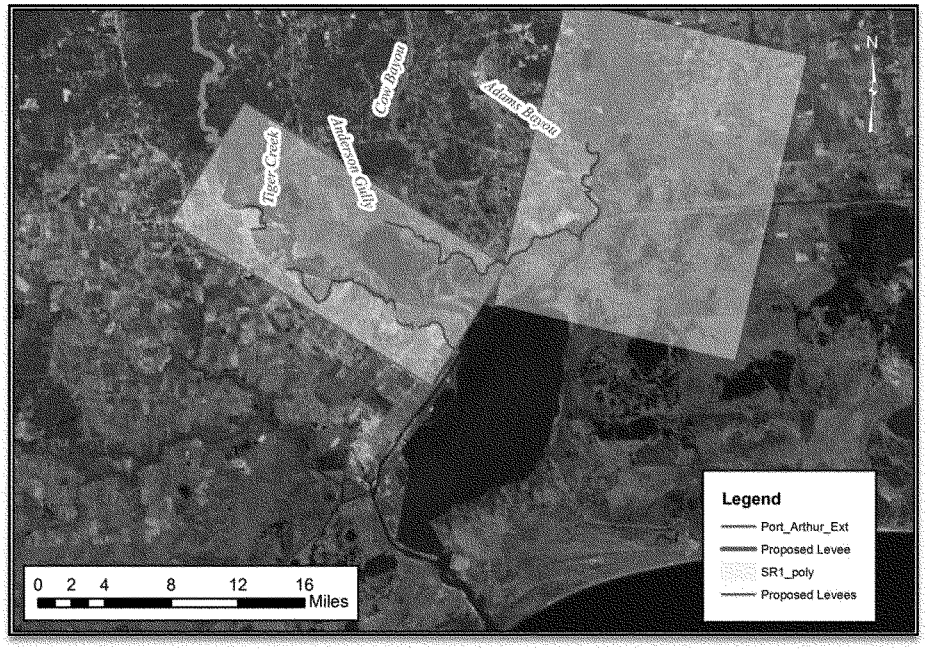


Figure 2-16: STWAVE Model Domains in Sabine Region

Each domain was forced with winds and offshore waves. The largest waves along each levee reach were summarized from all available runs. Figure 2-17 shows plots of the approximate locations of wave outputs used to inform the levee design. Wave output at the stations shown in the figure are included in Table 2-4. The values in the table are a combination of local wave model results and results from the storm simulation STWAVE models, where appropriate.

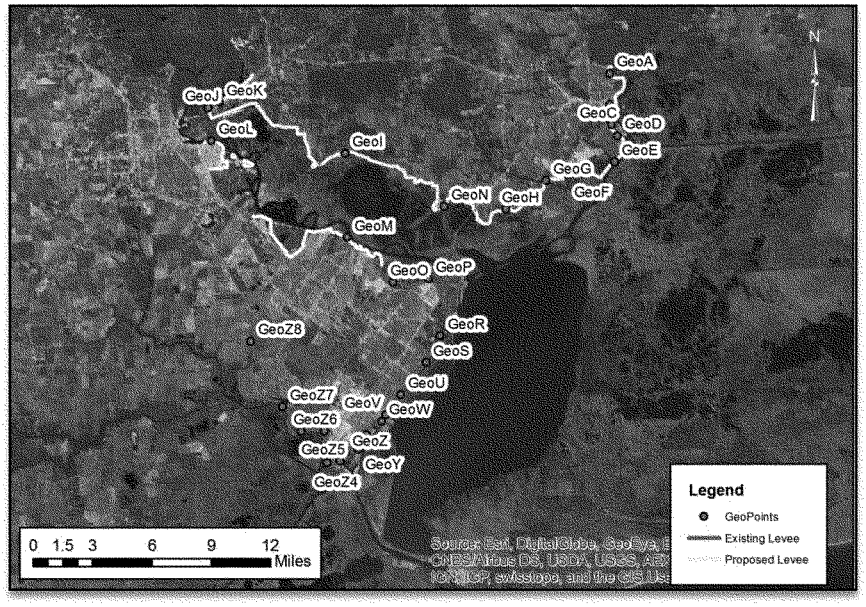


Figure 2-17: Sabine Local Wave Output Locations

Table 2-4: Summary of Wave Output for Sabine Region

Wave Output Station Name	Hm0, ft	Tm0, s	Wave Output Station Name	Hm0, ft	Tm0, s
GeoA	3.9	4.5	GeoR	2.1	5.0
GeoB	2.6	2.9	GeoS	2.3	4.3
GeoC	3.7	4.5	GeoT	2.3	4.9
GeoD	2.0	3.0	GeoU	2.3	4.9
GeoE	2.0	2.9	GeoV	2.3	5.0
GeoF	2.4	4.0	GeoW	2.3	5.0
GeoG	1.0	2.9	GeoX	2.1	4.6
GeoH	1.3	4.5	GeoY	2.3	2.9
GeoI	1.0	3.4	GeoZ	2.1	3.2
GeoJ	2.8	3.8	GeoZ1	2.9	2.9
GeoK	2.4	4.0	GeoZ2	2.9	2.9
GeoL	2.3	2.8	GeoZ3	2.2	3.2
GeoM	2.4	3.2	GeoZ4	1.4	3.0
GeoN	1.3	3.4	GeoZ5	2.0	3.4
GeoO	2.2	4.7	GeoZ6	1.9	3.4
GeoP	2.5	4.5	GeoZ7	2.1	3.4
GeoQ	2.1	4.9	GeoZ8	0.9	3.4

2.9.3 H&H Data for Levee NED Analysis

To determine the NED economics requires the average (50% CI) SWLs (still water levels) and associated run-up values. Economics also required RSLC values for the 20-year, 50-year, and 100-year periods post construction as discussed in ETL 1100-2-1. Section 2.13 of the Appendix includes the RSLC values. 50% SWLs. This data is used during economic analyses of the project in determining the plan with the most net excess benefits, and highest BCR (Benefit Cost Ratio). Reference the Economics Appendix for additional information.

H&H Supplied economics with specific information per request at specific locations to do the NED analysis. Table 2-5 presents the 50% SWLs and 50% run-up values (only100-year average run-economics requested for the Brazoria Region. The same data is provided in Table 2-6 for the Port Arthur Levee and Table 2-7 for the Orange Levee Region.

Table 2-5: H&H data for Freeport Region Economic Analysis

	SWL Avg by ACE (ft)							Runup
	10	20	50	100	200	500	1,000	(SWL 1% ACE Avg)
South_Storm_Levee	4.21	6.67	9.59	11.63	13.70	16.30	17.93	3.12
Old_River_at_Dow_Thumb	4.43	7.08	10.15	12.41	14.69	17.43	18.97	2.92
Freeport_Dock	4.47	7.17	10.30	12.63	14.96	17.78	19.37	2.43
A801_Wall	4.39	7.02	10.06	12.31	14.56	17.28	18.82	3.51
Tide_Gate	4.45	7.16	10.29	12.62	14.98	17.85	19.47	3.48
East_Storm_Levee	5.08	7.81	11.05	13.37	15.55	17.98	19.49	5.42
Dow_Barge_Canal_North_South	4.60	7.46	10.81	13.28	15.75	18.55	20.12	1.98
Dow_Turning_Basin	4.75	7.73	11.26	13.84	16.40	19.18	20.78	2.13
Oyster_Creek	4.91	8.14	12.33	14.74	16.72	18.86	20.26	3.23

Table 2-6: H&H data for Port Arthur Economic Analysis

	SWL Avg by ACE (ft)							Runup
	10	20	50	100	200	500	1,000	(1% ACE Avg)
Port_Arthur_8ft-10ft_I-Wall	2.86	4.31	6.95	9.25	10.96	12.72	13.87	4.34
Port_Arthur_Closure_Structure	3.47	5.04	6.94	8.26	9.37	10.56	11.30	5.21
Port_Arthur_I-Wall_Near_Valero	3.88	5.99	8.51	10.52	12.68	14.85	16.16	2.56
Port_Arthur_Tank_Farm	3.77	5.73	8.11	10.01	12.04	14.10	15.34	3.17

Table 2-7: H&H data for Orange Economic Analysis

		SWL Avg by ACE (ft)							Run-up
Geo ID	Levee	10	20	50	100	200	500	1,000	(1%ACE Avg)
A	Orange 3	2.54	3.67	5.18	6.29	7.18	8.16	8.86	4.28
B	Orange 3	2.61	3.73	5.31	6.46	7.39	8.40	9.11	3.32
C	Orange 3	2.47	3.68	5.24	6.62	7.55	8.54	9.22	5.04
D	Orange 3	2.56	3.70	5.35	6.56	7.50	8.52	9.22	3.68
E	Orange 3	2.67	3.84	5.52	6.83	7.87	9.02	9.80	3.58
F	Orange 3	3.18	4.57	6.37	8.22	9.56	10.95	11.82	4.13
G	Orange 3	3.14	4.54	6.43	8.11	9.44	10.83	11.69	3.11
H	Orange 3	3.76	5.73	8.05	9.67	11.14	12.67	13.59	4.36
I	Orange2/3	2.87	5.77	7.36	8.96	10.11	11.34	12.18	2.09
N	Orange 3	3.61	5.21	6.72	9.18	10.65	12.03	12.86	3.41

These data were provided to Economics, along with RSLC data (provided later in the H&H Appendix) to perform an analysis and optimization of the Final selected plan.

2.9.4 Wave Overtopping Analysis Methods

Wave overtopping calculations were conducted following guidance from the EurOtop Manual (Pullen, et al 2007). Both deterministic and probabilistic overtopping equations were calculated. In-house calculations were compared to the online overtopping calculator to verify results (http://www.overtopping-manual.com/). In addition to overtopping, 2.0 percent and maximum run-up values were calculated to inform comparison to typical FEMA requirements. Sensitivity analysis showed that various methods for calculating overtopping are not consistently conservative, meaning that selecting one method over another does not necessarily guarantee lower or higher values. For consistency, the EurOtop deterministic equations were applied to estimate overtopping rates for each reach. The locations shown for wave model output are used to summarize overtopping conditions.

The Hurricane and Storm Damage Risk Reduction System (HSDRRS) design guidelines (USACE 2012) criteria were applied to estimate required freeboard and determine levee crest elevation. The following criteria were applied:

- For the 1.0 percent exceedance still water, wave height, and wave period, the maximum allowable average wave overtopping of 0.01 cfs/ft at 50 percent level of assurance for grass-covered levees.
- For the 1.0 percent exceedance still water, wave height, and wave period, the maximum allowable average wave overtopping of 0.03 cfs/ft at 50 percent level of assurance for floodwalls with erosion-appropriate protection on the back side.

The HSDRRS criteria also include design guidance for the 90 percent level of assurance of no more than 0.1 cfs/ft for both floodwalls and earthen levees. The 90-percent assurance levels were

computed for the "typical" levee cross-section (Figure 4-7) and will be checked for each individual levee in the PED phase.

2.10 ADDITIONAL LEVEE ANALYSIS CONSIDERING FEMA AND USACE CRITERIA FOR REQUIRED LEVEE HEIGHTS

2.10.1 General Process

Waves and water levels from the ERDC-CHL storm surge and local wave modeling results were combined with the existing data gathered and analyzed to determine required levee heights based on EC 1110-2-6067 and CFR 2000 Title 44, and additional ERs, EMs, and ECs referenced below. The processes used for determining the required levee crest elevations were:

1. In areas subject to waves, levee crest elevation was calculated based on the maximum of:

    a. Freeboard associated with average overtopping rate plus the average 1 % ACE SWL
    b. 90 percent assurance level for the 1 % ACE SWL
    c. Freeboard associated with average overtopping rate plus FEMA required freeboard plus average 1 % ACE SWL (For coastal levees subject to overtopping, minimum required freeboard is 1 foot.)

2. In areas not subject to waves, levee-crest elevation was calculated based on the maximum of:

    a. 90 percent Assurance Level for the 1 % ACE SWL
    b. FEMA required freeboard plus average 1 % ACE SWL (For levees subject to SWL overtopping only, required freeboard is 3 feet.)

After the required levee height was determined as described above, RSLC was added to determine the final recommended height. Fifty-year Intermediate RSLC values were added, with the intention of this being adaptable to the 50-year High and the 100-year Intermediate RSLC rates. RSLC is added linearly in this analysis. Recommended levee-crest elevations based on other RSLC rates were also analyzed to support the RSLC decisions incorporated here. For additional information reference the plan formulation and economics appendices.

2.10.2 Recommended Elevations for Brazoria Region (Freeport)

Based on the analyses, crest elevations recommended for Freeport were determined using the criteria previously mentioned. Table 2-8 summarizes recommended elevations for earthen levees and floodwalls subject to waves and water-level overtopping only, respectively.

Table 2-8: Recommended Levee/Floodwall Elevations for Freeport as a Function of RSLC

Geo Point ID	Recommended Height, no RSLC	Recommended Height 50-Year Low RSLC	Recommended Height 50-Year Intermediate RSLC	Recommended Height 50-Year High RSLC
DBC_1	16.98	18.24	18.93	21.11
DBC_2	16.33	17.59	18.28	20.46
DBC_3	16.27	17.53	18.22	20.40
DBC_3v2*	15.90	17.16	17.85	20.03
DBC_4	16.14	17.40	18.09	20.27
DBC_4v2*	16.24	17.50	18.19	20.37
DBC_5	16.56	17.81	18.50	20.69
DBC_5v2*	15.40	16.66	17.34	19.53
W_1	13.87	15.13	15.82	18.00
S_1	14.91	16.17	16.86	19.04
S_2	14.46	15.71	16.40	18.58
S_3	15.89	17.15	17.84	20.02
S_4	14.92	16.18	16.87	19.05
S_5	14.38	15.63	16.32	18.51
PF_3-wave barrier	17.68	18.94	19.63	21.81
PF_3-thumb	16.34	17.59	18.28	20.46
PF_4 thumb*	16.02	17.28	17.97	20.15
PF_4 Phillips	14.23	15.49	16.17	18.36
PF_2	16.82	18.08	18.77	20.95
PF_1	22.91	24.17	24.86	27.04
US_2	17.10	18.35	19.04	21.22
US_2v2*	15.35	16.61	17.30	19.48
IH_1*	16.06	17.31	18.00	20.19
IH_1	15.99	17.25	17.94	20.12
N_1	18.83	20.09	20.77	22.96
N_2	19.49	20.75	21.43	23.62
N_3	20.24	21.50	22.18	24.37
N_4	20.26	21.52	22.21	24.39
N_6	19.87	21.12	21.81	24.00
N_5	20.17	21.42	22.11	24.29
N_7	20.22	21.47	22.16	24.35

LS_1	15.88	17.14	17.83	20.01
US_1	15.95	17.21	17.89	20.08
OC_1	17.37	18.62	19.31	21.49
OC_2	17.46	18.71	19.40	21.58
OC_3	16.97	18.23	18.92	21.10
OC_4	17.21	18.46	19.15	21.34
OC_5	16.86	18.11	18.80	20.98
OC_6	13.27	14.52	15.21	17.39
OC_7	10.46	11.71	12.40	14.58

2.10.3 Recommended Elevations for Sabine Region

Based on the analyses, crest elevations recommended for Sabine were determined using the criteria previously mentioned. Table 2-9 summarize recommended elevations for earthen levees and floodwalls subject to waves and water-level overtopping only, respectively.

Table 2-9: Recommended Levee/Floodwall Elevations for Sabine as a Function of RSLC

Geo Point ID	Recommended Height, no RSLC	Recommended Height 50-Year Low RSLC	Recommended Height 50-Year Intermediate RSLC	Recommended Height 50-Year High RSLC
GeoA	11.5	13.1	13.8	16.0
GeoB	11.7	13.3	14.0	16.2
GeoC	13.5	15.2	15.8	18.0
GeoD	11.2	12.8	13.5	15.7
GeoE	11.3	12.9	13.6	15.8
GeoF	13.0	14.6	15.3	17.5
GeoG	10.9	12.5	13.2	15.4
GeoH	14.9	16.5	17.2	19.4
GeoN	13.6	15.2	15.9	18.1
GeoO	10.7	12.3	13.0	15.2
GeoP	12.0	13.6	14.3	16.5
GeoQ	11.2	12.9	13.6	15.7
GeoR	11.3	12.9	13.6	15.8
GeoS	15.4	17.1	17.7	19.9
GeoT	15.6	17.2	17.9	20.1
GeoU	12.9	14.5	15.2	17.4
GeoV	16.2	17.9	18.6	20.7
GeoW	16.0	17.7	18.3	20.5
GeoX	12.8	14.5	15.2	17.3
GeoY	13.1	14.7	15.4	17.6
GeoZ	14.1	15.8	16.4	18.6
GeoZ1	15.6	17.3	18.0	20.1

GeoZ2	15.7	17.3	18.0	20.2
GeoZ3	13.5	15.1	15.8	18.0
GeoZ4	12.3	13.9	14.6	16.8
GeoZ5	12.2	13.8	14.5	16.7
GeoZ6	12.0	13.6	14.3	16.5
GeoZ7	11.5	13.1	13.8	16.0
GeoZ8	11.0	12.6	13.3	15.5

2.11 ADJACENT IMPACTS

This section discusses impacts to areas adjacent to the proposed new levees, including changes in water surface elevations during a surge event, run-up, and waves. The ERDC surge model was run with the full "maximum" footprint for the Freeport, Port Arthur, Jefferson, and Orange levees being considered. The model results showed induced impacts could reach levels of nearly 1 to 1.5 feet in some areas for the full configuration, particularly along the Neches River and the Orange County levee. The levees on the Neches River that were causing the most adjacent impact and could induce damages in this area have since been removed from the selected plan and these impacts will not occur. The existing systems of Port Arthur and Freeport showed negligible impacts during a 100-year event.

Regarding Orange 3, some induced flooding was determined, the largest was along the Neches River. Again these sections of levee have been removed from the final selected plan and impacts in this area will be negligible. This drastically reduces adjacent impacts caused by the proposed levee.

Finally adjacent impacts to the south and southeast of the levee has been further investigated. Most areas impacted are vacant areas of grasslands and wetlands with some trees and wetlands. Using the surge modeling data from ERDC for a 100-year flood the differences of with-project and without-project water surface elevations were calculated and mapped. It was found that adjacent impacts are minimal, with the only impacts that should not be considered negligible in close vicinity of the Orange 3 levee. This data has been mapped to show the adjacent impacts, and this map of adjacent impacts (for a 100-year event) can be found near the end of this Engineering Appendix. Most values are negligible besides the impacts at the levee mentioned before. Adjacent impacts south of the levee and into Louisiana are very small, in the .02 to .05 foot range. During PED this should be modeled again with the final levee configuration in ADCIRC/STWAVE.

There is always uncertainty as to whether any levee system would potentially induce flooding. Additional ADCIRC modeling will be performed during PED to determine whether there will be induced flooding and enable estimates of its magnitude. At feasibility level of design, the model

adequately addresses the limited potential for induced damages. The ADCIRC and Steady-State Spectral Wave (STWAVE) models may appear to provide a specific response of the Recommended Plan in any given scenario; however the model results are only a representative point of reference in a complex system. Calibration and verification efforts are employed in applying models, so that the results more closely replicate observed changes.

2.12 NED PLANS COMPARED TO RECOMMENDED FEMA CERTIFICATION AND USACE HEIGHTS

It is important to note that a planning study recommends the project that provides the most net excess benefits. That is what is being done at this level of the study to determine the limits of what items and percentages the Government would cost share. Reference the Main Report for cost share information. Additional considerations have been made and analyzed regarding how the NED plan will compare with FEMA CFR requirements and USACE requirements.

Levee elevations required to meet the three FEMA CFR 65.10 heights, the four USACE requirements, and the NED plan are all different. Heights were computed to meet USACE requirements and then compared to the FEMA heights for flood insurance. At all Geo Points, the final feasibility design levee heights met the FEMA requirements. How long in the future that the design elevations continue to meet FEMA maps will depend on the actual sea-level rise experienced and when it is incorporated into future FEMA maps. Soon before final PED heights are put into construction plans, it would be advisable to check current sea levels, current FEMA maps, and the final PED heights, to assure compliance with flood-insurance requirements.

The level of detail in the analysis conducted for this study does not allow for accurate estimation of the 90 percent level of assurance for overtopping. The 50 percent level of assurance will be applied for this feasibility study as required by planning studies, and the 90 percent level of assurance will be checked during the Preliminary Engineering and Design (PED) phase. For additional information on the topics in this section, reference the FIFR-EIS and Geotechnical Engineering section of this appendix.

2.13 CLIMATE CHANGE

2.13.1 Relative Sea-Level Change

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

specifies evaluating alternatives using "low," "intermediate," and "high" rates of future sea level change.

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

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

- At minimum 20-, 50-, and 100-year planning horizons should be considered in the analysis.
- Reinforces the concept that a thorough physical understanding of the project area and purpose is required to effectively assess the projects sensitivity to RSLC.
- Sea level changes should be incorporated into models at the mean and extreme events.
- Identification of thresholds by the project delivery team and tipping points within the impacted project area will inform both the selection of anticipatory, adaptive, and reactive options selected and the decision/timing strategies.

2.13.2 Historical RSLC

Historical rates are taken from the Center for Operational Oceanographic Products and Services (CO-OPS) at NOAA, which has been measuring sea level for over 150 years. Changes in MSL have been computed using a minimum 30-year span of observations at each location. These

measurements have been averaged by month to eliminate the effect of higher frequency phenomena such as storm surge, in order to compute an accurate linear sea-level trend.

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

Historical rates of local RSLC can be obtained from local tide records. The tide gage nearest to the Sabine Lake system with sea level trend information, with over 40 years of record, is at Sabine Pass (NOAA Gage 8770570). The NOAA MSL trend at this site (from 1958 to 2008) is equal to 5.66 mm/yr with a 95 percent confidence interval of +/- ± 0.98 mm/yr. Using the estimated historic eustatic rate equals that given for the modified NRC curves (1.70 mm/yr). This results in an observed subsidence rate of 3.96 mm/yr (5.66 mm/yr - 1.70 mm/yr). A vicinity map for NOAA Gage 8770570 is shown in Figure 2-18 on the next page.

The tide gage with sea level trend information nearest to the Galveston coast region, with over 40 years of record, is at the Galveston Pleasure Pier, which is on the Gulf of Mexico coast side of Galveston Island (NOAA Gage 8771510). The NOAA MSL trend at this site (from 1957 to 2008) is equal to 6.84 mm/yr with a 95 percent confidence interval of ± 0.74 mm/yr. If the estimated historic eustatic rate equals that given for the modified NRC curves, the observed subsidence rate would be 5.14 mm/yr (6.84 mm/yr - 1.70 mm/yr). A vicinity map for NOAA Gage 8771510 is shown in Figure 2-19.

Figure 2-18: NOAA Gage Sea Level Trend 8770570 Vicinity Map

Figure 2-19: NOAA Sea Level Trend Gage 877150 Vicinity Map

The tide gage with sea level trend information nearest to the Brazos River system, with over 40 years of record, is located at Freeport, TX Island (NOAA Gage 8772440). The NOAA MSL trend at this site (from 1954 to 20016) is equal to 4.35 mm/yr with a 95 percent confidence interval of ± 1.12 mm/yr. If the estimated historic eustatic rate equals that given for the modified NRC curves, the observed subsidence rate would be 2.65 mm/yr (4.35 mm/yr - 1.70 mm/yr). A vicinity map for NOAA gage 8772440 is shown in Figure 2-20.

Figure 2-20: NOAA Gage 8772440 Vicinity Map

2.13.3 Predicted Future Rates of RSLC for 20-Year Period of Analysis

The computed future rates of RSLC in this section give the predicted change between the years 2030 and 2050 for the Sabine Lake, Galveston Bay, and Brazos River systems. RSLC values for this 20-year period are summarized in Table 2-10 and plotted for each of the systems in Figure 2-21, Figure 2-22, and Figure 2-23

Table 2-10: Estimated RSLC over the First 20 Years of the Project Life (2030 - 2050)

Tide Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	1.08	1.38	2.32
Galveston Pleasure Pier, TX	6.84 mm/yr	1.30	1.60	2.55
Freeport, TX	4.35 mm/yr	0.83	1.13	2.07

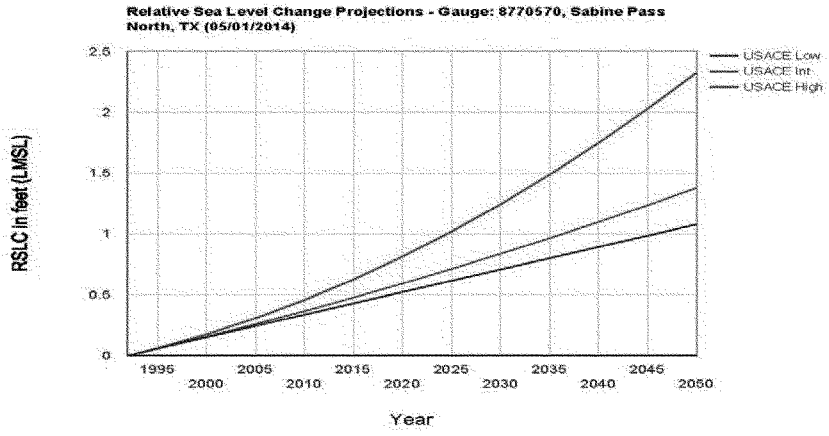


Figure 2-21: RSLC at Sabine, Texas over 20-Year Period of Analysis

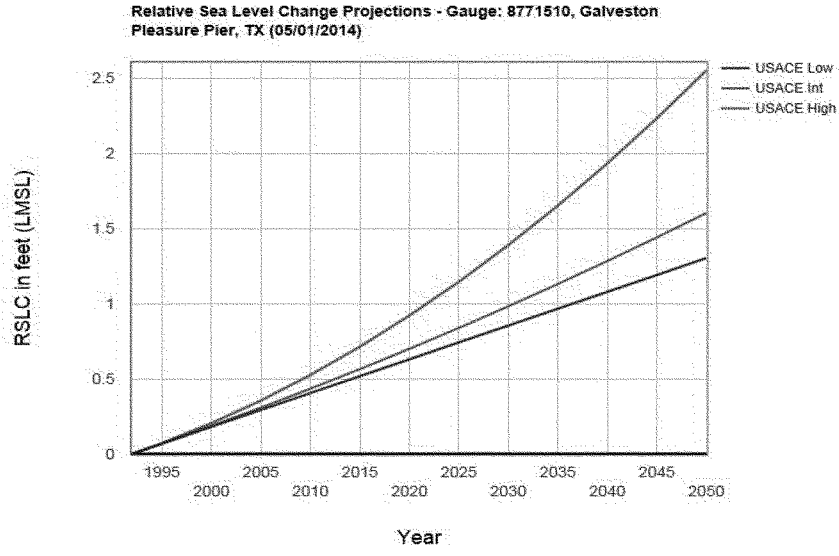


Figure 2-22: RSLC at Galveston, Texas over 20-Year Period of Analysis

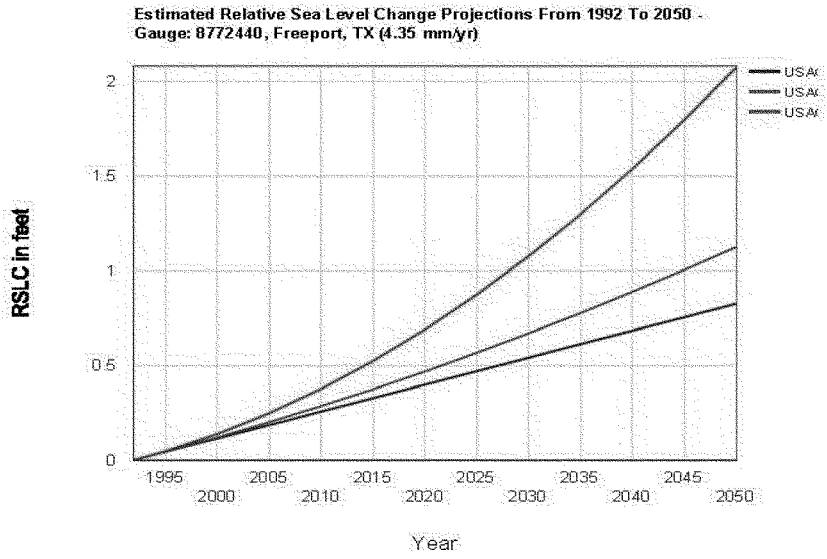


Figure 2-23: RSLC at Freeport, Texas over 20-Year Period of Analysis

2.13.4 Predicted Future Rates of RSLC for 50-Year Period of Analysis

The computed future rates of RSLC given here assume a 50-year period of analysis, and give the predicted change between the years 2030 and 2080 for the Sabine Lake, Galveston Bay, and Brazos River systems. Relative sea level change values for the 50-year period of analysis are summarized in Table 2-11.

Table 2-11: Estimated RSLC over the First 50 Years of the Project Life (2030 - 2080)

Tide Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	1.63	2.32	4.51
Galveston Pleasure Pier, TX	6.84 mm/yr	1.98	2.66	4.85
Freeport, TX	4.35 mm/yr	1.26	1.94	4.13

Figure 2-24 shows in graphical form the computed sea level change for the Sabine Lake system based on the latest guidance for the "low," "intermediate," and "high" rates of change.

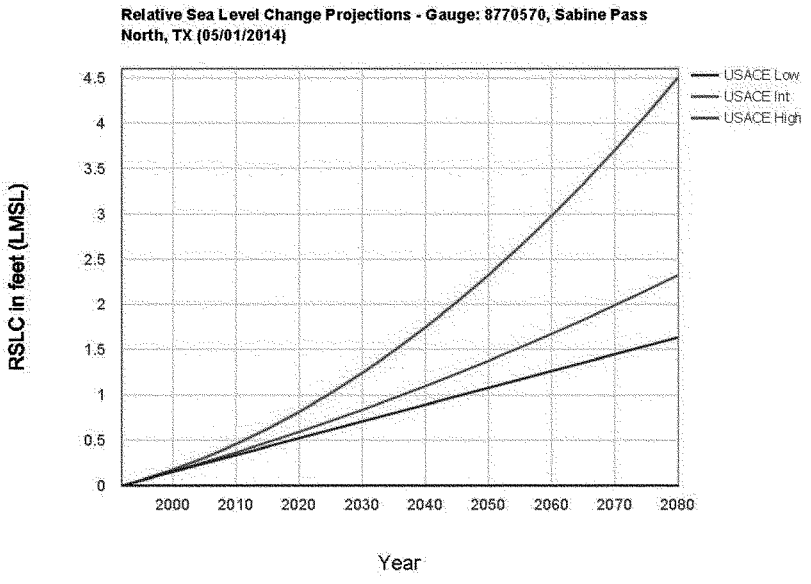


Figure 2-24: RSLC at Sabine Pass, Texas over 50-Year Period of Analysis

Using NOAA's Sea Level Rise and Coastal Flooding Impacts Viewer, it is apparent that much of the land around Sabine Pass in Jefferson County is low-lying. With just 1 foot of sea level rise, much of the coastline from Sabine Pass west to the Chambers County line is inundated during high tide. Areas as far as 10 miles inland experience increased inundation under this sea level rise scenario. There is substantial risk for lowland flooding without consideration of storm surge and waves. Adding surge and wave attack from a large hurricane to even the lowest SLR estimate yields substantial additional flooding. At 2 feet of sea level rise, the coastline west of Sabine Pass in Jefferson County becomes inundated without consideration of storm surge and waves, as does much of Port Arthur. Beaumont experiences more widespread flooding as well (Figure 2-25).

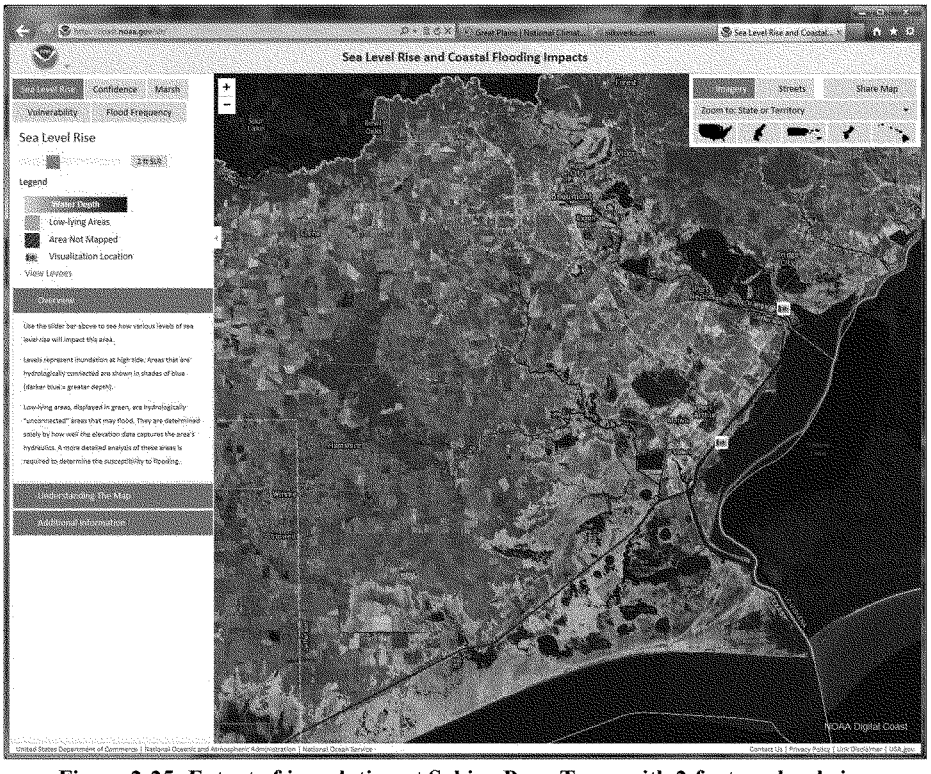


Figure 2-25: Extent of inundation at Sabine Pass, Texas with 2-foot sea level rise

Figure 2-26 shows the computed sea level change for the Galveston Bay system based on the current USACE guidance for "low," "intermediate," and "high" rates of change.

The Galveston County coastline is elevated higher than Jefferson County's coastline. At a 2-foot rise in sea level, the centerline of Bolivar Peninsula west of Rollover Bay remains above water. Chambers County, on the other hand, experiences significant flooding around Galveston Bay. However, the majority of Galveston County is mostly unaffected (Figure 2-27).

Figure 2-28 shows the computed sea level change for the Brazos River system based on the current USACE guidance for "low," "intermediate," and "high" rates of change.

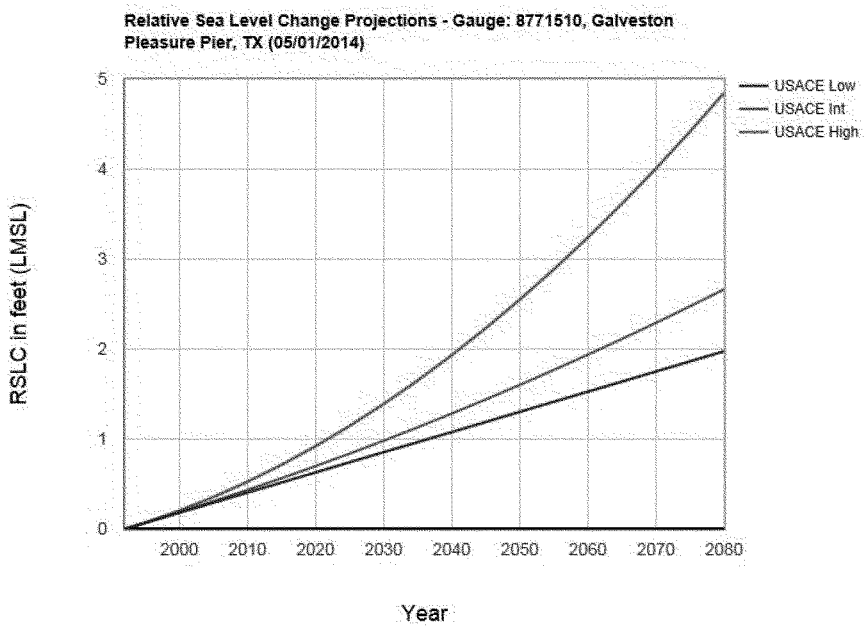


Figure 2-26: RSLC at Galveston Bay, Texas over 50-Year Period of Analysis

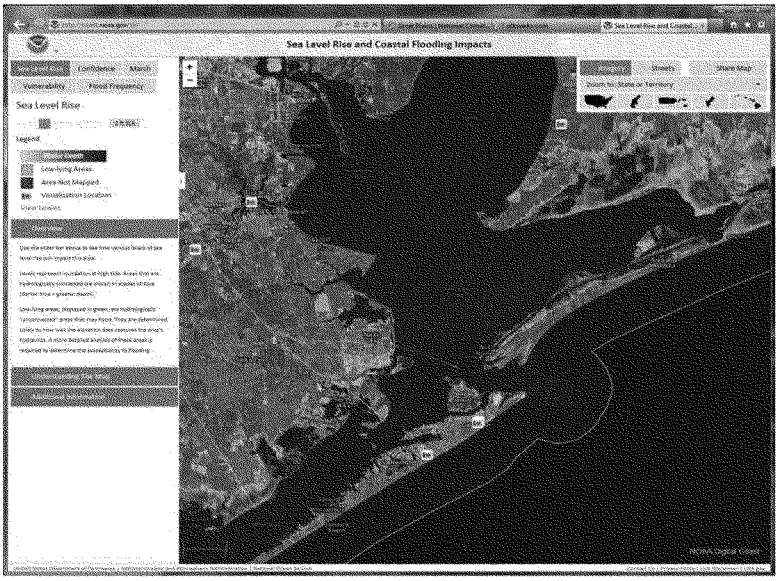


Figure 2-27: Extent of inundation at Galveston, Texas with 2-foot sea level rise

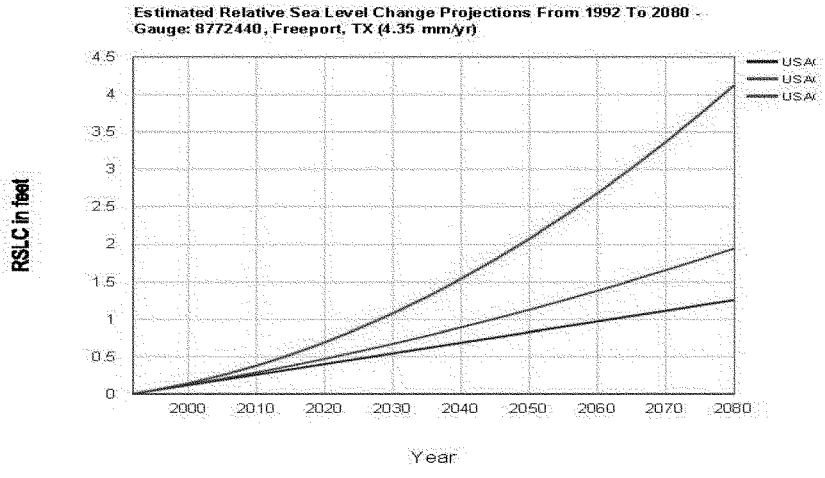


Figure 2-28: RSLC at Freeport, Texas over 50-Year Period of Analysis

Much of the area in the Freeport vicinity is low-lying. The majority of these low-lying areas are undeveloped, consisting of empty plots of land, some including marshes and wetlands. At 1 foot of sea level rise, several of these plots are inundated. It is important to note that water has begun to impact the Surfside Beach community just east of the Freeport Entrance Channel under this sea level rise scenario. At 2 feet, water begins to flood some central parts of Surfside Beach, inundating dozens of homes. For all considered sea level rise scenarios, safety from storm surge and wave attack for low-lying areas consistently decreases (Figure 2-29).

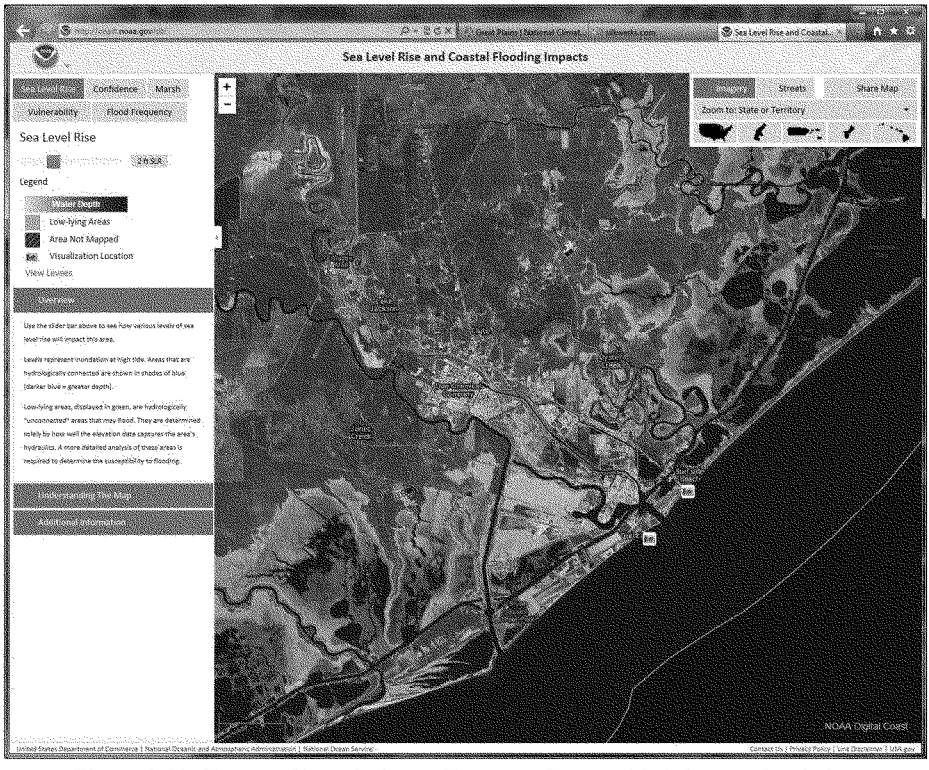


Figure 2-29: Extent of inundation at Freeport, Texas with 2-foot sea level rise

2.13.5 Predicted Future Rates of RSLC – 100-year Sea-Level Change

The planning, design, and construction of a large water resources infrastructure project can take decades. Though initially justified over a 50-year economic period of analysis, USACE projects often remain in service much longer. The climate for which the project was designed can change over the full lifetime of the project to the extent that stability, maintenance, and operations may be

affected. These changes can cause detrimental or beneficial consequences. Given these factors, the project planning horizon (not to be confused with the economic period of analysis) should be 100 years, consistent with ETL-1110-2-1.

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

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

Using the high SLC curve elevation at 100 years, the potential future affected area has been approximately defined. This includes both the vertical and the horizontal extents of potential SLC impacts. Since this is an initial screening level, detailed modeling has not occurred yet. This basic approach will provide a first-level assessment of how the project and project area might be impacted, and follows the guidance in ETL-2-1. More detailed engineering analyses will be conducted during PED.

The future affected areas, as defined by the 100-year high rate of RSLC, can impact resources, including economics. These resources can be identified and quantified, such as critical infrastructure (schools, roads, water supply, community buildings, etc.), impacted property, life-safety concerns, and environment and ecosystems. The consideration of the potentially larger area of impact facilitates discussion of what actions may need to be considered at certain trigger points. Community, as well as other stakeholder expectations will be better defined. Evaluation of coastal storm-damage risk reduction in the context of RSLC may also involve societal thresholds. Potential system and cumulative effects should be explored qualitatively when formulating plans.

An essential element of developing a good understanding of the project area's exposure and vulnerability is assessing how quickly the individual scenarios might necessitate an action due to thresholds and tipping points. It is important to identify key milestones in the project timeline

when impacts are expected. This involves inputs from all members of the PDT as the threshold or tipping point could be a vast variety of different items or combinations of items.

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

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

Utilizing the online sea-level calculator referenced in ER 1100-2-8162, estimates of 100-year RSLC, assuming a starting date of 2030 and ending date of 2130, were determined for this project. Table 2-12 lists the predicted low, medium, and high RSLC values for 2130. Figure 2-30, Figure 2-31, and Figure 2-32 graphically show the RSLC information generated by the calculator.

Table 2-12: Predicted RSLC over the First 100 Years of the Project Life (2030 - 2130)

Tide Gage	Measured Relative SLR Rate (NOAA)	Low (ft)	Intermediate (ft)	High (ft)
Sabine Pass, TX	5.66 mm/yr	2.56	4.26	9.62
Galveston Pleasure Pier, TX	6.84 mm/yr	3.10	4.79	10.16
Freeport, TX	4.35 mm/yr	1.97	3.66	9.03

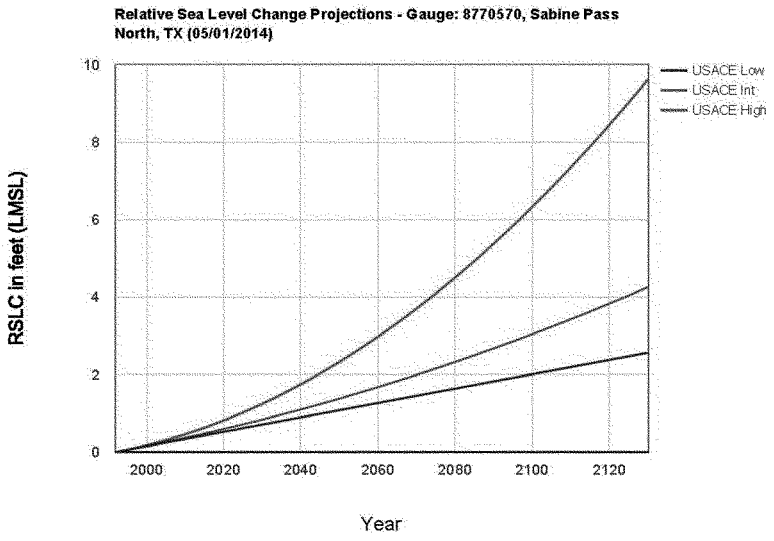


Figure 2-30: Predicted RSLC at Sabine, Texas over 100-Year Period of Analysis

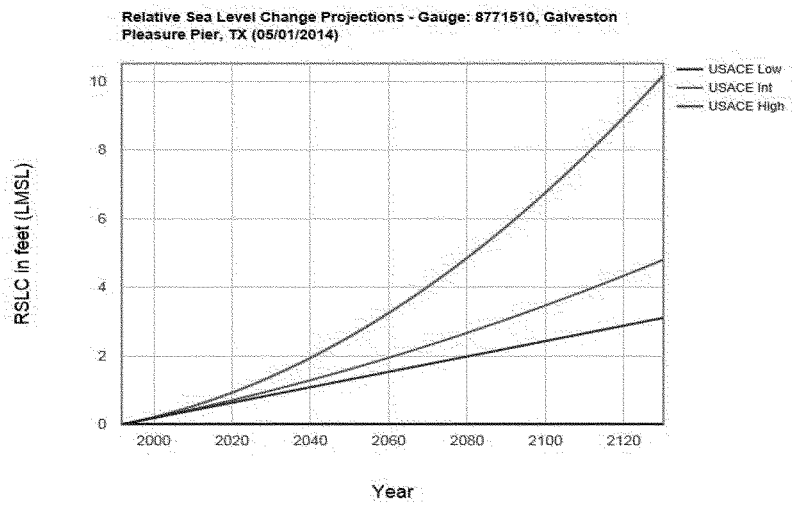


Figure 2-31: Predicted RSLC at Galveston, Texas over 100-Year Period of Analysis

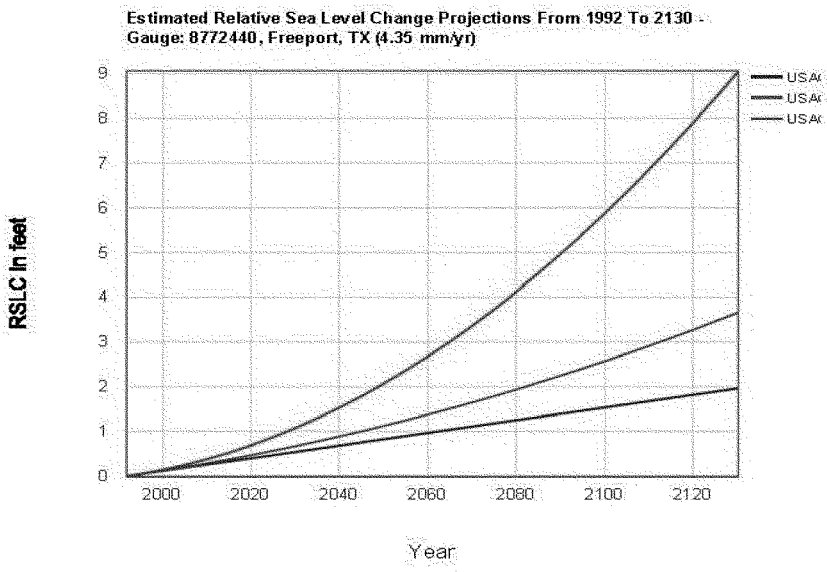


Figure 2-32: Predicted RSLC at Freeport, Texas over 100-Year Period of Analysis

2.13.6 Total Water Level Approach

The Total Water Level Approach framework is designed to emphasize several key principles described in USACE policy and guidance. Procedures to Evaluate the Magnitudes and Effects of Total Water Levels at USACE Projects include:

- Linking Tidal and Geodetic Datums
- Identifying Coastal Design Performance Factors
- Applying Coastal Forcing/Total Water Level Approach
- Applying RSLC and future scenarios
- Scaled analysis and decision making

For the Recommended Plan an initial Total Water Level approach was performed to:

- Identify Coastal Design Performance Factors
- Apply Coastal Forcing/Total Water Level Approach
- Observe RSLC and impacts on future scenarios

- Scaled analysis and decision making, such as when a threshold elevation may be reached or levee height may need modification.

"Total" water level is the sum of "sea level" at a particular time plus storm surge, but does not include runup over structural overtopping. Figure 2-33 and Figure 2-34 show sea level for the low, intermediate, and high RSLC curves, and plot storm surge as the red shaded area above the high sea-level curve. The plot shows the impact that RSLC will likely have on surge levels; by 2080 the surge levels are estimated to be 4 feet higher than currently due to RSLC (using the Intermediate Rate Curve).

In addition to the steady-state sea levels, the **current Base Flood Elevation** (BFE) is shown as a single diamond-shaped point for the FEMA 100-year storm.

The project's **Elevation Threshold** is the elevation at which the levee is at risk of overtopping, shown as the dotted line of a steady elevation in Figure 2-33 and Figure 2-34. (Risk is characterized as "Large" when the overtopping probability reaches 30%, "Medium" when 15-30%, and "Low" when less than 15%.)

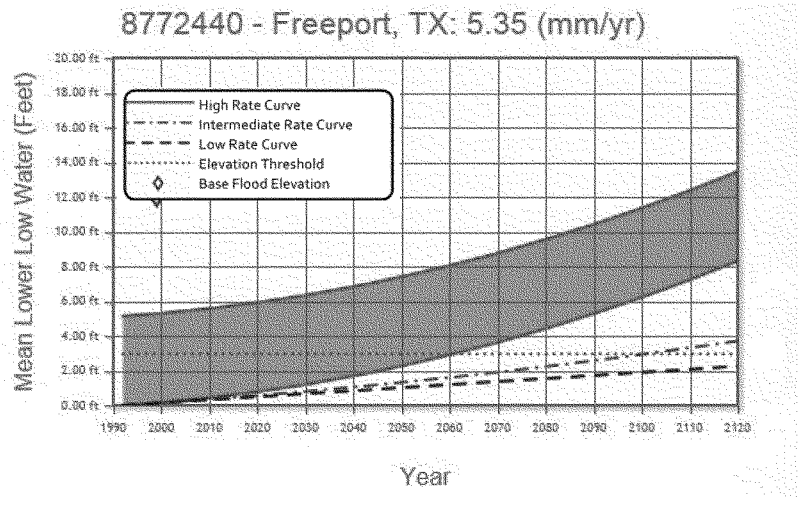


Figure 2-33: RSLC and Total Water Level Plot for Brazoria Region (Gage #8772440 used for this plot is near the Freeport levee.)

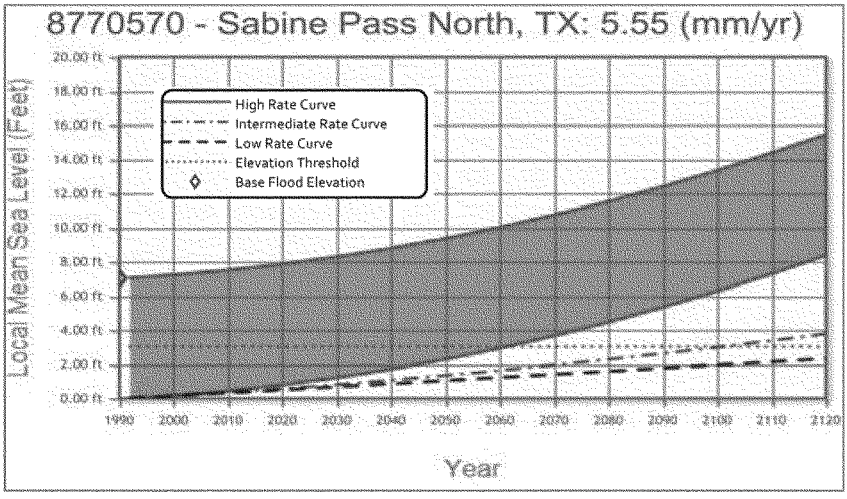


Figure 2-34: RSLC and Total Water Level Plot for Sabine Region (Gage #8770570 used for this plot is near the Orange and Port Arthur levees.)

Figure 2-35 shows the different components that together make up the total water forcing ("Total Water Level" plus runup). This information will be used to determine when modifications will need to be made, when threshold elevations are at risk of being reached, and other design and O&M purposes. Tides are not shown in Figure 2-35, as they are included in the surge model elevations.

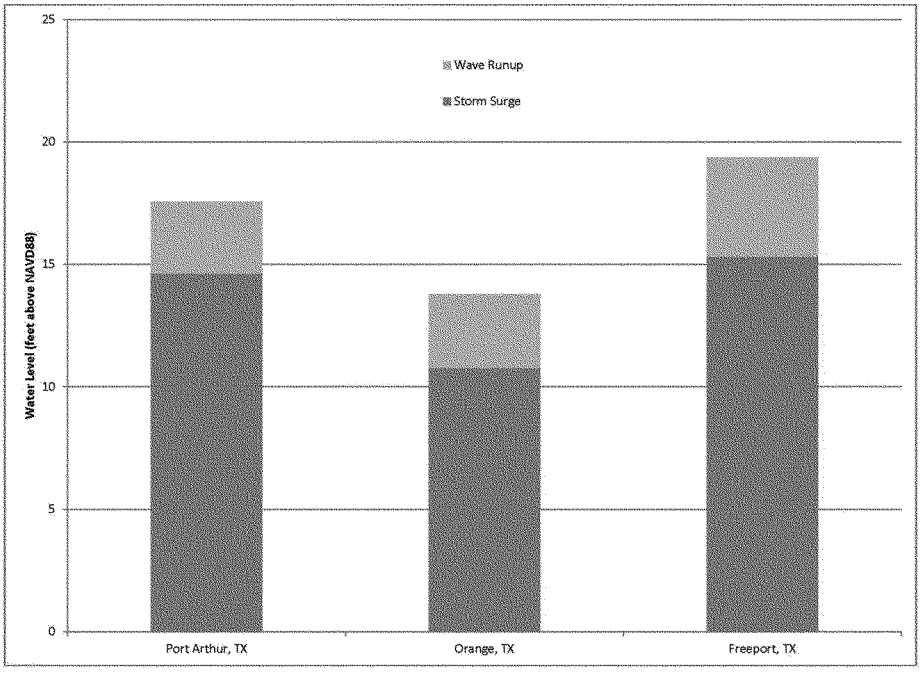


Figure 2-35: Bar Charts to Determine Total Water Level Forcing (Port Arthur and Orange levees are near the Sabine Gage #8770570 used in Fig. 2-33. Freeport levee is near the Freeport/Brazoria Gage #8772440 used in Fig. 2-32.)

2.13.7 Additional Climate Change Considerations

This section discusses future climate change expected based on current scientific evidence and studies. Climate change is expected to pose several challenges along the Texas coast. It is expected to vary greatly along the extensive Texas coast from the Mexican border to the Louisiana border. USACE will be pressed to 1) find ways to resolve increasing competition for land, water, and energy resources, 2) conserve ecological systems, and 3) enhance the resilience of people to the impacts of climate extremes (USACE 2014). These challenges will unfold against a backdrop that includes a growing urban population, incentives for energy production, and advances in technology.

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

Patterns of precipitation change are affecting coastal areas in complex ways. The Texas coast saw a 10 to 15 percent increase in annual precipitation between 1991 and 2012 compared to the 1901-1960 average (Figure 2-36). Texas coastal areas are predicted to experience heavier runoff from inland areas, with the already observed trend toward more intense rainfall events continuing to increase the risk of extreme runoff, flooding, and possibly creating life safety issues.

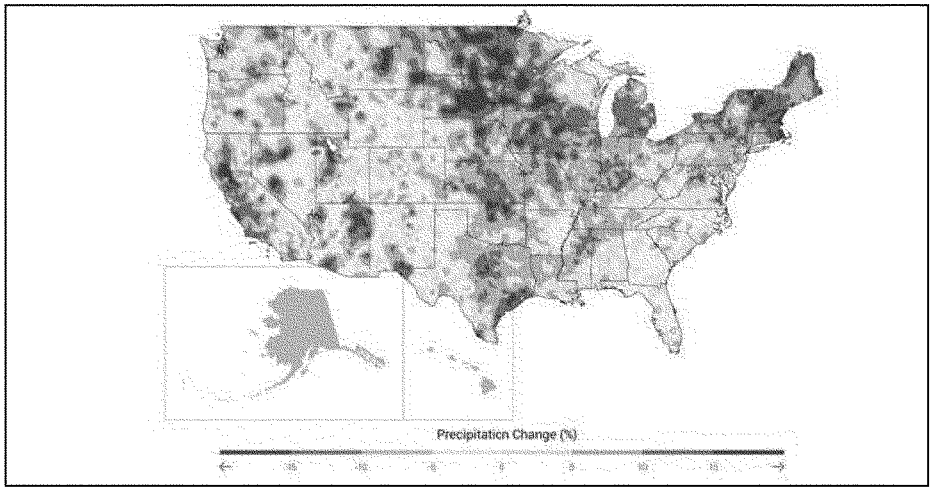


Figure 2-36: Percent Change in Annual Precipitation for 1991-2012 Compared to 1901-1960

Texas' Gulf Coast historically averages three (3) tropical storms or hurricanes every four (4) years, generating coastal storm surges and sometimes bringing heavy rainfall and damaging winds hundreds of miles inland. The estimated change in sea level will result in the potential for greater damage from storm surge along the Texas Gulf coast and miles inland. Tropical storms have increased in intensity in the last few decades. Future projections suggest increases in hurricane

rainfall and intensity (with a greater number of the strongest - Category 4 and 5 - hurricanes) (Melillo 2014).

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

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

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

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

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

2.13.8 Conclusions and Recommendations regarding Climate Change and RSLC

The impacts of the RLSC values in the Tables are considered in all aspects of the feasibility designs and analyses for all three levee systems and study area. This includes modifications of existing levees and design of proposed levees and gate structures. Additionally, these values should be used when designing preliminary drainage features and for the environmental assessment of the project. New drainage structures have been oversized to accommodate the predicted increase in precipitation in ETL 110-2-1. Levees have been recommended to include extra height to meet the 50-year intermediate RSLC values, and being preliminarily designed to be adaptable to the 50-year high or 100-year intermediate (whichever is highest). RSLC estimates for 20-year, 50-year, and 100-year planning horizons, following guidance in ER 1110-8162 and ETL1110-2-1 have been included in the preliminary design and cost of the proposed projects. As the tidal epoch changes the RSLC equation will change in 2019 or 2020. It is recommended RSLC estimates and the preliminary design of features in this project based on current RSLC estimates and guidance be reevaluated in PED.

2.14 INTERIOR DRAINAGE

The existing and proposed levee systems need to maintain drainage of rainfall-induced runoff of the levee interior area during normal rainfall events, and also during tropical events during which the system will be closed to reduce storm surge damages. The following describes the preliminary interior drainage analysis performed and drainage plan for the existing and proposed levee components.

For the proposed new levee systems, flows were calculated using rational and regression methods. Drainage structures were conservatively sized based on the 50-year and 100-year flow events. The calculated flows were increase by a magnitude of 10 percent to account for climate change and the anticipated increases in precipitation predicted. This is further discussed in Section 2.13 - Climate Change.

For the existing systems at Port Arthur and of Freeport, the existing drainage systems and possible modifications or improvements that could be made were evaluated. Known deficiencies in interior drainage structures (pipes, pumps, etc.) are not addressed in this evaluation of existing systems as

they would be Operations, Maintenance, Repair, Replacement and Rehabilitation (OMRR&R) issues. Only improvements and modifications with economic benefits that establish a Federal interest were considered for the existing systems. Section 2.15 details the study efforts of interior drainage for both regions.

2.15 EXISTING LEVEE SYSTEMS INTERIOR DRAINAGE

An extensive data collection effort was performed for the Regions of study. Data collected included USACE Design Memorandums, Plans and Specifications, levee inspection report, Hydrologic and hydraulic models from counties, the state of Texas, Cities, Ports, and Levee Districts, among other sources including consultants were gathered and used when appropriate.

A Joint Probability Analysis (JPA) was performed between Stillwater levels and flow rates (Discharge). This demonstrated a five-day time lag of Discharge. This time lag was used to estimate significant reductions in necessary pumping rates in Orange County, resulting in significant cost savings. The theoretical method is detailed in section 2.15.3, with the key illustrative curves in Figure 2-40. Details of the application are in 2.15.10 Pumps.

The sensitivity analysis referred to as 10-15% was a comparison of results from different models used to compute interior drainage flow rates, Q (cfs). The USGS runoff model equations and statistics that quantify uncertainty are listed in Table 2-15. The second method was the Federal Highway Administration (FHWA) method. Statistics on the uncertainty of those results are listed in Table 2-16. Both methods are described in detail in section 2.15.9 "Regression Method". Confidence in the results was achieved through (1) examination of the statistics in Table 2-15 and Table 2-16 and (2) the fact that the two different methods produced results within 10-15% of each other.

2.15.1 Brazoria Region Data (Freeport and Vicinity)

Levee construction plans, hydrologic and hydraulic studies, FEMA data, TXDOT data, county data, Periodic Inspection Reports, and FEMA data for FEMA studied bodies of water were used. Maps of the area and historical data regarding water and inundation paths were used to identify areas of concern. Additionally data from the on-going USACE Risk Management Center Freeport SQRA was obtained including surge, drainage, and other hydrologic and hydraulic models to use. Preliminary investigation determined that current interior drainage infrastructure is adequate and there are no known deficiencies. Some interior drainage components will need reconstruction or repair as work on the recommended plan dictates. One new drainage structure will be needed for the recommended. At the DOW barge canal the recommended plan calls for a sector gate structure, which will require an expanded pump location to drain water past the proposed gate structure.

More detailed study of this structure is recommended during PED. During PED it is recommended that all major waterways, creeks, bayous, and other waterways within or adjacent to the levee system be surveyed and hydrologic/hydraulic models be update or recreated.

2.15.2 Sabine Region Data (Port Arthur and Vicinity)

Data from DMs, plans and specifications other studies for existing Port Arthur and the surrounding areas, Periodic Inspection Reports, coordination with the local Drainage District, the current Alligator Bayou Pump Station 408 study, and FEMA data for the area was used to investigate the interior drainage of Port Arthur. Preliminary hydrologic and hydraulic investigation determined that the current interior drainage infrastructure is adequate and there are no known deficiencies or need to change the interior drainage features besides remediation pump stations. Five pump stations that discharge rainfall runoff during surge events need reconstruction or repair as work. The remediation will not impact the function or capacity of the pumps. These pumps are identified below in Figure 2-37.

Figure 2-37: Port Arthur Pump Stations in Need of Rehabilitation

The current pumps and other drainage structures could be constructed with the capability to discharge additional interior drainage than the current pumps and structures, following guidance

in ETL1110-2-1 which predicts increased rainfall in the area. More detailed study of the Port Arthur drainage structures is recommended during PED. During PED it is recommended that all major waterways, creeks, bayous, and other waterways within or adjacent to the levee system be surveyed and hydrologic/hydraulic models be updated or created for further evaluation.

2.15.3 Preliminary Screening of Neches River Gate Alternative

An alignment for a closure gate on the mouth of the Neches River recommended by Orange County Study was selected for additional H&H study and analysis. The original Orange County Report alignment was refined to minimize environmental and navigation impacts, and identify a more specific location for a pumping station. This pumping station would need to have the ability to pump discharges from the inland Neches River into Sabine Lake.

Both alternatives were configured to provide the same level of protection (and benefits). USACE must recommend a plan that maximizes net excess benefits. With the benefits for each alternative providing the same benefits the alternatives could be compared based on cost data. A joint probability analysis of riverine discharge and storm surge on the Neches River was conducted to assist in determining the feasibility of an alternative that would place a closure gate on the Neches River. The analysis calculates the probability of discharge with respect to extreme water level. This analysis is appropriate for initial screening. This preliminary screening was performed to determine if the Neches River gate continued to remain a viable alternative or would be dropped from further consideration.

Figure 2-38 shows the location of gages that provided data used in this analysis. The nearest gage measuring river discharge was an USGS gage at the Neches River Saltwater Barrier. The USGS gage has a period of record (POR) from 04 June/2003 until present. The nearest gage measuring water level was a NOAA gage at Rainbow Bridge. The NOAA gage has a POR from 01 January 1993 to present.

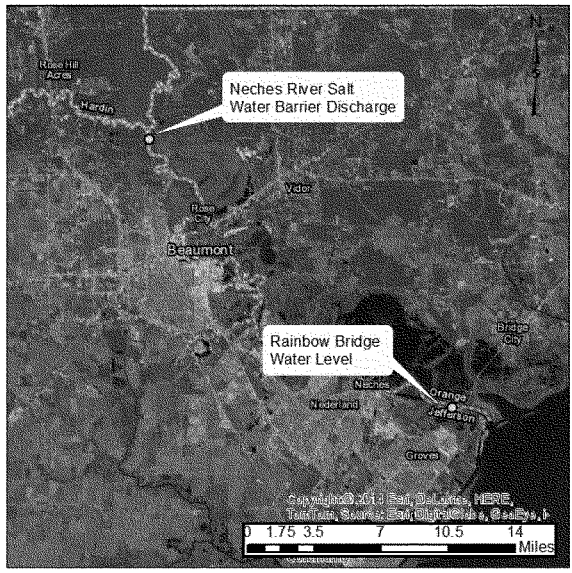


Figure 2-38: Location of Gages Used in this Analysis

Figure 2-39 plots all available overlapping water level and discharge data. The time period from 2003 to present was used for this analysis. Figure 2-40 plots discharges and water levels during Hurricane Rita (2005). Rita made landfall in the study area as a Category 3 Hurricane. Since water levels and discharges are both influenced directly by tropical storms, a joint probability analysis is required to determine the probability of discharge volumes (using rainfall runoff flow and surge levels) during variable surge events that would require the gate to be closed.

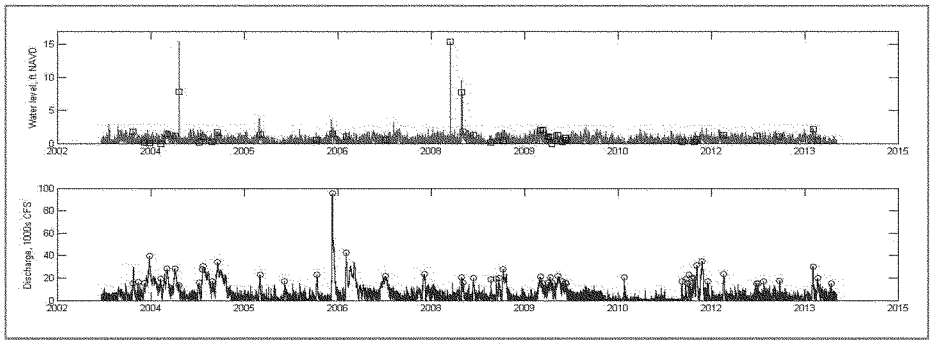


Figure 2-39: Water Level and Discharge Data from 2003 to Present

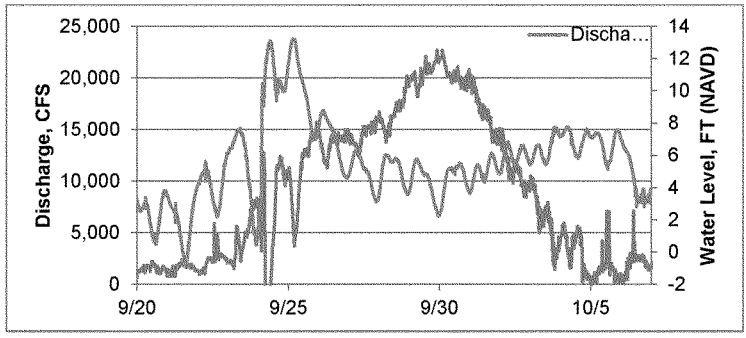


Figure 2-40: Discharge and Water Level during Hurricane Rita

The data gathered from NOAA and USGS gages were utilized in performing a joint probability analysis of discharge and water level. First, the peak over threshold approach was used to determine extreme water level and discharge events. Water levels over 3.3 feet and discharges over 15,000 CFS were specified as extreme and included for analysis. Frank and empirical Copula bivariate distribution functions were then fit to the data to calculate the distribution following the method applied in Michalsen (2014). Figure 2-41 plots the probability distribution calculated with the Frank (top) and empirical (bottom) Copula functions. The colors and contours show probability in return period. Figure 2-41 shows that the highest discharges tend to occur at lower water level. It is important to point out that this is a relatively short data record. A longer data record would need to be synthesized to attempt to improve the accuracy of these results. It is also noted the Neches River downstream of the USGS gage would incorporate additional drainage area and runoff so it should be expected that flow near the proposed gate location would be higher.

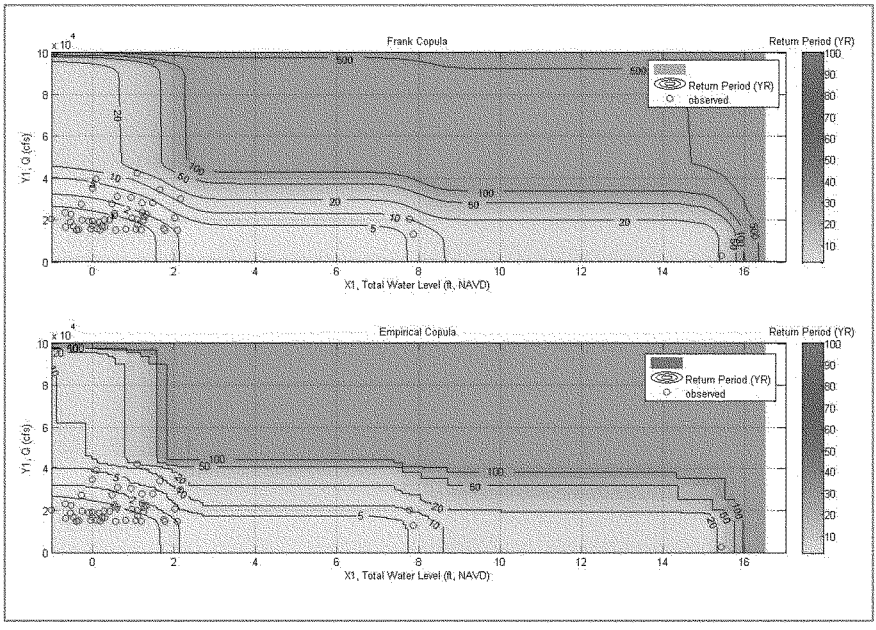


Figure 2-41: Joint Probability of Discharge (Q) and Water Level

In summary, the analysis leads to the following general conclusions:

- 100-year return period Neches River discharge could reach levels up to 40,000 cfs for coincident riverine/surge events that would occur during gate closure.
- If the gate remains the preferred alternative, more detailed analysis of joint probability of water level and discharge should be conducted to inform operations and design.

2.15.4 Consideration of Storm Surge Damages in Port/City of Beaumont

A preliminary investigation was conducted by USACE to evaluate the Beaumont areas vulnerability to storm surge, and if the alternatives being considered could provide beneficial protection in the area. For this investigation USACE collected data, studied inundation maps for a range of storm frequencies, and contacted local and national entities with knowledge of flooding issues in the area. During this investigation USACE contacted the Port of Beaumont, Jefferson County Drainage Districts 6 and 7, the FEMA local flood administrator, FEMA Regions VI and IV, the City of Beaumont Water Utilities Department, and the Sabine Neches Drainage District.

The Port of Beaumont stated that surge in the Port did occur during Hurricane Ike, but it caused only minor damage to docks and a few electrical systems. The Port of Beaumont was fully operable 2 to 3 days after Hurricane Ike passed. Hurricane Rita caused almost no surge at the Port. Damages from Rita in Beaumont were almost entirely due to wind.

The local floodplain administrator (Adena Ward) provided additional information on surge related damages in the Beaumont area. Ike flood damages were focused in two areas. The first area was along Pine Street in Beaumont, which experienced significant flooding. Most of the properties damaged at this location have since been bought out. The other location that was damaged by surge was the Exxon Mobil facility area located just south of the Port of Beaumont. FEMA Region VI provided damage claim amounts for the Ports of Orange and Beaumont during Hurricanes Ike and Rita. For Ike, 87 percent of damage claims were Category A (debris removal) with minimal damages to infrastructure or facilities. Damages claimed during Rita only amounted to $109,000.

Sabine Neches Navigation District (SNDD) had little info on Port of Beaumont. SNDD did relay that considerable damages had occurred along Taylors Bayou during Ike. They have since constructed a large diversion culvert to route water around the area and prevent flood water damages on Taylors Bayou during future rainfall events. The Water Utilities Department noted that the salt water barrier intake on the Neches River was damaged during Ike, but the cost of repair was minimal. Jefferson County Drainage District 6 provided data on high water marks during Ike that correlated well with the information other contacts had provided.

In summary, surge events have historically caused minimal damages to the Port and City of Beaumont. Drainage features have been constructed to alleviate flooding along Taylors Bayou, and buyouts have been performed in Beaumont to remove structures from flood-prone areas. The only area that has experienced damages and not been protected or removed from flood prone areas is the Exxon facility area (note that this area would be protected by the alternatives currently being considered in this USACE study). During surge events, water is almost entirely contained within the undeveloped Neches floodplain in the vicinity of Beaumont and causes minimal damages. The inundation in the vicinity of Beaumont from a 100-year frequency storm is displayed in Figure 2-42.

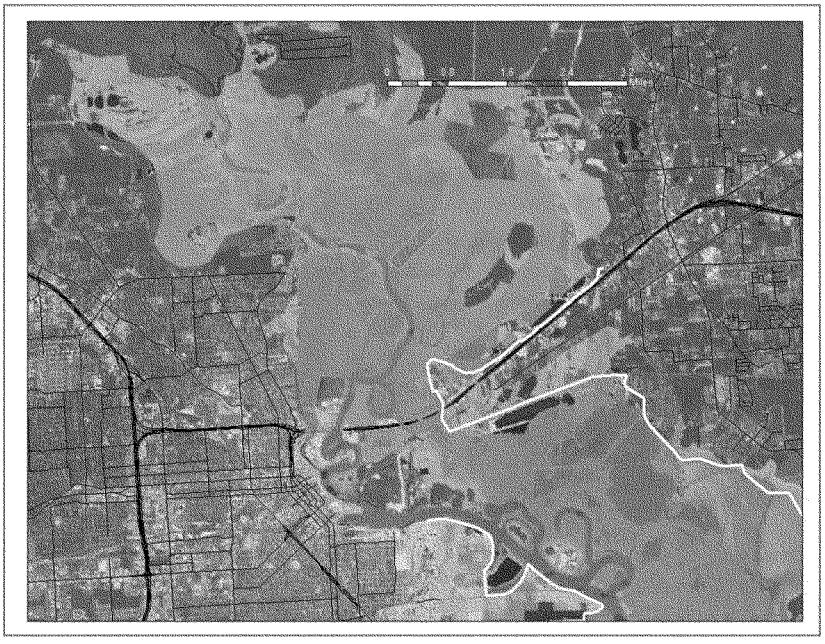


Figure 2-42: 100-year Frequency Inundation in Beaumont Vicinity

Orange County Levee/Gate Alternatives: Alignments and Preliminary Feasibility Approach
USACE used levee alignments established in the Orange County Flood Protection Planning Study (2012). The levee alignment was refined in some areas to maximize benefits, reduce cost, reduce environmental impacts, and protect critical infrastructure. Additionally, steps were taken to avoid major pipeline corridors/conflicts and identify potential properties for buyouts. For additional information and details on the alignment study, alignment selection, economics, cost, real estate, and other factors that led to the recommended plan alignment, please refer to those sections of this report.

2.15.5 Interior Drainage Analysis of Proposed Orange Levee System

2.15.6 Drainage Area Delineation

Drainage areas for the interior of the levees were delineated using a combination of LiDAR, USGS maps, aerial maps, and documents gathered from the county and cities in the area. A closure gate on the Neches River was considered and eliminated due to cost. Drainage Area Maps for the entire proposed Orange, Beaumont, and Jefferson sections of the Recommended Plan are included in the

H&H exhibits section of this H&H. These maps also contain preliminary drainage structure locations and sizes.

2.15.7 Drainage Area Discharge Estimates

Runoff was calculated using the Rational method for Areas under 200 acres and using Regression methods for areas larger than 200 acres. Details of the runoff calculations are summarized in the following sections. Measured gage data in the area is sparse, but what is available is being used. Preliminary Hydrologic and Hydraulic Models of Cow and Adams Bayous were obtained from the Orange County Economic Development center and used.

2.15.8 Rational Method

For areas 200 acres or less, the Rational method was used to calculate runoff due to rainfall events. The Rational Equation is the simplest method to determine peak discharge for smaller drainage basin runoff. It is not as sophisticated as the SCS TR-55 method, but is the most common method used for sizing sewer systems and adequate for the purposes used in this study.

The Rational Equation is: Q=CIA

where:

Q = Peak discharge (cfs)

C = Rational method runoff coefficient

I= Rainfall intensity (inches/hour)

A = Drainage area (acres)

The Rational method runoff coefficient (C) is a function of the soil type and drainage basin slope. C is reflective of the type of land coverage. For example, C for pervious grassy/forest areas that allow infiltration and slow down rainfall runoff would have a C value in the range of 0.35. An impervious area such as a concrete lot or roadway would have a C value as high as 0.95, signifying increased runoff. Areas of mixed land coverage would have a value reflecting the coverage of that specific area. For each drainage area, a weighted C value was calculated to reflect each drainage areas land coverage.

The Rainfall intensity (I) is typically found from Intensity/Duration/Frequency curves for rainfall events in the geographical region of interest. The duration is usually equivalent to the time of concentration of the drainage area. The rainfall intensity was calculated using USGS pub (reference). The 2-hour rainfall in inches was used in this analysis. The Rational method requires a value in inches per hour at the outfall location. To obtain the intensity in inches per hour at the outfall location, the time of concentration was calculated for each watershed. The total rainfall in

inches was divided by the time of concentration to obtain the intensity used in the runoff calculations.

Time of concentration is the time it takes for a point rainfall to travel to the outfall, and creates the maximum contribution of runoff from the drainage area. It is calculated by evaluating different travel paths to the outfall and calculating the time it would take for the entire drainage area to contribute to the discharge at the outfall.

As discussed previously, there is little to no data available to calibrate/verify/validate runoff estimates in many of these remote areas. Therefore, Rational method calculations were performed using a second method to calculate the intensity. The Intensity was based on IDF curves, time of concentration calculations, and runoff "C" Coefficients for the drainage areas. Using this independent method produced runoff results that showed good agreement (typically within 5-10 percent) with the previous flow estimates. This increased confidence that the previous estimates were fairly accurate and were adequate to be used later to size the structures associated with these areas. Table 2-13 tabulates the flows estimated for Orange County using the Rational method.

Table 2-13: Rational Method Calculated Discharges for the Sabine Region

Watershed ID	2-Year Discharge	5-Year Discharge	10-Year Discharge	25-Year Discharge	50-Year Discharge	100-Year Discharge
OC4	183	271	273	353	455	601
OC5	83	132	124	160	207	273
OC6	173	293	259	335	433	572
OC7	171	301	256	331	427	565
OC8	207	356	310	401	518	685
OC11	139	218	207	268	345	456
OC12	193	177	285	371	470	590
OC14	55	37	82	107	136	172
OC15	5	121	152	197	249	311
OC18	115	177	171	222	280	349
OC19	418	483	606	787	979	1,191
OC20	141	167	195	247	296	324
OC21	145	187	214	279	353	441
OC22	180	272	266	345	437	543
OC23	42	37	60	78	98	120
OC24	258	371	379	491	619	764
OC26	241	338	355	460	579	715
OC27	332	408	485	630	794	982
OC28	223	310	331	432	550	696
OC29	83	84	122	158	199	247
OC30	125	157	185	240	313	414
OC31	150	187	220	287	372	491

Watershed ID	2-Year Discharge	5-Year Discharge	10-Year Discharge	25-Year Discharge	50-Year Discharge	100-Year Discharge
OC34	83	84	122	158	199	247

2.15.9 Regression Method

Regression equations were used to calculate runoff for areas over 200 acres. Two Regression methods were used to limit uncertainty by comparing results of the two methods. Regression calculation methods can have large uncertainties and a by using two separate Regression methods it was attempted to limit uncertainty. The first Regression method is one used by the USGS.
The regression equation used for the USGS Regression analysis is:

$$Q_T = P^c S^d \times 10^{[e\Omega + a + bA^\lambda]}$$

Q_T = peak discharge of recurrence interval T years (cfs)
P = mean annual precipitation in inches, from Texas Parks and Wildlife Board maps of the mean annual precipitation
S = dimensionless main channel slope
Ω = Omega value (Dimensionless parameter for specific areas of Texas, taken from TXDOT Hydraulic Manual 2014)
A, b, c, d, e = regression coefficients specific for the recurrence interval

The omega value for each location is taken from 2004 USGS maps for interior areas.

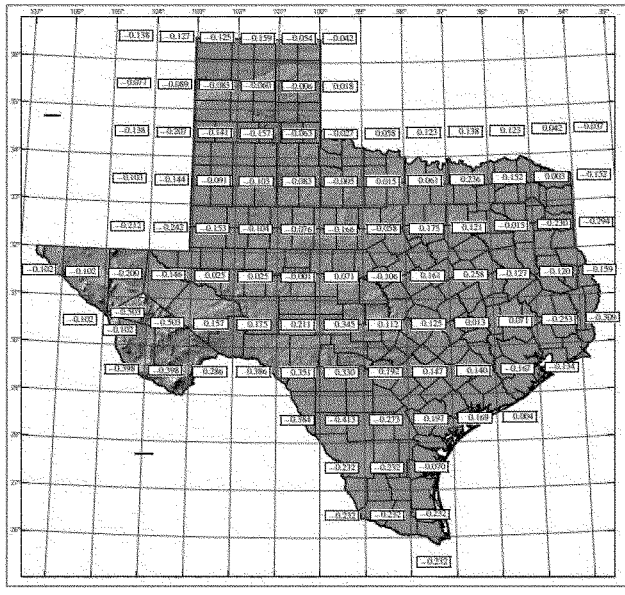


Figure 2-43: Mean Annual Precipitation Values 2014

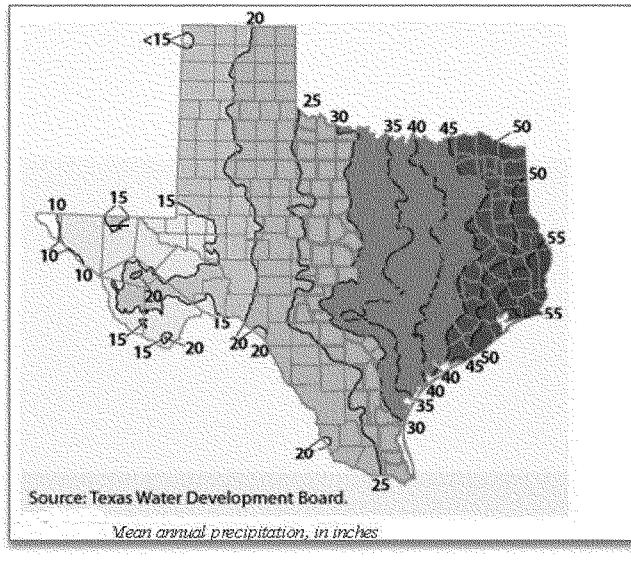


Figure 2-44: Omega Values Used for Regression Runoff Estimates

Table 2-14: Regression Method Calculated Discharges using FHWA Methodology

Watershed ID	2-Year Discharge	5-Year Discharge	10-Year Discharge	25-Year Discharge	50-Year Discharge	100-Year Discharge
OC9	155.22	217.76	255.99	305.65	341.28	867.88
OC10	762.72	1,730.88	2,137.10	2,707.97	3,146.49	6,324.27
OC13	78.40	85.56	96.26	108.85	117.27	327.84
OC16	159.37	225.73	265.91	318.40	356.22	905.22
OC17	1,386.83	3,644.42	4,512.84	5,739.67	6,691.90	12,341.25
OC25	124.06	161.05	187.83	222.59	247.48	666.45
OC32	102.23	123.45	141.79	164.67	180.60	492.39
OC34	138.00	184.85	213.98	249.81	274.56	681.74
OC 39	97.61	115.82	132.53	153.13	167.36	457.45
OC40a	206.39	317.71	376.90	454.29	510.18	1,221.36
OC40b	155.22	217.76	255.99	305.65	341.28	867.88
OC41	762.72	1,730.88	2,137.10	2,707.97	3,146.49	6,324.27

Table 2-15: Regional Regression Equations Used in Second mthod for This Feasibility Analysis

Regression Equations	RSE	Adj. R-squared	AIC statistic	PRESS statistic
$Q_2 = P^{1.398} S^{0.270} \times 10^{[0.776\Omega + 50.98 - 50.30A^{-0.0058}]}$	0.29	0.84	273	64.6
$Q_5 = P^{1.308} S^{0.372} \times 10^{[0.885\Omega + 16.62 - 15.32A^{-0.0215}]}$	0.26	0.88	122	49.1
$Q_{10} = P^{1.203} S^{0.403} \times 10^{[0.918\Omega + 13.62 - 11.97A^{-0.0289}]}$	0.25	0.89	86.5	46.6
$Q_{25} = P^{1.140} S^{0.446} \times 10^{[0.945\Omega + 11.79 - 9.819A^{-0.0374}]}$	0.26	0.89	140	49.5
$Q_{50} = P^{1.105} S^{0.476} \times 10^{[0.961\Omega + 11.17 - 8.997A^{-0.0424}]}$	0.28	0.87	220	55.6
$Q_{100} = P^{1.071} S^{0.507} \times 10^{[0.969\Omega + 10.82 - 8.448A^{-0.0467}]}$	0.30	0.86	320	64.8
$Q_{500} = P^{0.988} S^{0.569} \times 10^{[0.976\Omega + 10.40 - 7.605A^{-0.0554}]}$	0.37	0.81	591	98.7

Again, two different methods were used to check runoff estimates, as measured data are not available for calibration/verification/validation. Methodology for these estimates is based on equations and guidance outlined by the U.S. Department of Interior and U.S. Geological Survey (USGS) Water-Resources Investigations Report 96-4307.

The second Regression Equation used is a Federal Highway Administration (FHWA) developed equation, and has been commonly used in Texas by entities such as TxDOT for many years. This Regression approach is based on the equation: $Q_T = aA^bSH^cSL^d$

where:

A = Drainage Area (Mi2)

SH = Basin Shape Factor (SH) (Mi.2/Mi.2)

SL = Mean Channel Slope (SL) (Ft./Mi.)

A, b, c, d = Regional Regression Coefficients from the TXDOT 2004 Hydraulic Manual

Q_T = Discharge

Regional regression coefficients were taken from maps created by the USGS. Orange and Jefferson Counties are in Region 11, as seen in Figure 2-45. The Region 11 Regression Coefficients for 2-year, 5-year 10-year, 25-year, 50-year, and 100-year are listed in Table 2-16.

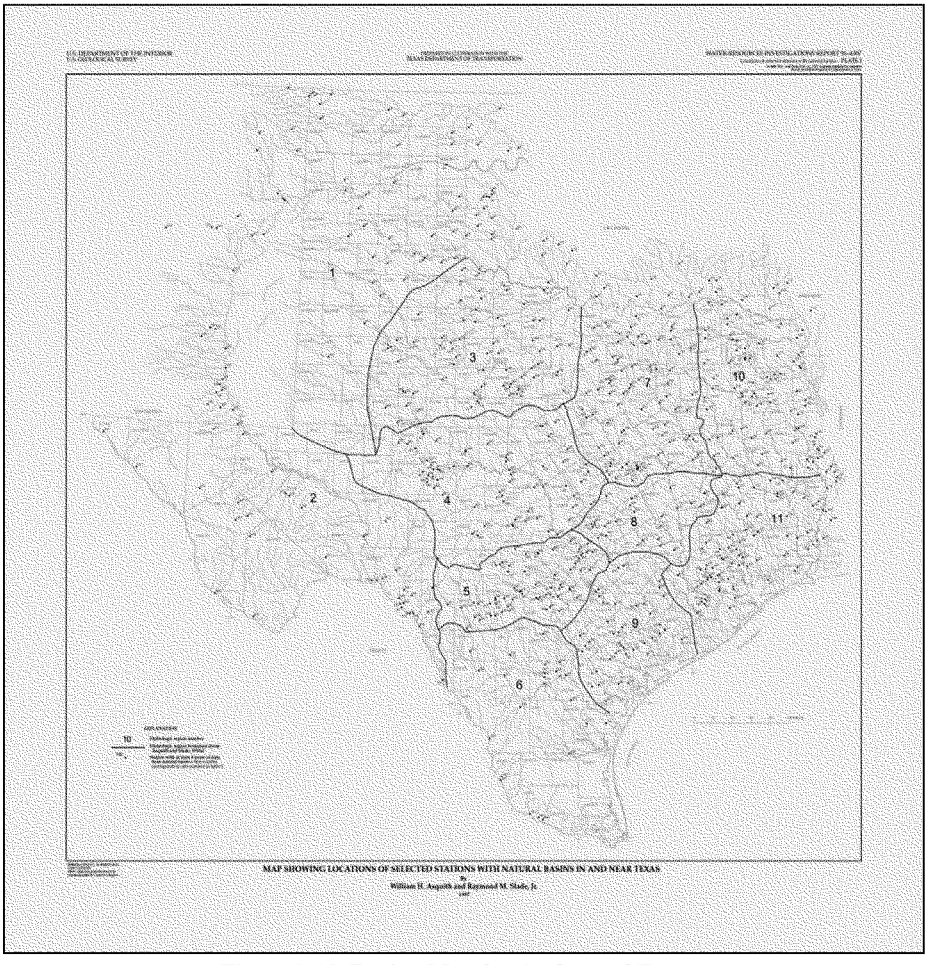


Figure 2-45: Region Map for the State of Texas

Table 2-16: Region 11 Regression Coefficients for Orange and Jefferson County

	a	b	c	d
2-Year	159	0.669	-0.262	0.000
5-Year	191	0.696	-0.186	0.130
10-Year	199	0.718	-0.151	0.221
25-Year	201	0.713	0.000	0.313
50-Year	207	0.735	0.000	0.380
100-Year	213	0.755	0.000	0.442

Results using the USGS/USDI Regression methods compared well with the Results calculated with the FHWA Regression method. The difference in flow estimates fit within the expected error of the previously used method, increasing confidence in the flow estimates. The Rational method can sometimes have considerable error and uncertainty, and being able to use two different Regression methods and obtain similar Discharge estimates provided verification that the results calculated using the Regression method were sufficient to use. These estimates were used to size structures for the new levee sections of the Sabine Region. Table 2-17 summarizes flows calculated by the Regression Methods.

Table 2-17: Regression Method Calculated Discharges using USGS/TxDOT Methodology

Watershed ID	2-Year Discharge	5-Year Discharge	10-Year Discharge	25-Year Discharge	50-Year Discharge	100-Year Discharge
OC9	192	295	359	464	526	591
OC10	1551	2401	2930	3812	4315	4840
OC13	91	134	160	191	216	242
OC16	166	218	236	292	298	304
OC17	5145	7749	9542	10377	12327	14448
OC25	151	231	284	341	396	456
OC32	97	156	194	267	306	347
OC34	166	250	296	407	444	481
OC 39	120	177	213	252	288	325
OC40a	298	446	532	682	759	838
OC40b	120	187	235	282	335	393
OC40	372	567	695	836	968	1109

The flow estimates were of the 2 Regression methods were compared and differences evaluated. Regression equations are known to have considerable uncertainty in them. The level of detail is not that of a HEC-HMS model or similar model. Therefore, for feasibility design the higher of the predicted flows from the Regression calculations were used in sizing structures. The flows used are in Table 2-18 below.

Table 2-18: Flows from Regression Calculations used for Sizing Structures

Watershed ID	2-Year Discharge	5-Year Discharge	10-Year Discharge	25-Year Discharge	50-Year Discharge	100-Year Discharge
OC9	174.62	267.81	326.30	421.83	477.89	867.88
OC10	1,410.08	2,182.77	2,663.89	3,465.37	3,923.01	6,324.27
OC13	83.11	121.80	145.40	173.20	196.01	327.84
OC16	159.37	225.73	265.91	318.40	356.22	905.22
OC17	4,677.27	7,044.49	8,674.10	9,433.61	11,206.08	13,134.90
OC25	137.60	209.66	257.74	310.15	360.17	666.45
OC32	102.23	141.44	176.69	243.02	278.20	492.39
OC34	150.67	227.01	269.37	370.31	403.42	681.74
OC 39	108.84	160.83	193.34	229.31	261.50	457.45
OC40a	271.32	405.50	483.75	620.18	689.64	1,221.36
OC40b	174.62	267.81	326.30	421.83	477.89	867.88
OC40	1,410.08	2,182.77	2,663.89	3,465.37	3,923.01	6,324.27

It is recommended a detailed model such as HEC-HMS be used to obtain more precise flows during PED.

2.15.10 Pumps

When the system is closed during a tropical event, pumps will be required to discharge internal floodwaters. Preliminary requirements for pump discharge were estimated to offset any interior flooding due to the lack of outfalls during system closure. Initially, 12 new pump stations were proposed for the Orange 3 levee reach. However, due to the high cost of construction and maintenance for these structures, a reduction in the pump discharge and number of pump stations was analyzed. The outline of a more detailed analysis and changes to the analysis are listed below:

1. The Joint Probability Analysis (JPA) described in Section 2.15.3 was used to estimate new discharge rates. In is well known that there is a time lag between peak water levels and peak discharge, as illustrated in Figure 2-40. Note the five-day time lag for the Neches basin, as shown by the differences in the peaks between the two curves in that figure. The required discharge (blue curve) at the time of peak water level (red curve) is about 30%

less than would be the case if the two peaks coincided. Therefore, required pump discharges were reduced by 30% for the Orange 3 area.

2. Another significant cost saving was introduced by combining pumps. Unit costs for small pumps are much higher than for large pumps. Significant cost savings were achieved by combining pumps, reducing the initial 12 pumps to 7.

3. Two assumptions were made in the original pump calculations that resulted in an over-conservative design. The pumps were designed for a 25-year storm, and an additional pump capacity of 10% was added as an arbitrary estimate of possible precipitation increase, due to climate change (Total CFS = 28,014). Since there were good data behind the storm-size calculations, it was decided to keep those calculations, but remove the arbitrary 10%. These pump calculations and estimates of climate-change impacts will be revisited in the PED phase.

When the JPA and scrutiny of the preliminary discharge rates were completed, the total discharge for the Orange 3 area was 13,200 CFS. Locations of pumps are shown on drainage area map plates (Attachments: D-1 to D-10). Many will require detention basins, routing features, and acquisition of land. These areas have been preliminarily identified, and there is adequate space to construct these pump features.

The proposed new levee section includes an existing operating pump. This pump discharges Coopers Gully into the Sabine River, draining the majority of the City of Orange south of Interstate 10. The Orange County pump has sufficient capacity to drain the watershed currently connected to it, and should only require minor modifications (1994, City of Orange Report). No increase in flows to the Orange pump will be created by the proposed project, since the drainage area and runoff will not be altered. The pump is in need of maintenance and some part replacements, which is being addressed by the City of Orange. Some additional pump capacity (5-10 percent) may be needed for expected increases in precipitation (for climate change as discussed in Section 2.4 of this appendix).

2.15.11 Gate Structures

The proposed levee system would include two major gates structures with necessary appurtenances. The gates structures would be on Cow Bayou and Adams Bayou, which are both used for small ship navigation. The channel dimensions are 100 feet by 14 feet MLLW for Cow Bayou and 100 feet by 13 feet MLLW for Adams Bayou.

Preliminary gate configurations were determined and modeled in simple HEC-RAS models to determine and minimize impacts on the upstream floodplains. These models should be refined and checked in detail upon and follow the guidance from HEC in the latest HEC-RAS manual. Regression equations were used to estimate flows. It is recommended that HEC-HMS models be constructed during PED. This was not possible during the feasibility phase due to the large and complex watersheds discharging into the Bayous

The Cow Bayou closure gate system would include a sector gate in the main channel and vertical lift gates on either side for rainfall runoff to pass through. The Adams Bayou gate structure would include a sector gate in the main channel and a vertical lift gate on the west sides of the channel. On the east side of the proposed Adams Bayou gate location, are two old placement areas that will be used as part of the levee system. Therefore, no vertical lift gate or other relief structure is proposed on the east side of the Adams Bayou gate. Both gates will require substantial pump stations to discharge interior runoff during a system closure. As mentioned previously, Orange County is currently working on modeling effort of the existing Bayou and it is recommended that USACE work with the county on the modeling efforts of the with-project models in PED. It is conceivable that Orange will have completed their HEC-HMS and HEC-RAS models of the Bayous by the time USACE enters the PED phase. If so, the models from Orange County should be utilized and modified as needed to meet USACE regulations and standards.

2.16 LEVEE INTERIOR FLOODPLAIN IMPACT ANALYSIS

The methods used in the preliminary design of the levee outfalls and adjacent waterbodies was to minimize impacts on all existing floodplains. Outfalls for interior drainage were sized to pass the 100-year storm plus at least a 10 percent increase in flow accounting for predicted climate change. The culvert outfalls were aligned and sized in a manner that mimics the existing waterways. Culvert spans and heights were chosen to provide widths that would prevent head build-up on the upstream side of the culverts, which could cause adverse impacts. This is because of the flat topography in the project area. The Cow and Adams Bayou gate structures were configured to allow a 100-year flood event to be discharged without impacting their respective floodplains.

For most of the waterways, only basic hydrologic and hydraulic methods were used for calculating runoff and sizing culverts and pumps. Use of HEC-HMS and HEC-RAS (or similar acceptable H&H models) is recommended to model the final outfalls in PED. Additionally more detailed analysis of pumps should occur during PED. The minimum goal should be to have negligible impacts on the 100-year floodplain (0 foot increase) for waterways inside the Orange levee system.

Quantitative impacts for Neches River floodplain and a Qualitative assessment for Sabine River indicate minimal or insignificant impacts. The vast majority of the existing and proposed levee

system is outside the banks of the rivers and is not in the 100-year floodplains. The Neches River passes between levee systems, and the Sabine River passes along the east side of levee. Levees were kept out of the floodplains of the rivers as much as possible to minimize impacts. The intention was to not disturb the natural courses of the Rivers.

The alignment, outfall location/type/size, and materials were selected to minimize impacts in tidal areas, some of which are quite sensitive, particularly along the south portion of the Orange levee and adjacent Bessie Heights. No proposed levees infringe on Bessie Heights. This is further discussed in the H&H section, which focuses on environmental considerations.

2.17 SEDIMENTATION AND SEDIMENT TRANSPORT

Freeport

Inland sediment transport and deposition:

The drainage features (including the waterways, culverts, and pumps) will remain unchanged from their current configuration, and sedimentation is expected to remain unchanged. The one place where sediment transport, deposition, or scour may change is at the proposed gate on the DOW Barge Canal.

DOW Barge Canal: During normal operations (no surge event) the gate will be left open. The cross section here will decrease, likely leading to increased velocities in the vicinity of the gate. This will likely change the sediment transport at this location, so some increase can be expected. Once though the gate, the sedimentation will then return to normal conditions. Some scour upstream of the gate and deposition downstream of the gate is likely. The exact pattern of deposition and transport near the gate can be addressed in and further studied, including such detailed modeling in PED. The sediment transport (rate) near the gate and the amount of sediment (quantity) carried should be modeled in PED. This additional modeling in PED will also provide the design with scour/deposition amounts and locations.

During a surge event the gate will be closed, and sediment will build up behind the gate. The amount is not expected to be great, due to the configuration and characteristics of the canal. It is a dead-end canal with some interior drainage inflows. There is likely to be some change (increase) in the sediment transported to the gate. As the surge event passes, any sediment built up behind the gate will be released slowly, since the gate will be opened slowly. Fine-grain sized sediment (silt and clay) will be carried out into the adjacent waterway, while it is likely the larger grain sizes (sand) will deposit rather quickly downstream and possibly cause some minor dredging to maintain adequate depth.

Since the changes in sediment transport will be minor for the Freeport system, it is not expected that the changes will be an issue, but some additional O&M will be needed here. The exact details of the changes in sediment transport due to the DOW gate should be modeled during PED, providing an estimate of what changes will occur. It is recommended that the sediment transport be monitored through survey and sampling, in order to have a complete understanding of the sediment transport and its resulting scour and deposition. Topographical changes are expected to be minor, as the sediment transport change is expected be minor, but may lead to some additional O&M costs.

Coastal sediment transport:
Since the levee alignment and configuration are to remain the same in the with-project conditions, no change in longshore sediment transport or cross-shore sediment transport are to be expected. This should be checked and verified during PED.

Port Arthur

Inland sediment transport and deposition:
Port Arthur's interior drainage features (including waterways, culverts, and pumps) will remain unchanged from their current configuration, transport and sedimentation are not expected to alter.

Coastal sediment transport:
The Port Arthur levee alignment and configuration will remain the same as in the with-project condition. Effects on sediment transport outside the levee are expected to be minimal or negligible. Only slight changes due to the new proposed Orange 3 system may occur. Due to the location and lack of directional variation of the levee, no changes in coastal sediment are expected to occur. This can be verified by hydrodynamic modeling during PED.

Orange 3

Inland sediment transport and deposition:
Waterways leading up to outfalls are not being modified and will remain in their natural state, until they are near the levee. Sediment transport in the waterways inside the levee should remain the same.

During normal operations (no surge event):
Culvert outfalls have been oversized and configured to minimize impacts on sediment transport. Culverts have been oversized, not only to minimize impacts on sediment transport, but for other reasons as well. Some examples are: the culverts have low flowlines for environmental reasons, in order to maintain environmental connectivity (species passage) between inside and outside the

levee. Additionally, the culverts have been oversized and configured to allow 100-year-plus flood events to pass without impacting the water-surface elevations. The preliminary culvert configuration expands to cover the flood plain (and more) in an attempt to mimic and avid any impacts to the current floodplain. Culverts were oversized to be adaptable to accommodate currently predicted increased rainfall in southeast Texas. (This will be gradual, and the additional culvert cross-sectional area won't truly be needed until 2080) and/or for adaptation to RSLC. The Culvert crossing flowlines were kept at low heights and large span to match existing floodplain widths (plus some extra width). There will be some sediment transport changes at culvert outfalls that will require some O&M, which is typical of culvert crossings. (They will need some O&M, debris removal, possible cut/fill on one side or the other, and basic repairs like riprap replacement.)

An exception is the Sabine River. During large events, the same amount of sediment will be coming down the Sabine River as it currently does (not accounting for changes in the Sabine River such as widening, or its operation). The levee, configured to block surge from inundating Orange County south of Interstate-10 during large rainfall events, will have some impact on sediment transport. Currently there is an underpass of I=10 just west of the Sabine River where flow passes through during large rainfall events, the proposed levee includes a closure structure for this underpass, preventing flanking of the levee be large events on the Sabine River. The River will no longer be able to take sediment from behind the levee and transport it, but will be blocked. The levee will deflect more of the flow to the south and east, an adjacent to the levee (adjacent impacts discussed in section xx and mapped in the drawings later in the Engineering Appendix). The change in adjacent WSLs is minimal, for the most part negligible, WSLs changing /3 feet or less. It is likely the River will deposit an additional minimal amount of sediment in the Louisiana Parishes to the east/southeast of the levee. Modeling of the Sabine River is recommended during PED to determine the amount of sediment the River would transport and deposit in this area for both with-project and without-project conditions. No hydrologic or hydraulic model of the Sabine River exists at the time of this report. Creating hydrologic and hydraulic models of the Sabine Rivers is recommended during PED (if it has not been done by that time)

The Neches River will be largely untouched by this project, the only change being that some of the Neches River floodplain would be diverted by the Orange 3 levee during large events. The sediment transport in the Neches will remain effectively the same. The adjacent impacts caused by the Orange 3 levee will have a very small impact on the River's flow, stage, velocity and other factors based on a preliminary HEC-RAS analysis. The analysis should be refined and evaluated in PED, as there may be changes not related to this project to the Neches River before the Orange 3 levee construction has begun.

Cow and Adams Bayous will be left in their natural state up to the approaches to the gated structures needed on them. At the gates sediment transport will change some as the cross sections change, as the velocities in the vicinity of the gates change. This will likely change sediment transport at these locations. After passing the gates, deposition will occur, compared to the without-project conditions. Scour should be expected near the inflow side of the gates. The hydraulic details should be modeled as part of (or in conjunction) with detailed hydrologic/hydraulic modeling of all the interior waterways during PED, as recommended in the interior-drainage section of this Appendix. Modeling during PED should include the exact dimensions and operation procedures of the gates which is currently not available, but will become available during PED.

Pumps will be in place during normal operations, but the plan is to use them only during surge events. They should have no effect on sediment transport during normal operations.

During a surge event:
During a surge event, all the culverts will be shut, as well as the gates, and the pumps will be put to use. This will have some impacts on sediment transport. Pumps have been strategically placed around the levee to pump out rainfall runoff during a surge event. All major water bodies lead directly to pump stations. Some smaller water bodies will be diverted to these pumps stations using ditches, pipes, or other means. Currently the diversions are preliminary and may have their routes or materials changed during PED, upon further detailed analysis. For now the pump system is set up to ensure more than adequate pumping capacity and will be revisited in detail in PED.

Coastal sediment transport: The levee will have some effects on sediment transport and deposition outside of the levee.

2.18 ENVIRONMENTAL IMPACTS OF PROPOSED DRAINAGE SYSTEM

Modifications to the existing systems and the construction of new levee systems have the potential to cause adverse environmental impacts. This section details studies done to assess possible impacts and discussions and decisions made to minimize impacts of drainage structures on environmental aspects of the levee systems.

New drainage components were evaluated for possible impacts on the existing environment in Orange and Jefferson Counties, and to the extent possible efforts were made to minimize any adverse impacts. ERDC-CHL conducted a study to determine possible impacts due to the closure gate structures that would be needed on Cow and Adams Bayou gate as part of the levee. Outfalls consisting of box culverts and concrete pipe culverts were sized and placed in a manner minimizing

impacts on the environment. Overall, a least impact configuration was established through coordination and meetings with the EPA, NMS, USFW, TXDOT, TWDB, and TPWD.

The details discussed herein support the environmental assessment of the project as established during the study feasibility phase. The exact configuration and additional details regarding the proposed drainage structures design shall be refined as needed in PED. Continuous coordination with all involved environmental agencies shall occur through PED and construction. It is worth noting that the initial levee footprint shown to the environmental agencies has significantly decreased and so have the environmental impacts.

2.18.1 Gate Structures on Cow and Adams Bayous

ERDC-CHL conducted a study to qualitatively and quantitatively assess possible environmental impacts of the proposed sector gates on Cow and Adams Bayous (Gunkel and Brown, March 2015). The implementation of the gate structures on the bayous has the potential to constrict the inlets to both bayous (near the bayous confluence with the Sabine River). The constriction on the bayou inlets created by the proposed gates could impact velocities, salinity, and cause storm water impoundment. ERDC-CHL utilized a Desktop Off-Channel Wetland Salinity Mitigation Model (DOWSMM) to perform an analysis to quantitatively assess the impacts of the proposed gates. DOWSMM is a mass and energy balance model that assumes each bayou can be represented as a single control volume. This model was used in lieu of more sophisticated numerical models for several reasons. These include:

- The paucity of available data for the Bayous (especially velocity and discharge data) makes calibration and validation of a numerical model impossible without a significant data collection effort.
- The Bayous being evaluated fit the description of systems for which DOWSMM is designed (i.e. small, single inlet tidal systems with a single inflow and rainfall/evaporation).
- The DOWSMM analysis, in the absence of sufficient field data for calibration, is designed as a screening analysis only: i.e., bracketing potential impacts. The intent is to use the results of this analysis to determine whether or not a more significant investment in more detailed numerical modeling is necessary.

Figure 2-46 shows the Cow and Adams Bayous areas of interest. The blue lines indicate major and minor streams and the yellow line indicates the proposed structure alignment.

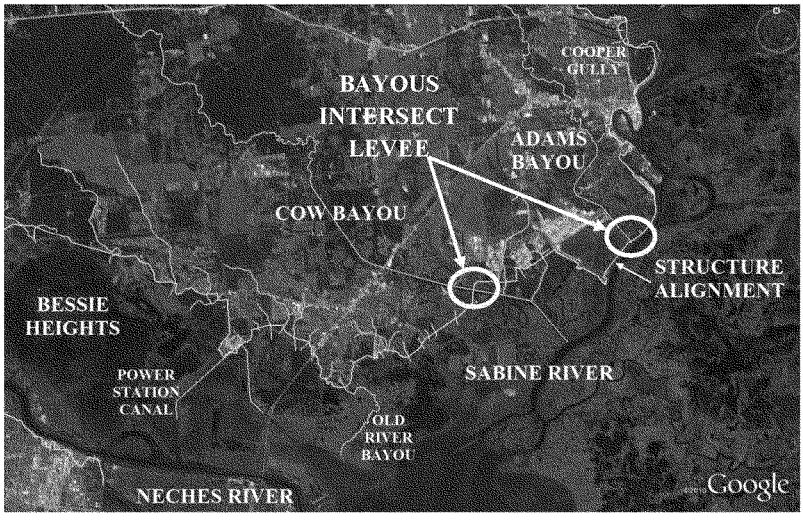


Figure 2-46: Cow and Adams Bayou Intersection with Gate Structures

DOWSMM requires time-varying boundary conditions. These include tide and salinity at the inlet, rainfall/evaporation over the wetland (or bayou) and freshwater inflow into the wetland (or bayou). For this study, these data were taken from a TABS-MDS model study performed in support of a larger feasibility study associated with proposed channel deepening in the Sabine Neches Estuary (Brown, et. al. 2006).

For this DOWSMM exercise, data associated with an observation point in close proximity to the intersection of the Sabine River and Adams and Cow Bayous were chosen for the tide and salinity boundary condition data. The data point is identified as Gage 9 (the location of Gage 9 is depicted in Figure 2-47). This gage was used to obtain low and median flow tide and salinity boundary conditions. Applied net rainfall data (rainfall minus evaporation) for low and median flow simulations were used to calculate discharge. This discharge was calculated by multiplying net rainfall rate by the surface area of the drainage area of each bayou.

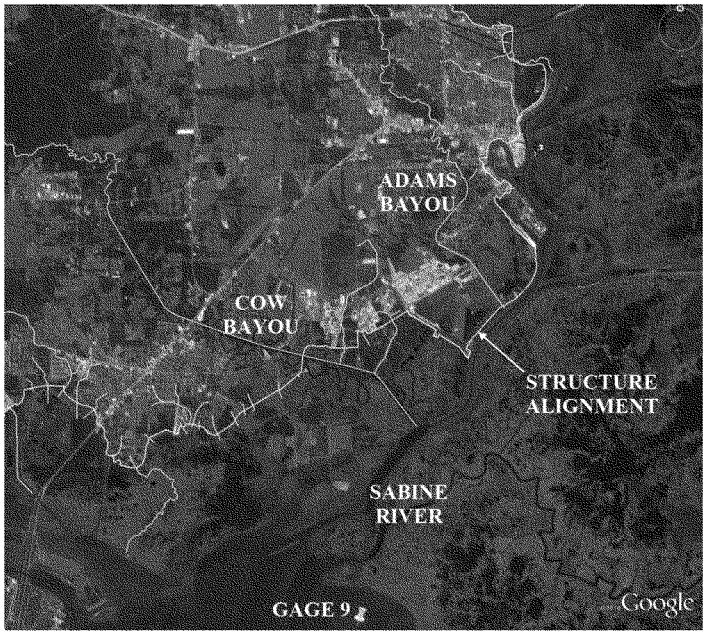


Figure 2-47: Gage 9 Location

2.18.2 Cow Bayou Analysis

The intersection of Cow Bayou and the proposed structure is approximately 2.5 miles north of the mouth where Cow Bayou meets Sabine River. Figure 2-46 shows the location of the proposed gated structure on Cow Bayou. A series of varying inlet widths were tested, including 120 feet, 110 feet, 100 feet, 80 feet, and 50 feet widths. Table 2-19 contains all base parameters used for the Cow Bayou model runs.

Table 2-19: Cow Bayou DOWSMM Model Parameters

Parameter	Base
Wetland surface area (ft^2)	21000000
Wetland width (ft)	100
Wetted surface area factor (0=wet,1=dry)	0.75
Roughness height for the wetland	0.1
Width of the inlet (ft)	100
Elevation of the bed in the inlet (ft)	-11

Elevation of the top of the sill in the inlet (ft)	-11
Elevation of the bed in the wetland (ft)	-2.0
Gravitation constant (ft/s^2)	32.2

Low flow conditions inlet widths of 120 feet, 110 feet, 100 feet, 80 feet, and 50 feet were tested and results for 120 feet and 50 feet are provided here. Table 2-20 and Table 2-21 show resulting statistics from the low flow runs. The minimum and maximum columns are the minimum and maximum values, respectively, of the respective parameters. The remaining 90, 50, and 10 percent columns represent percent exceedance values; meaning that 90 percent of the values for that parameter exceed the value.

Table 2-20: Cow Bayou Base Parameters: Low Flow, 120-foot Inlet Width

Parameter	Minimum	90 % exceedance	50 % exceedance	10 % exceedance	Maximum
Inlet Water Surface Elevation	-0.310	0.420	1.180	1.730	2.760
Inlet Salinity	5.040	8.050	16.420	20.170	22.260
Wetland Freshwater Inflow	0.000	0.000	0.000	134.758	1395.312
Inlet Discharge Magnitude	0.000	91.904	465.462	919.008	1552.101
Inlet Velocity Magnitude	0.000	0.062	0.321	0.632	1.150
Wetland Water Surface Elevation	-0.288	0.420	1.171	1.735	2.760
Wetland Salinity	0.479	5.232	13.915	19.207	20.565

Table 2-21: Cow Bayou Base Parameters: Low Flow, 50-foot Inlet Width

Parameter	Minimum	90 % exceedance	50 % exceedance	10 % exceedance	Maximum
Inlet Water Surface Elevation	-0.310	0.420	1.180	1.730	2.760
Inlet Salinity	5.040	8.050	16.420	20.170	22.260
Wetland Freshwater Inflow	0.000	0.000	0.000	134.758	1395.312
Inlet Discharge Magnitude	0.000	93.268	466.529	914.058	1547.946
Inlet Velocity Magnitude	0.000	0.152	0.775	1.507	2.759
Wetland Water Surface Elevation	-0.286	0.420	1.172	1.735	2.760
Wetland Salinity	0.486	5.221	13.910	19.207	20.562

Under low-flow conditions, the velocity at the inlet increases roughly in proportion to the degree of contraction of the inlet. This is because the energy loss across the inlet is negligible, and hence the discharge though the inlet is nearly the same for the 120 feet and 50 feet inlet width conditions. No significant impacts were seen for the salinity or water surface elevations. When comparing the results from the maximum inlet width tested of 120 feet to the minimum inlet width tested of 50 feet, the only differences seen in the water surface elevation or salinity are on the order of 0.001, and the differences in salinity are on the order of 0.05 ppt.

For median flow the same inlet widths were tested, and results for 120 feet and 50 feet are provided here. Table 2-22 and Table 2-23 show resulting statistics from the median flow runs with the different inlet widths.

Table 2-22: Cow Bayou Base Parameters: Median Flow, 120-foot Inlet Width

Parameter	Minimum	90 % exceedance	50 % exceedance	10 % exceedance	Maximum
Inlet Water Surface Elevation	-0.930	0.530	1.320	1.960	3.050
Inlet Salinity	-0.130	0.160	2.370	11.360	17.010
Wetland Freshwater Inflow	0.000	0.000	0.000	195.938	5425.234
Inlet Discharge Magnitude	0.000	93.419	461.537	934.180	5759.486
Inlet Velocity Magnitude	0.000	0.063	0.314	0.637	3.837
Wetland Water Surface Elevation	-0.868	0.520	1.319	1.964	3.178
Wetland Salinity (ppt)	0.000	0.235	1.297	10.140	14.153

Table 2-23: Cow Bayou Base Parameters: Median Flow, 50-foot Inlet Wwidth

Parameter	Minimum	90 % exceedance	50 % exceedance	10 % exceedance	Maximum
Inlet Water Surface Elevation	-0.930	0.530	1.320	1.960	3.050
Inlet Salinity	-0.130	0.160	2.370	11.360	17.010
Wetland Freshwater Inflow	0.000	0.000	0.000	195.938	5425.234
Inlet Discharge Magnitude	0.000	95.524	459.812	926.542	5757.070
Inlet Velocity Magnitude	0.000	0.152	0.755	1.518	9.204
Wetland Water Surface Elevation	-0.866	0.522	1.318	1.966	3.298
Wetland Salinity (ppt)	0.000	0.235	1.295	10.144	14.144

According to these results, for a large rainfall event (the event tested is the observed rainfall associated with Tropical Storm Allison) only about a 0.10-foot impact was seen on the water surface elevation. Inlet constricts the outflow such that there is some increase in both the magnitude and duration of the stormwater flooding in the marsh. To mitigate this effect, any significant constriction of the inlet will include design elements (such as flap gates, vertical lift gates, equalizer culverts, or gated culverts) to allow stormwater release from behind the structure and allow outflow of water avoiding adverse impacts upstream of the gate structure.

2.18.3 Adams Bayou Analysis

The proposed structure on Adams Bayou is very near the inlet to the Sabine River. The same set of flows and salinity data collected from Gage 9 that were used for Cow Bayou were also used for Adams Bayou. Figure 2-46 shows the location of the structure alignment in relation to Adams Bayou and the Sabine River.

Base parameters for Adams Bayou were chosen from the HEC-RAS model provided by Carroll & Blackman, Inc. (CBI) for the width of the inlet, depth, and length of the section. These parameters were modified to some extent by information from Google Earth (2015). Figure 10 shows the wetland surface area that was approximated by using Google Earth (2015); the remaining parameters were estimated. A series of varying inlet widths were tested, the results from the maximum width of 350 feet and minimum width of 100 feet are shown here. Table 2-24 contains all base parameters used in the runs.

Table 2-24: Adams Bayou DOWSMM Model Parameters

Parameter	BASE
Wetland surface area (ft^2)	50000000
Wetland width (ft)	350
Wetted surface area factor (0=wet,1=dry)	0.75
Roughness height for the wetland	1.0
Width of the inlet (ft)	350
Elevation of the bed in the inlet (ft)	-5
Elevation of the top of the sill in the inlet (ft)	-5
Elevation of the bed in the wetland (ft)	-2.0
Gravitation constant (ft/s^2)	32.2

Low flow conditions modeling was performed as described previously in 6.2.2. Table 2-25 and Table 2-26 contain the statistical results from the low flow runs for Adams Bayou.

Table 2-25: Adams Bayou Base Parameters: Low flow, 350-foot Inlet Width

Parameter	Minimum	90 % exceedance	50 % exceedance	10 % exceedance	Maximum
Inlet Water Surface Elevation (ft)	-0.310	0.420	1.180	1.730	2.760
Inlet Salinity (ppt)	5.040	8.050	16.420	20.170	22.260
Wetland Freshwater Inflow (cfs)	0.000	0.000	0.000	45.158	467.578
Inlet Discharge Magnitude (cfs)	0.000	235.329	1075.041	1910.239	2871.270
Inlet Velocity Magnitude (ft/sec)	0.000	0.111	0.509	0.896	1.239
Wetland Water Surface Elevation (ft)	-0.204	0.417	1.154	1.723	2.759
Wetland Salinity (ppt)	5.080	7.139	15.270	19.415	20.553

Table 2-26: Adams Bayou Base Parameters: Low Flow, 100-foot Inlet Width

Parameter	Minimum	90 % exceedance	50 % exceedance	10 % exceedance	Maximum
Inlet Water Surface Elevation (ft)	-0.310	0.420	1.180	1.730	2.760
Inlet Salinity (ppt)	5.040	8.050	16.420	20.170	22.260
Wetland Freshwater Inflow (cfs)	0.000	0.000	0.000	45.158	467.578
Inlet Discharge Magnitude (cfs)	0.000	261.733	1069.031	1771.663	2580.447
Inlet Velocity Magnitude (ft/sec)	0.000	0.407	1.754	2.944	3.857
Wetland Water Surface Elevation (ft)	-0.167	0.439	1.150	1.713	2.754
Wetland Salinity (ppt)	5.080	7.150	15.128	19.433	20.501

As with Cow Bayou, the velocity at the inlet increases roughly in proportion to the degree of contraction of the inlet. This is because the energy loss across the inlet is minimal, and hence the discharge though the inlet is nearly the same for the 350 ft and 100 ft inlet width conditions. Similar to Cow Bayou, no significant impacts are seen in the water surface elevation or salinity.

Median flow conditions were also modeled as described previously. Table 2-27 and Table 2-28 contain the statistical results for the median flow runs for Adams Bayou.

Table 2-27: Adams Bayou Base Parameters: Median Flow, 350-foot Inlet Width

Parameter	Minimum	90 % exceedance	50 % exceedance	10 % exceedance	Maximum
Inlet Water Surface Elevation (ft)	-0.930	0.530	1.320	1.960	3.050
Inlet Salinity (ppt)	-0.130	0.160	2.370	11.360	17.010
Wetland Freshwater Inflow (cfs)	0.000	0.000	0.000	56.109	1553.590
Inlet Discharge Magnitude (cfs)	0.000	248.127	1064.117	1929.731	3507.700
Inlet Velocity Magnitude (ft/sec)	0.000	0.113	0.491	0.888	1.489
Wetland Water Surface Elevation (ft)	-0.751	0.532	1.305	1.952	3.058
Wetland Salinity (ppt)	0.067	0.337	1.767	10.387	14.075

Table 2-28: Adams Bayou Base Parameters: Median flow, 100-foot Inlet Width

Parameter	Minimum	90 % exceedance	50 % exceedance	10 % exceedance	Maximum
Inlet Water Surface Elevation (ft)	-0.930	0.530	1.320	1.960	3.050
Inlet Salinity (ppt)	-0.130	0.160	2.370	11.360	17.010
Wetland Freshwater Inflow (cfs)	0.000	0.000	0.000	56.109	1553.590
Inlet Discharge Magnitude (cfs)	0.000	265.851	1050.655	1813.801	3329.004
Inlet Velocity Magnitude (ft/sec)	0.000	0.412	1.693	2.900	5.021
Wetland Water Surface Elevation (ft)	-0.729	0.549	1.298	1.946	3.072
Wetland Salinity (ppt)	0.071	0.348	1.744	10.353	13.972

As with Cow Bayou, an increase in the water surface elevation associated with the storm event is observed. The effect of the constriction is qualitatively similar to that observed at Cow Bayou, but is less in magnitude. This is because Adams Bayou has more wetland surface area, and hence the impounded stormwater can spread over a larger area (the same storage volume requires less depth). The structure will designed with relief structures including vertical lift gate structures to allow additional flow to pass and mitigate any impacts on the upstream floodplain.

2.18.4 Neches River Gate

A closure gate on the Neches River near Sabine Lake was considered as an alternative during the screening process. The gate was eliminated from inclusion in the proposed plan based on benefit/cost considerations. Therefore, no detailed modeling was done to assess environmental impacts a gate on the Neches River would have. If the gate is later determined to be a Locally Preferred Alternative, an analysis of environmental impacts will need to be performed.

2.18.5 Discussion and Conclusions of Cow and Adams Proposed Gate Structures

The DOW-SMM modeling discussed above determened minimal potential impacts would be created by increased velocities in the inlets on larval transport into the bayous. This can be inferred from higher order model work that was performed at ERDC to investigate similar impacts for the Keith Lake Fish Pass Baffle (Brown and Lackey, 2011). In this work, it was demonstrated that the larval transport is not impeded by increases in velocity due to a constriction, but is impeded by the formation of large eddies associated with flow around blunt obstructions. Therefore, if the constrictions are designed with smooth transitions from wide to narrow, it is unlikely that the increased velocities alone will be a significant hindrance to larval recruitment.

Impacts imparted to the regular, tidal variation of water surface elevation and salinity within Adams and Cow Bayous from the proposed inlet constrictions were found to be negligible. This negligibility was determined by the sensitivity analysis conducted on the inlet size for each bayou. It was determined that the limited tidal prism associated with the bayous results in minimal energy loss across the connection between the bayous and the Sabine River; hence, constriction of this access point results in little change in the tidal energy passing into the bayou.

The median flow simulation contains a significant rainfall event (Tropical Storm Allison), so the extent to which these constrictions tend to impound stormwater within the bayous has also examined. For both Cow Bayou and Adams Bayou, the inlet constriction causes some increase in both the magnitude and duration of the stormwater flooding in the marsh. This flooding will be mitigated by inclusion of design elements (flap gates, vertical lift gates, or gated culverts) that allow stormwater release from behind the structure. More detailed study of impoundment and the design element to mitigate any impoundment should be performed in PED.

Additional sensitivity analyses were conducted to investigate the impact of changes on each of the estimated parameters that define the bayous. The values were independently perturbed by 25-50 percent, and the results compared to the results given in this report for the "base" parameters. In no case were significant impacts observed.

Hence, in spite of the paucity of data available to properly define and calibrate/validate these desktop models of Adams and Cow Bayous, the insensitivity of the tidally varying water surface elevation and the salinity impacts on a wide range of estimated parameters give high confidence that the general conclusions of the ERDC study are robust. They are as follows:

- For general tidal conditions, the limited tidal prism associated with each of these bayous results in little energy loss across the inlet and hence, constriction of the inlet, even significant constriction, results in minimal impacts on water surface elevation and salinity within the bayous.
- For large freshwater inflow events, a significant constriction at Cow and Adams Bayous could result in additional impoundment of stormwater behind the structure. To mitigate for this additional stormwater drainage features will be utilized in the design.

2.18.6 Culverts and additional Interior Drainage Structures

Additional structures were preliminarily assessed to allow rainfall runoff from the interior of the proposed levee system to discharge rainfall runoff from the interior of the levees. Culverts and pump structures were placed along the proposed levee alignments and preliminary design parameters for these structures were determined. Existing outfalls and pumps were identified and data gathered on them where available. It is recommended more data be gathered in the field during PED. Locations and sizes of proposed culverts and pumps are discussed in Section 5 of this appendix. In this section additional focus on the environmental aspects of the proposed drainage system is evaluated. The interior drainage structures are to be strategically placed to:

- Maintain existing drainage and minimize or eliminate any adverse impacts on floodplains
- Provide interior drainage via pump systems to evacuate floodwaters during a tropical event that would be associated with a system closure
- Maintain connectivity of environmental areas such as marshes and wetlands
- Minimize constriction of waterways by drainage structures and maintain cross sectional areas as best practicable
- Minimize environmental impact by utilizing and configuring the proposed drainage structures in a manner that aims to mimic existing without-project conditions

This section discusses how possible environmental impacts associated with the proposed interior drainage systems were considered and how possible impacts were addressed using BMPs and principles.

To provide interior drainage of the proposed levee system, minimize impacts on areas that are tidally influenced, and maintain connectivity between environmentally linked areas, a preliminary plan was developed for the culverts and pumps that would be necessitated by the construction of the proposed levee. Bayous, creeks, gullys, and all waterways that cross the levee systems were identified. All watersheds that the levee systems intersect or impact were identified. Detailed drainage area maps are included in the Exhibits section of this appendix. These maps include locations of all proposed outfall and pump stations. Drainage areas were delineated using a combination of LiDAR, USGS maps, aerial maps, historical photos, survey data, construction plans and specifications, agency input from meetings and discussions with TPWD/USFWS/NMFS/USEPA/TXDOT/TWDB, and historical reports and documents.

Culvert locations were identified using all the information obtained from data gathering, state and agency input, and the interior drainage analysis performed (Section 5 of the H&H section of engineering appendix). Several distinct types of culverts were distinguished with regards to their required functionality draining the interior of the levee system, surrounding environments, upstream watershed characteristics, and characteristics of the land downstream of the outfall. The culverts were broken into four subgroups.

1. Culverts at high elevation, typically surrounded by dry land that would have minimal if any environmental impact.
2. Culverts that serve as drainage outfalls in lowlands and/or environmentally sensitive areas.
3. Culverts that are tidally influenced in low-lying coastal areas, including those that would need to allow tidal flow to pass through.
4. Culverts that serve as equalizer culverts were identified in discussions with state and agency representatives and by reviewing aerial maps. These culverts are not required to drain the interior. The purpose of these culverts is to maintain connectivity between environmentally sensitive area such as marshlands or wetlands, and would rarely, if ever, serve as a pathway for interior drainage.

Culverts have been strategically placed and sized to best mimic the natural waterways and environment as much as practicable. All culverts placed for interior drainage are of a multiple structure configuration (i.e., have numerous openings) with widths and locations intended to mimic the natural waterways. This includes utilizing culverts with more width than height in an attempt to maintain cross sectional areas and natural channel cross sections. This approach serves multiple purposes, including minimizing impacts on culverts located in tidal passes. Additionally, having larger span culverts will reduce the backwater (upstream head) that would occur during storm runoff events. The study area is in general very flat and high water surface elevation on the interior of the culvert is undesirable, as it could produce adverse impacts on the upstream floodplain.

Culverts will include will include shoreline baffles and/or ramps (e.g., rock rubble, riprap, articulated concrete mats) that slope to the structure invert to enhance organism passage where appropriate. Various ramp designs will be considered depending on site specific conditions. Culverts have been sized and preliminarily designed to produce velocities of 3 ft/s for a 2-year storm event to prevent siltation and prevent debris build-up, as is standard practice. Culverts will use sluice gates and flap gates to close openings during storm events. At all other times, the culverts should remain fully opened, with the exception of short duration closures for maintenance and inspections. The specific details and design of these riparian access features and culvert flow-lines will be refined during PED.

Drainage pathways, including sheet flow, over flow, and shallow concentrated flow, shall remain the same inside of the levee. The flows will be collected by toe drains at the base of the levee and directed to the outfall. Detailed design of these drains will occur during PED; it is anticipated the toe drains will vary on a case by case basis in term of material, slope, size, and configuration. Once the water is discharged through the multiple dispersed culverts crossing to the exterior of the levee, the relatively flat culverts will allow for the water to disperse rapidly and follow its natural course.

During conversations and meetings between environmental agencies and USACE, several areas were identified to place 'equalizer' culverts to maintain environmental connectivity and decrease environmental impacts and decrease mitigation needs. Most of these culverts will be 24 to 36-inch pipes, but three will be box culverts, including a sizable multiple box culvert equalizer culvert connecting the east side of the marsh near the Adams Bayou/Sabine River confluence.

Low lying tidally influenced culverts are sized to maintain tidal prisms/cross sectional areas, and minimize changes in velocities to the extent practicable. These culverts are to be designed to best match velocities correlating to flood and ebb tides. The current practice is to limit the maximum velocity of tidal velocities to 2.6 ft/s (preferably less, in the range of 0.5 ft/s to 0.82 ft/s) to minimize impacts on larval fish (NMFS 2008).

NMFS Fisheries 'Friendly Design and Operation Considerations for Hurricane and Flood Protection Water Control Structures' (NMFS 2008) was utilized for additional guidance on drainage structure placement and design considerations. This document was used to help identify design and operational guiding principles that would optimize passage of estuarine dependent marine fisheries species, or at least, minimize adverse impacts on their passage through hurricane and flood protection water control structures. The number of drainage structures and distances between structures closely match without-project conditions, and shall be further optimized to minimize migratory distances from the openings to enclosed wetland habitats during PED.

An operational plan will be completed in conjunction with the PED phase of the project. The plan will include the direction that culverts and gates will remain fully open at all times except during surge events, for short duration operational testing, and maintenance checks and inspections. The operational plan will also include direction on timing of closing and opening of culverts and gates as a storm approaches and passes. The operational plan shall include procedures to allow timely opening of culvert and gate structures in the absence of an off-site power source.

2.18.7 Pumps

Proposed pump stations were preliminarily designed and located to have minimal environmental impact. Selected locations for pump stations are included on the drainage area maps in the exhibits of this section of the engineering appendix. Pumps are not for use under normal conditions, only during surge events to evacuate water from the interior of the levee while the culverts and gates are closed. One exception is the existing pump station used by the City of Orange, draining Coopers Bayou. This pump station drains the majority of the City of Orange south of Interstate 10 using a variety of typical urban drainage features including but not limited to: storm sewers, open ditches, and diversion channels. It is active during normal conditions for drainage of rainfall runoff, discharge from the City of Orange and the plan is to let this pump function as intended. This station will remain active during storm events when the levee system is closed, as it will need to continue to evacuate interior rainfall runoff.

Some areas will be disturbed or altered on the interior of the levee to place the proposed pump stations with associated features. The footprint and impacts will be optimized, reassessed, and detailed during the PED phase of the project. These features could include detention/retention ponds, toe drains along the levee to direct flow to the pumping stations, and other typical pump station ancillary features. The pumps shall be designed to avoid impacts on wetlands as much as possible. Smaller features such as riprap and stepped structures along the toe drains and other features for wildlife will be included as appropriate and detailed during PED.

For the existing Freeport and Port Arthur systems it is not anticipated that any new culverts, pumps, or other drainage changes besides some minor modifications and possibly some replacements/removal of older drainage structures may be needed. Existing pump stations currently have adequate capacity and will be studied in further detail during PED. More information and design calculations will be needed during PED to further assess existing pump stations.

2.18.8 Drainage Environmental Impacts Summary and Conclusions

The proposed levee system will require numerous drainage structures, including culverts, pumps, and two large closure gate structures. Best Management Practices were used extensively to minimize environmental impacts caused by the proposed levee system. Culverts were sized and placed in configurations that attempt to mimic the natural without-project characteristics to the extent practicable. This included using multiple structures at each drainage outfall for the proposed levee system. Additional reinforced concrete pipes were strategically placed to maintain connectivity of environmental area, with substantial coordination with the USEPA, USFW, TPWD, TXDOT, TBWD, and NMFS. These 'connectivity' culverts are not needed for discharging rainfall runoff from the interior of the proposed levees; their purpose is solely to minimize the environmental impacts of the proposed levee.

Closure gate structures will be required on Cow and Adams Bayou to prevent surge from entering the proposed levee interior. A variety of gate configurations were modeled by ERDC using DOWSMM to determine possible impacts on velocities, tidal prisms, and stormwater impoundment due to the gate structures. The study found that for general tidal conditions, the limited tidal prism associated with each of these bayous results in little energy loss across the inlet, and that even significant constriction results in minimal impacts on water surface elevation and salinity within the bayous. For large freshwater inflow events, a significant constriction at Cow and Adams Bayous could result in additional impoundment of stormwater behind the structure. To offset stormwater impoundment, additional drainage features will be constructed adjacent to the main gate structures (Gunkel and Brown 2015).

The drainage components of the levee system were optimized to minimize environmental impacts. Further refinement and optimization will occur during the PED phase of the project, and changes shall be documented and provided to the environmental agencies to review and submit recommendations.

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USGS Gage

3 SURVEYING, MAPPING, AND OTHER GEOSPATIAL DATA REQUIREMENTS

FEMA LiDAR data from 2010 was used in the H&H storm surge modeling. This data was also imported into Bentley InRoads to create ground surfaces along the proposed new HFPP alignments that were used to determine the relative levee and floodwall heights and to calculate associated fill quantities for the levee construction. The data for the entire region was isolated to the project areas and thinned out to be within the program's capability of processing it. Some spot checking was proposed and performed in order to cross-check elevations obtained from the LiDAR surveys comparing them to the elevations physically taken at the ground surface of each core boring using Real Time Kinematic (RTK) system equipment. It was found that the LiDAR elevations near the core boring locations compared favorably with the core boring elevations, with differences typically being between 0.10 and 0.60 foot.

Other surveying, mapping, and geospatial information/tools came from the following resources:

- Satellite imagery and data published by Google Earth Pro
- Satellite imagery published by ESRI
- FEMA Flood Insurance Rate Maps
- Published tide and water level data from NOAA stations
- Oil and gas pipeline GIS database maintained by the Texas Railroad Commission (TRRC)
- Local Sponsor surveys (existing systems)

For the existing levee systems, Port Arthur and Freeport, the as-built construction documents were utilized to map out the current stationing for their respective alignments. Surveys completed by the local sponsors were utilized in determining elevations for the levee and floodwall of the existing systems. The Freeport HFPP contains different stationing for each of its reaches, which may lead to confusion during futures phases of the project. The Port Arthur HFPP utilizes numerous equations in its alignment. During PED, the stationing for each of the existing systems should be re-done to current standards to contain one continuous stationing throughout their alignments, for construction purposes and ease of use.

4 GEOTECHNICAL

4.1 SUMMARY

The objective of this chapter is to provide a detailed background of the geotechnical work performed throughout the preliminary design of a proposed Hurricane and Storm Damage Risk Reduction (HSDRR) system. The system will include levee embankment, floodwall and other features. This feasibility document focuses on foundation conditions and levee embankments, floodwall details are covered in the Structural chapter of this appendix.

4.2 INTRODUCTION

This geotechnical feasibility chapter covers the concept design for construction of a new HSDRR system that would reduce flood damage risk for parts of Orange County and would improve the existing systems located in Jefferson and Brazoria Counties in the state of Texas.

The proposed system is a Hurricane and Storm Damage Risk Reduction system. The segments proposed are divided in three major areas, proposed system in Orange (Figure 4-1) and improvements in the existing systems in Freeport (Figure 4-2) and Port Arthur (Figure 4-3). Approximate lengths of the work areas are detailed in Table 4-1 and Table 4-2 below. The total length for Orange includes distances within the alignment for pump stations, road closure gates and navigation structures. This document presents and describes the criteria, assumptions, procedures and recommendations made based on preliminary results related to the geotechnical analysis performed at the feasibility level regarding the design and improvement of levees.

Floodwall design is covered in Chapter 7, Structures.

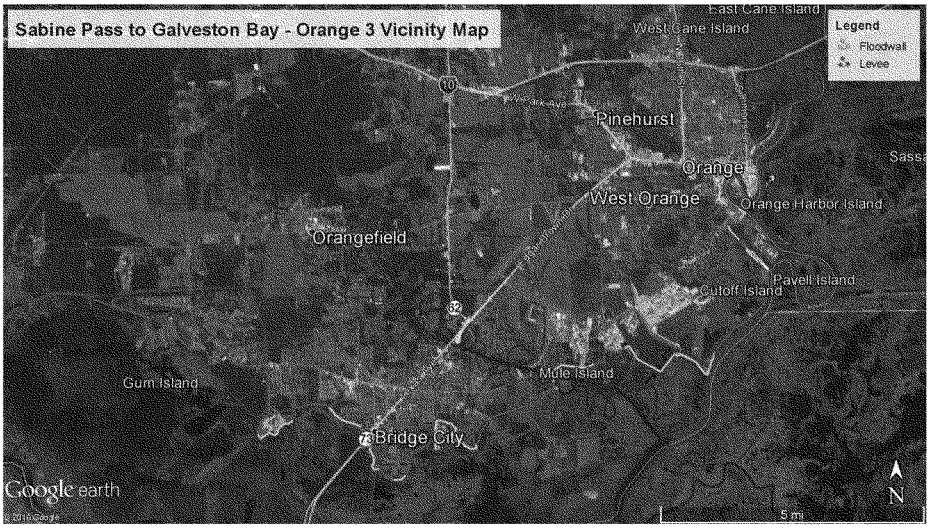

Figure 4-1: Sabine Pass to Galveston Bay – Orange 3 Vicinity Map

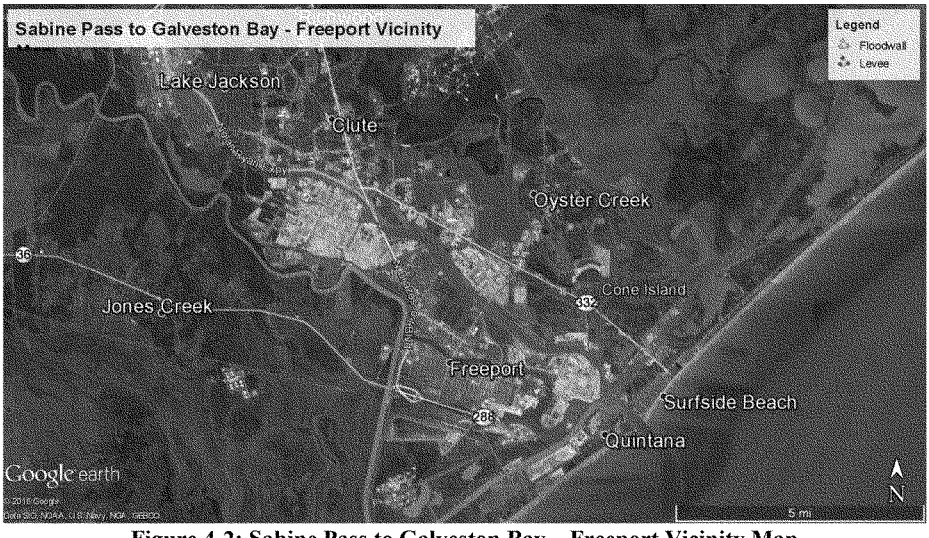

Figure 4-2: Sabine Pass to Galveston Bay – Freeport Vicinity Map

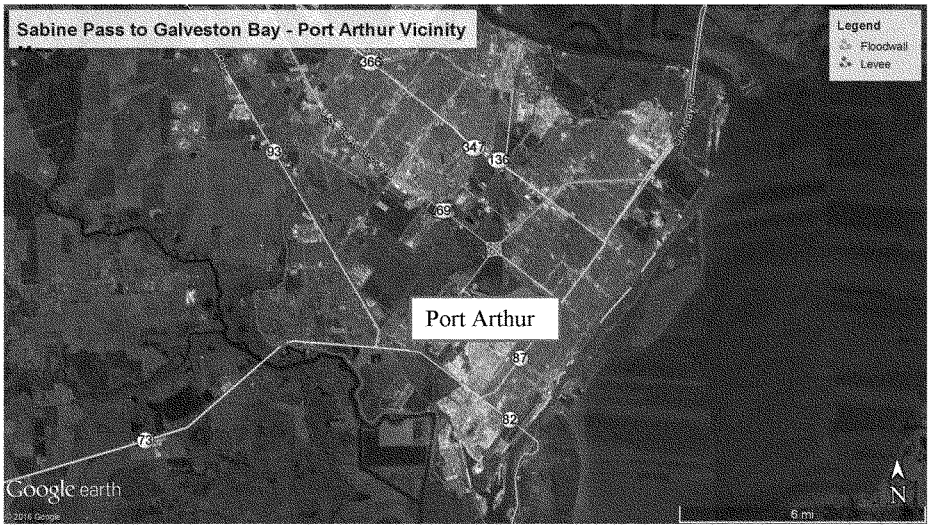

Figure 4-3: Sabine Pass to Galveston Bay – Port Arthur Vicinity Map

Table 4-1: Approximate Lengths of Proposed Features per Area

Reach	Total Length (ft)	Length Of Features (ft)	
		Levee	Floodwall
Orange 3	141,064	82,169	56,755

Table 4-2: Approximate Lengths of Proposed Work on Existing Features

Reach	Total Length (ft)	Length Of Features (ft)	
		Levee	Floodwall
Freeport	217,217	69,375	29,205
Port Arthur	162,162	31,030	30,090

4.3 DESIGN CRITERIA

4.3.1 Selection of Design Criteria

Per Table B-1 of ER 1110-2-1806[9], the proposed HSDRR system would be classified as a high hazard structure. Therefore design efforts are required to conform to the most stringent applicable requirements. Several Engineering Manuals (EM) and other types of guidance published by the United States Army Corps of Engineers (USACE) apply to the proposed structures. Main design criteria includes, but is not limited to:

- Hurricane and Storm Damage Risk Reduction System Design Guidelines, June 2012[10]

- EM 1110-2-1913, Design & Construction of Levees, April 2000[6]

4.3.2 Historical Documentation and Input Data

Preliminary design included a search for historic, relevant, and useful documentation. Little to no relevant documentation was found for the proposed HSDRR system except for the "Flood Protection Planning Study Hurricane Flood Protection System Orange County, Texas", December 2012 which was prepared for Orange County and The Texas Water Development Board. No geotechnical investigations were performed for such study. Therefore feasibility level design relies heavily on the geotechnical investigation performed in 2015 as detailed in Section 10 of this chapter.

Design Documentation Reports and latest levee inspections were referenced for the devised improvement of existing systems.

4.3.3 Survey Data

All elevations used in design refer to the North American Datum of 1988, NAVD88 US Survey Feet.

4.3.4 Reference Documents

4.3.4.1 USACE Engineer Manuals

[1] EM 1110-1-1804 Geotechnical Investigations, 1 January 2001

[2] EM 1110-1-1901 Seepage Analysis and Control for Dams, 30 April 1993

[3] EM 1110-1-1904 Settlement Analysis, 30 September 1990

[4] EM 1110-2-1902 Slope Stability, 31 October 2003.

[5] EM 1110-2-1906 Laboratory Soils Testing, 20 August 1986

[6] EM 1110-2-1913 Design & Construction of Levees, April 2000

4.3.4.2 USACE Engineer Technical Letters

[7] ETL 110-2-569 Design Guidance for Levee Underseepage, May 2005

4.3.4.3 USACE Engineering Regulations

[8] ER 1110-2-1150 Engineering and Design for Civil Works Projects, August 1999

[9] ER 1110-2-1806 Earthquake Design and Evaluation for Civil Works Projects, July 1995.

4.3.4.4 Other USACE Engineering Guidelines

[10] Hurricane and Storm Damage Risk Reduction System Design Guidelines – INTERIM, June 2012.

4.3.4.5 Drawings and Reports

[11] Flood Protection Planning Study Hurricane Flood Protection System, Orange County, Texas, December 2012.

4.3.5 Surficial Geology

Brazoria, Jefferson and Orange Counties are in three major land resource areas (MLRA's). About 50 percent of the area lies within the Gulf Coast Prairies MLRA. About 35 percent of the area is in the Gulf Coast Marsh MLRA. About 15 percent of the area lies within the Western Gulf Coast Flatwoods MLRA mostly in the northern part of Orange County. The Gulf Coast Prairie MLRA has mostly dark colored loamy and clayey soils that formed under prairie vegetation. The Gulf Coast Marsh is comprised of sandy, clayey, or loamy soils that are submerged for part of the time with saline or fresh water. The Western Gulf Coast Flatwoods MLRA has mostly light colored loamy and silty soils that formed under pine forest vegetation. The major land uses in the Gulf

Coast Prairies include farming and ranching. The major land use for the Gulf Coast Marsh is wildlife. The major land use for the Western Gulf Coast Flatwoods is woodland.

4.3.6 Software

SEEP/W & SLOPE/W Version 8.12.3.7901
Software used to perform preliminary analysis to verify general assumptions against current criteria. At the time of this write up, SWG has not performed any validation efforts in order to check results obtained with this version against the previous versions of the software. Further stages of design would need to be supported or performed with a validated version of the software.

4.4 GEOTECHNICAL ANALYSIS

4.4.1 Foundation Conditions

Orange

A Geotechnical investigation was performed in 2015 to document the general foundation conditions for the proposed features throughout the Orange 3 alignment. The investigation comprised of 15 core borings and 22 cone penetration tests (CPT). General overview of the core boring plan and CPT plan are shown in Figure 4-4 and Figure 4-5 respectively. Draft results of these efforts were used in the performance of shear plots and subsequently in the demarcation of design reaches and to devise features at this conceptual stage.

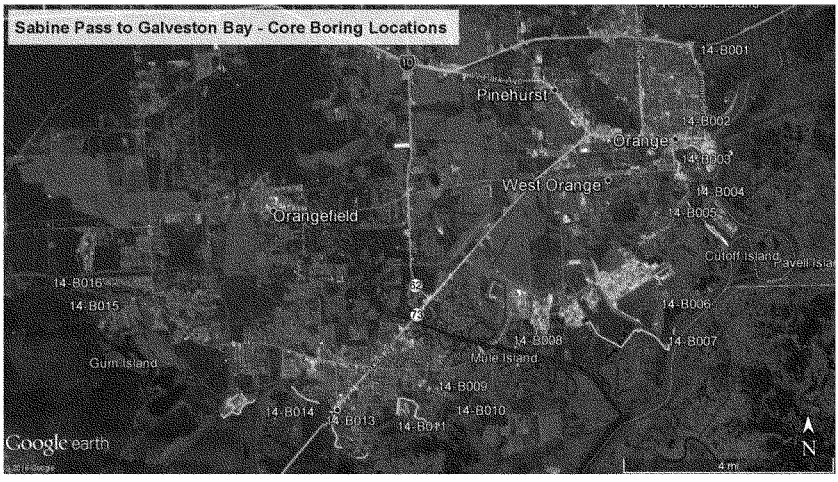

Figure 4-4: Core Boring Plan on Orange

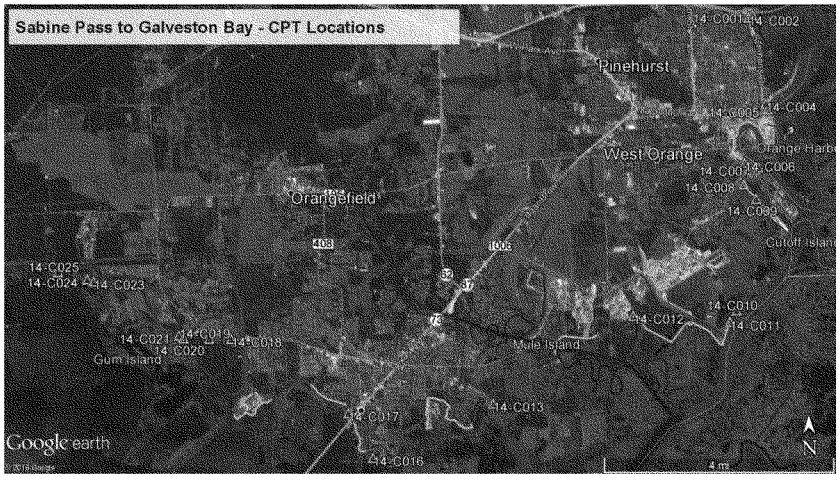

Figure 4-5: CPT Plan on Orange

Freeport

Design Memorandum on the existing Freeport system details the soils near surface deposits consisting of soft clays, sands and silts in the southern portion of the area. Medium to very stiff clays, dense sands, and silts are predominant in the northern portion of the project. Sediments below a depth of about 15 feet generally consist of stiff to very stiff reddish brown clay. These recent sediments range in thickness from 16 to more than 50 feet.

Port Arthur

Design Memorandum on the existing Port Arthur system detail the foundation soils throughout the alignment consist of stiff to very stiff clays and sandy clays with occasional thin layers of sand or silty sands.

4.4.2 Analysis Cross Section Selection and Soil Parameters

In order to come up with a conceptual design that would cover general features needed throughout the project, controlling geometry and soil configurations were identified for representative reaches. Several reaches were selected based on the scope of the work and/or mechanical data obtained from the geotechnical investigations performed for the project. Core borings and CPTs were grouped based on proximity and their similarities of strata classifications, configuration and properties.

The CPT information gathered and displayed in shear plots was calibrated using the laboratory test results in order to developed shear plots, the Orange Reach was selected in order to obtain an Nk value for the project area.

Those selected cross sections representative of scope and general conditions are:

4.4.2.1 Orange

Orange reach was developed within Orange 3 and shear strength plot IV, and is comprised of Core Borings 14-B005, 14-B006 and 14-B007 along with CPT 14-C008, 14-C009, 14-C010 and 14-C011. The resulting plot exhibits the weakest soil configuration observed and was therefore identified as potentially producing unique features independent from other areas where the sub-surface conditions possessed better mechanical properties. The parameters from this area (located at the borings listed above) along the alignment were used throughout the proposed levee system for design purposes of the levee and floodwall cross sections.

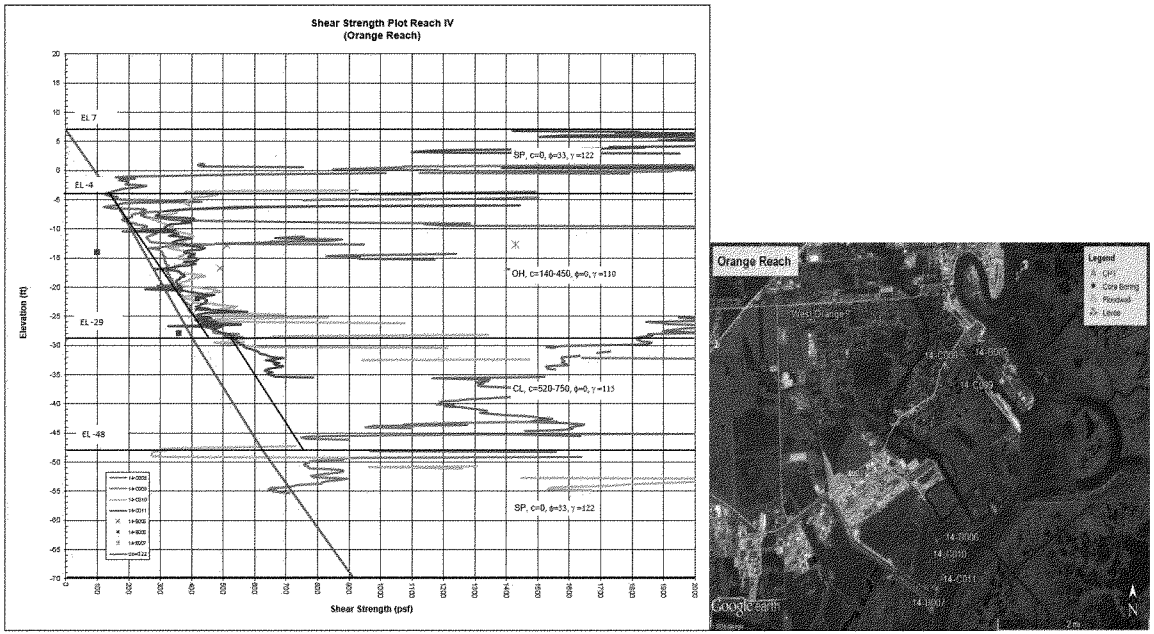

Figure 4-6: Orange Reach represented by shear strength plot IV (left) and its general location (right)

4.4.2.2 Freeport and Port Arthur

Existing systems were considered as one reach each since the required improvement as devised by the NED are similar in scope. Additions to the embankment range between 0.5 and 5 feet, as shown in Table 4-3 and Table 4-4.

Table 4-3: Length of work on existing levee embankment at Freeport

Segments	Length of Work and Addition to the Levee Embankment (ft)							Sub-Total
	0.5	1.0	1.5	2	2.5	3	3.5	
Oyster Creek & Ext	23,700					4,700		28,400
East Storm			9,370	4,000	4,000			17,370
DOW Barge Canal						4,600	4,550	9,150
Old River North						3,030		3,030
Tide Gate								0
Old River South						1,625	5,400	7,025
South Storm		4,400						4,400
East Bank Brazos								0
							Total	69,375

Table 4-4: Length of work on existing levee embankment at Port Arthur

Segments	Length of Work and Addition to the Levee Embankment (ft)				Sub-Total
	1	1.5	2	5	
Reach 1					0
Reach 2		9,000			9,000
Reach 3	6,788	1,462			8,250
Reach 4		1,450	7500		8,950
Reach 5		3,000			3,000
PA Extension				1,830	1,830
				Total	31,030

4.4.3 Geotechnical Design Assumptions

Assumptions made throughout the performance of this study are:

- Steady state conditions for all seepage analysis
- Proposed material on levee embankment is compacted impervious fill
- No seismic accelerations were considered, see Section 4.4.5.3 Earthquake Loads (EQ) of this document

4.4.4 Material Properties

4.4.4.1 Saturated Unit Weights

- Water 62.4 pcf
- Impervious Embankment Fill 115.0 pcf
- Silt (ML) 117.0 pcf
- Fat Clay (CH) 119.0 pcf
- Lean Clay (CL) 115.0 pcf
- Organic Clay (OH) 110.0 pcf
- Sands (SP & SM) 122.0 pcf

4.4.5. Design Loads

The following load conditions were considered in all stability analyses unless stated otherwise.

4.4.5.1. Dead Load (D)

Dead load (D) includes the weight of superimposed water and embankment backfill. The unit weight of materials is listed in Paragraph 4.4.4.1.

4.4.5.2 Hydraulic Load (H)

Hydraulic load (H) includes hydrostatic pressure (Ps) and uplift pressure (U). These loads are developed from the hydraulic head produced from the design pool level pertaining to End of Construction (EoC), Still Water Level (SWL), Water at Project Grade (WPG) conditions. Water elevations used in preliminary analysis were developed with a 1% annual chance exceedance at a 90% confidence as per HSDRR guideline while taking in account wave and were used for all the analysis done in this document.

4.4.5.2.1. Hydrostatic Pressure (Ps)

The hydrostatic pressure (Ps) is taken into account as a force acting perpendicular to the surface retaining water as in the equation bellow:

$$P_s = \gamma_w h$$

Where: γ_w = unit weight of water
h = depth of water at calculation point

4.4.5.3 Earthquake Loads (EQ)

According to current USACE criteria, the project area is classified as a Zone 0 on Figure C-1 of ER 1110-2-1806, Earthquake Design and Evaluation for Civil Works Projects. [9] No earthquake loads need to be considered at a Zone 0 site. No seismic loads were taken in to consideration as part of the preliminary design of levee embankment.

4.4.6 Seepage Analysis

Background, from EM 1110-2-1901, 30 Sep 86, Chapter 4-9 Paragraph B:

"The escape or exit gradient, i_e, is the rate of dissipation of head per unit of length in the area where seepage is exiting the porous media. For confined flow, the area of concern is usually along the uppermost flow line near the flow exit, e.g., at the downstream edge of a concrete or other impermeable structure. Escape gradients for flow through embankments may also be studied by choosing squares from the area of interest in the flow net (usually at or near the exit face and downstream toe) and calculating gradients. If the gradient is too great where seepage is exiting, soil particles may be removed from this area. This phenomenon, called flotation, can cause piping (the removal of soil particles by moving water) which can lead to undermining and loss of the structure. The gradient at which flotation of particles begins is termed the critical gradient, i_{cr}. Critical gradient is determined by the in-place unit weight of the soil and is the gradient at which upward drag forces on the soil particles equal the submerged weight of the soil particles."

All exit gradients used in the seepage analysis performed for Sabine to Galveston were obtained with the SEEP/W module of SLOPE/W, where modeling results values are displayed by selecting the area of interest. Exit gradient outputs were then used as input variables in the equation below. The quantitative values shown represent the factor of safety calculation for East Bridge City Reach for water to project grade (WPG) as an example of the calculation.

$$FS_{piping} = \frac{i_{cr}}{i_e} = \frac{\gamma'/\gamma_w}{(dh/dl)} = \frac{(115-62.4)/62.4}{0.42} = \frac{0.842}{0.42} = 2.0$$

Where:
dh, is head loss between each equipotential line.
dl, is the dimension of a flow net square or distance between equipotential lines.

Exit gradients were evaluated at, but not limited to, key feature locations such as land side slopes of the embankment and throughout all proposed stability berms slopes.

The following tables summarize the seepage analyses results:

Table 4-5: Seepage Analysis Criteria

Hydraulic Condition	Required Factor of Safety
SWL	1.6
WPG	1.3

The cross section shown in Figure 4-7 was found to satisfy the above criteria.

4.4.7 Slope Stability Analysis

The following factors of safety were considered in the stability analysis, using the Spencer method, according to Table 3.1 of the HSDRRSDG[10], based on criteria established by EM 1110-2-1902 Slope Stability[4].

Table 4-6: Stability Analysis Criteria

Hydraulic Condition	Required Factor of Safety
EoC	1.3
SWL	1.5
WPG	1.4

The cross section shown in Figure 4-7 was found to satisfy the above criteria.

4.4.8 Settlement Analysis and Results

Settlement analysis was performed with preliminary data on several locations throughout the proposed alignment. The results of the analysis averaged 4ft of settlement. Overbuilt for the levee embankment of the same amount was considered on all design analysis and included in the final quantities for the cost estimate.

4.5 RECOMMENDATIONS

For purposes of the study, all borrow material is assumed to come from commercial sources. A quick investigation of available borrow sources at each project location found several possible borrow areas. Borrow sources at each project location should be verified during the PED phase if they have enough material available for the required levee templates.

4.5.1 Orange

Based on the geotechnical investigations and analysis (i.e. seepage and stability) performed at this feasibility stage, for estimate purposes, a ten foot crown along with 3H:1V slopes (Figure 4-7) was found to be geotechnically adequate for the entirety of the project where a levee is being proposed. The recommended section includes an area of foundation preparation (3 feet depth, the width of the levee) and a 3ft x 10ft exploratory trench in the center of the levee foundation. Both of these

features will aid in construction of the levee interface with the existing ground (levee foundation), as well as provide some form of seepage cutoff for the levee section. All of these features will be reevaluated during PED. The levee heights, which were calculated with 3:1 side slopes, can be found in Chapter 1 of this Appendix. A refinement of the levee design will be required in further stages of the project in order to ensure design assumptions still apply in areas that could not be captured due to the simplified nature at this feasibility level stage. A comparison with changing levee heights and flood side slopes will likely be required in order to have the most appropriate cross section for a given area of the system alignment.

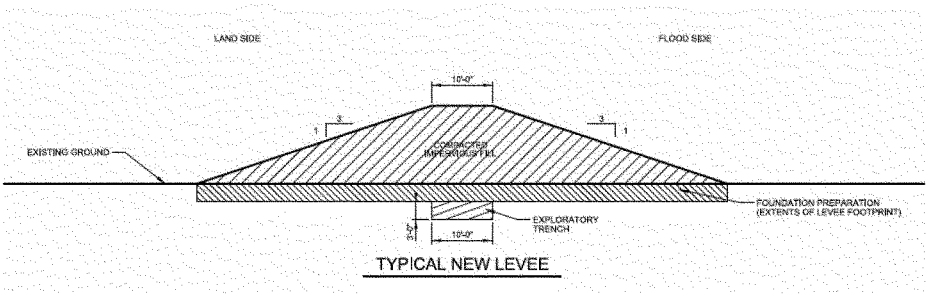

Figure 4-7: Typical proposed levee section.

4.5.2 Existing Systems – Port Arthur and Freeport

Proposed levee raises are varied throughout the existing project alignment, there are areas where no work is required but in those areas that do require work the embankment raise will range between 0.5 – 3.5 ft. Typical sections of the raise are shown in Figure 4-8 and Figure 4-9. It is recommended that in subsequent design stages a refinement of the design is performed. This should entail the evaluation of existing data and gathering complementary soil information in order to comply with existing criteria.

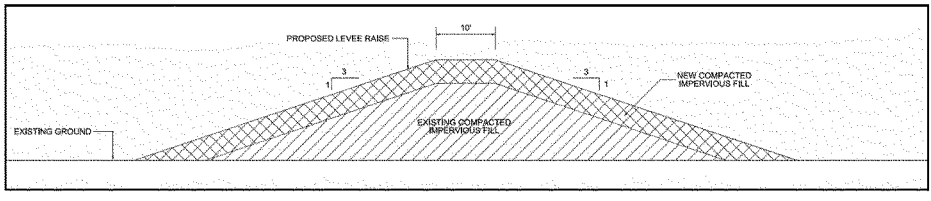

Figure 4-8: Typical for proposed levee raise section.

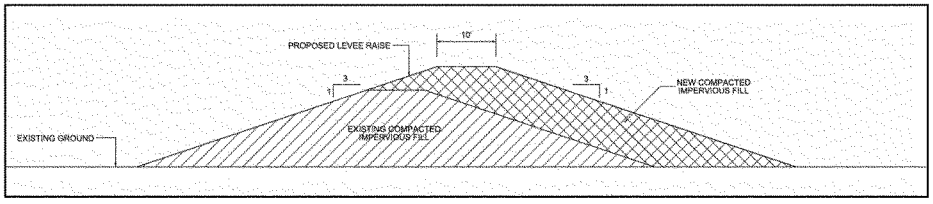

Figure 4-9: Alternate typical for proposed levee raise section

5 ENVIRONMENTAL IMPACTS AND ENGINEERING

5.1 USE OF ENVIRONMENTALLY RENEWABLE MATERIALS

Construction of the projects involves earthwork to build and raise levee embankments, and to excavate the ground for the floodwall footings; the placement of reinforced concrete for the floodwalls; installation of sheet pile cutoff walls; the building of gate structure and pump station housing; installation of steel gates; riprap placement; installation of resiliency elements; and pump installations. Soil excavated incidental to the levee and floodwall construction that is satisfactory for use as structural fill material will be used for this purpose. Beyond that, the fill material will be imported from local commercial sources. Stripped topsoil will be conserved and used to plate the levee embankment. Although there is little opportunity to incorporate renewable materials into the project due to the nature of its construction, much of the project will or can be built using materials that are reusable or recyclable, such as concrete, steel, and material made of polymers (e.g., high-performance turf reinforcement mattress (HPTRM), fiber-reinforced polymer (FRP) sheet piling, and high-density plastic drain pipe).

5.2 DESIGN OF POSITIVE ENVIRONMENTAL ATTRIBUTES INTO THE PROJECT

Incorporating positive environmental attributes into the project feature designs was a primary consideration in deciding the proposed alignments for the CSRM plans in Orange and Jefferson Counties. These alignments were laid out, and the types of structures (i.e., levee or floodwall) were designed to avoid and minimize direct impacts the construction easements would have on existing forests and wetlands and indirect impacts the systems, as configured, would have on affected floodplains to greatest extent practicable.

To minimize potential impacts of the Cow and Adams gate structures and the culverts in the Orange levee system on marine fishery organism migration, final structural designs will incorporate fisheries-friendly considerations recommended by National Marine Fisheries Service (Fisheries Friendly Design and Operation Considerations for Hurricane Flood Protection Water Control Structures, 2008) to the greatest extent possible. This document is presented in Appendix O (Attachment 4). Final feasibility design will be completed during PED.

In addition, culverts will be designed with longer spans and lower heights than would typically be used in an attempt to replicate natural drainage cross-sections. Sluice gate culverts are planned for use everywhere there are tidal flows; flap gate culverts may be utilized in upstream areas above tidal influence. Gated culverts would be placed everywhere existing drainages intersect the system

alignment, and they will be placed in additional areas where they are needed to ensure adequate flows to adjacent wetlands. The sluice gates would remain open except when surge protection is needed; they would be closed temporarily for a short period before and after a storm occurs. Flap gate culverts would provide for one-way flow downstream from the levee system. During a surge event the sluice gates would be closed, pumps would be used to pump rainfall runoff from the interior to the exterior. The pumps are being conservatively sized to avoid floodplain impacts to the interior of the levee system, and to allow overbank flooding in the streams in the floodplain outside of the levee during high flow events. Hydrologic flows, as well as the exchange of sediment, nutrients and organic material would thus be very similar to the No Action Alternative flows and in location, duration and magnitude, both upstream and downstream of the levee system. The Cow and Adams Bayou structures, and the culverts would be closed only in anticipation of storm surge and occasional maintenance activities, and the closings would be short-term.
Consequently, positive environmental attributes are largely built into the project designs by way of deliberately circumventing habitat areas and reducing the project footprints, which avoids adverse environmental impacts altogether or otherwise minimizes them (ER 1110-2-1150, Paragraph 13.6.8).

For the proposed Orange CSRM plan and modifications to the existing Freeport and Port Arthur HFPPs, resiliency features are to be built in to withstand erosion forces from wave run-up and overtopping. To a considerable extent, these resiliency features will be constructed using high performance turf reinforcement mats wherever deemed acceptable, which is a more environmentally friendly, cost-effective alternative to hard armor systems. The levee slopes will be vegetated with native grass. Additionally, drainage structures will be strategically located and appropriately sized to maintain freshwater flow balances within affected habitats.

Because much of the HFPP construction will be in areas that are already developed, and avoids environmental habitats, there is little opportunity to design environmental attributes into the recommended plans that would enhance the existing project areas. Given the limited opportunities, the principal focus of the engineering effort related to designing-in environmental attributes was to avoid impacting critical habitats in the first place.

5.3 INCLUSION OF ENVIRONMENTALLY BENEFICIAL OPERATIONS AND MANAGEMENT FOR THE PROJECT

During PED, an Operating Plan will need to be developed for the Orange CSRM plan , and updates incorporated into the existing Operating Plans for the Port Arthur and Freeport HFPPs. Project impacts and environmental mitigation for the Orange CSMR plan have been based on assumptions that the proposed surge gates at Cow and Adams Bayou will be closed only when needed to reduce the risk of storm surge impacts, and that the culvert system will have negligible effects on

hydrologic flows. Based on these assumptions, it was determined that the levee would have minor impacts on the hydrology of the floodplain and sediment/nutrient exchange both inside and outside of the levee system. Because this determination rests heavily on these assumptions, resource agencies have requested to be involved in the development of Operating Manual during the PED Phase and during subsequent periodic reviews when operating plans are reevaluated to determine project performance under future conditions, including potentially higher than anticipated rates of RSLC. Requirements that the surge gates, sluice gates, and culverts remain open except during storm events would be incorporated into the Operating Manual.

The grassed levees will have to be regularly mowed and the floodwalls and gate structures routinely maintained. Occasional maintenance and repairs of the roadway on the levee crown will also be required. Other than that, the levees and floodwalls will remain in a passive state. Operationally, the functionality of the affected floodplains will not be compromised. Openings at closure points will be kept open and drainage structures allowed to flow freely when the system is not activated.

5.4 BENEFICIAL USES OF SPOIL OR OTHER PROJECT REFUSE DURING CONSTRUCTION AND OPERATION

While it is assumed that all fill material necessary to build the levees comprising the proposed Orange CSRM Plan and Port Arthur CSRM Addition will be brought in from local commercial sources, it is anticipated that much of the material from required excavations can be used for some purpose in the construction. No material from the construction is expected to be reused for beneficial purposes. If there is excavated material in excess of construction needs, placement areas will need to be identified. . During the construction phase, proposed placement areas will be identified and reviewed for environmental and wetland impacts. The plan for the disposal of this material will avoid or minimize additional adverse impacts to the maximum extent practicable. If significant impacts are identified for a proposed placement area, environmental review and coordination will be conducted in compliance with the National Environmental Policy Act and other applicable regulations. The projects should not generate much refuse during their operation, but refuse and debris will collect at the gated drainage structures, mostly during flooding events. This debris will be removed and conventionally disposed of in approved landfills.

5.5 ENERGY SAVINGS FEATURES OF THE DESIGN

Other than the pump stations and navigation gate facilities, there are no features available where energy savings can be realized due to the nature of the CSRM projects. The projects are horizontal construction projects that consist of earthen and concrete barrier structures. Nevertheless, opportunities to economize maintenance of the levees and floodwalls will be explored when designing the project features.

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

The landscape/horizon of the Orange CSRM and Port Arthur CSRM Addition project sites will be altered by the new levees and floodwalls. These levees and floodwalls will result in a prominent line of earthen embankment and concrete wall along ground surfaces that are relatively flat. Forest areas within the alignment corridors will be cleared. To the extent practicable however, the project designs preserve existing forest and wetland habitats. Where environmental impact is unavoidable, the designs minimize the project footprints. The levee slopes will be turfed with native grass. Resiliency elements, to the maximum extent possible, will be designed to be "green" to blend in with the natural setting. Over time, the CSRM plans will have less of an effect on the ecology of the area as the ecology adapts to the relatively modest changes in the environment.

Terrestrial wildlife would still be able to access habitats divided or cut off by earthen levee segments, as it does now across the Port Arthur HFPP levees. Floodwall segments would generally be located in developed areas and limited in length; wildlife would be able to utilize nearby levee segments for access as needed. Fisheries access would be maintained at No Action Plan levels. The recommended projects are not expected to impact migratory birds or their habitat within the project areas.

The recommended projects have been determined to be the best at satisfying the purpose and need of the projects to provide increased CSRM in a cost-effective manner with minimized impacts to the environment. They best meet the balance of providing a higher level of protection against coastal storm surge, minimizing environmental impacts, and being compatible with the surrounding environment.

5.7 CONSIDERATION OF INDIRECT ENVIRONMENTAL COSTS AND BENEFITS

Indirect environmental costs and benefits were considered in the preliminary layouts of the proposed HFPPs in Orange and Jefferson Counties. Their impacts on the environment are discussed in the FIFR-EIS. To the extent practicable, the proposed alignments were purposely routed to avoid environmental habitats. Where such avoidance was not possible, the project footprints were maximally reduced in several places by assuming more expensive floodwall segments where levees, which would have had a wider footprint, would have sufficed.

Section 7 of the FIFR-EIS describes each project's potential impact on soils, water quality, air quality, aquatic and terrestrial habitats, wildlife, threatened and endangered species, HTRW, and social and cultural resources. All of the Recommended Plan's environmental impacts are

associated with the proposed Orange and Port Arthur Addition CSRM plans. The construction of these systems would disrupt hydrology and result in the eventual loss of about 15 acres of forested wetlands and the 120 acres of coastal marsh. In addition, operation of surge gates in Cow and Adams Bayous would adversely affect fisheries access to the extensive marshes in their floodplains, resulting in indirect functional impacts to about 2,137 acres of emergent marsh. Mitigation has been proposed to compensate for the all indirect functional impacts to these wetlands, as well as for all direct impacts associated with construction of the new CSRM system. Improvements to the existing Port Arthur and Freeport HFPPs are not expected to result in any wetland impacts. However, potential exists for impacts due to buried hazardous and toxic materials during construction of improvements. The proposed projects do not impact Federally listed threatened or endangered species or their designated critical habitat.

5.8 INTEGRATION OF ENVIRONMENTAL SENSITIVITY

Project features will be designed with environmental sensitivity in mind. To minimize potential impacts of the Cow and Adams gate structures and the culverts in the Orange levee system on marine fishery organism migration, final structural designs will incorporate fisheries-friendly considerations recommended by National Marine Fisheries Service (Fisheries Friendly Design and Operation Considerations for Hurricane Flood Protection Water Control Structures, 2008) to the greatest extent possible. Resiliency features will be constructed using high performance turf reinforcement mats wherever deemed acceptable, which is a more environmentally friendly, cost-effective alternative to hard armor systems. The levee slopes will be vegetated with native grass. Additionally, drainage structures will be strategically located and appropriately sized to maintain freshwater flow balances within affected habitats. Best management practices will be incorporated into construction contracts to minimize release of sediments into nearby waterbodies and unnecessary disturbance of vegetation outside of construction right-of-ways.

5.9 CONSIDERATION OF ENVIRONMENTAL PROBLEMS ON SIMILAR PROJECTS WITH RESPECT TO THE ENVIRONMENTAL REVIEW GUIDE FOR OPERATIONS (ERGO)

Environmental issues/concerns on similar projects and lessons learned will be considered during the design of the project features to make sure that systems and facilities comply with applicable environmental laws and regulations and will comply with these laws and regulations during operations. Environmental concerns will be appropriately addressed/mitigated for in the project designs and operating manuals. Construction of the projects will not proceed until the Non-Federal Sponsor has provided a clean corridor free of any HTRW contamination.

5.10 INCORPORATION OF ENVIRONMENTAL COMPLIANCE MEASURES

As the projects comprising the Recommended Plan are further developed and designed, environmental compliance measures will be incorporated into the feature designs. Best management practices will be incorporated into project design and construction contracts. For example, silt curtains will be required to prevent sediment disturbed by construction from adversely affecting aquatic habitats and species. These will be necessary during construction of new levee systems and improvements to existing levee systems. In particular, construction of improvements to Port Arthur and Vicinity CSRM Plan levees and floodwalls facing the Sabine-Neches Canal may require a silt curtain or other turbidity barrier from releasing sediments into this waterway. Specially-equipped marsh buggies and other equipment will be required to minimize impacts to existing marsh when placing hydraulic pipelines for marsh restoration as required by the mitigation plan. Access routes to construction areas will be required to utilize work areas identified in this document to ensure avoidance of sensitive environmental areas.

5.11 ENVIRONMENTAL IMPACTS

The direct impacts of the Orange and Port Arthur CSMR plans reflect the assumed loss of all forested and marsh wetlands within the construction right-of-way. A total of about 55 acres of forested wetlands and about 160 acres of coastal marsh would be destroyed by construction. A mitigation plan has been developed to fully compensate for these direct construction losses, and the indirect functional losses described above in Section 5.7. The mitigation plan would permanently preserve 559 acres of swamp and bottomland hardwoods, and restore about 1,179 acres of fresh and estuarine emergent marsh in the project area. Details of the mitigation plan are presented in Section 6.1 and Appendix O of the FIFR-EIS.

6 CIVIL DESIGN

This section presents the general civil design considerations that were made for the projects comprising the Recommended Plan.

6.1 SITE SELECTION AND PROJECT DEVELOPMENT

The general project areas were identified through the Plan Formulation process, discussed in Appendix B of the FIFR-EIS, where structural measures were developed to reduce the risk of flood damages from coastal storm surges and to provide environmental benefits. These structural measures included the construction of new regional CSRMs in Orange and Jefferson Counties and improvements to, and the reconstruction of existing HFPP elements comprising the existing Port Arthur and Freeport systems. For the Freeport HFPP, the structural measures also included adding a new navigation gate structure in the Dow Barge Canal to serve as a flood barrier. After screening the measures, alternative structural plans were formulated for the Sabine, Galveston, and Brazoria Regions comprising the six-county study area. The initial arrays of structural plans for the Sabine and Brazoria Regions are listed in Appendix B and the recommended plan in Table 1-1 of this appendix. Of these structural plans, Alternatives Nos. S5 (Sabine Inland Barrier CSRM Focus (Neches Gate/Sabine Levees/HFP)) and B2 (Brazoria Coastal Barrier CSRM Focus (revised)) were ultimately carried forward for further detailed analyses and development as the Recommended Plan, where the plans were economically and environmentally optimized.

6.1.1 CSRM Alignments

6.1.1.1 Orange-Jefferson County Alignment

Preliminary alignments for the proposed Orange-Jefferson County CSRM were initially laid out referencing preliminary layouts that a joint group of engineering firms had previously investigated and recommended for Orange County and eastern Jefferson County as a basis. This group conducted a flood risk reduction planning study for a countywide CSRM in Orange County, which is documented in the Orange County Report. The alignments recommended by the report are called the "Neches Crossing and Sabine River Alignment" and the "Industries Alignment". These alignments were chosen based on their ability to meet the requirements of providing flood risk reduction countywide including the major industrial areas within Orange County. Factoring into the decision on the Neches Crossing and Sabine River Alignment were assessments of the valuations of the properties to be protected and potential flood damage losses that would be prevented. In addition, this alignment would protect industrial areas and the majority of the land area within Orange and Jefferson Counties.

The Recommended Plan alignments draw on the "Protection System on East & West Bank of Neches River (SR + NR + NRW)" alternative alignments presented in the Orange County Report (see Figure 6-1 on the next page). To a considerable degree therefore, the alignments comprising the Recommended Plan generally coincide with the earlier recommended alignments. With these well-defined alignments as a starting point, a parametric approach was used to modify and refine the alignments to what became the Recommended Plan alignments. Site assessments were made based on existing information and aerial photos to selectively decide the property and environmental assets that would be worth protecting, and that would be economically viable of protecting. These assessments were augmented by site visits and limited site investigations. When routing the CSRM alignment, consideration was given to the environmental impacts to bottomland hardwood and wetland areas. This consideration significantly dictated the course of the alignment. Other principal considerations were taken into account as well. Considerations were made to avoid cutting through or getting too close to existing buildings and infrastructure, crossing low areas constantly under water, crossing areas with foundation conditions that are likely to be poor, water bodies, and crossing or paralleling too close to major pipeline corridors. All this was being done within the framework of the H&H modeling results in which the potential economic losses from flood damages corresponding to assumed SWEs were evaluated against the costs of providing the respective levels of flood risk reduction.

After refining the CSRM alignment, the Orange County system was broken down into three (3) separable reaches, rationally based on existing geographical features and the areas that would be protected to maximize the economic benefits. These reaches (each of which was evaluated as an alternative in deriving the Recommended Plan) are called "Orange 1," "Orange 2," and "Orange 3." The recommended plan includes the Orange 3 reach as described in Table 1-1 and depicted on Plate C-01. The project that produced net excess economic benefits became the Orange-Jefferson CSRM component of the Recommended Plan.

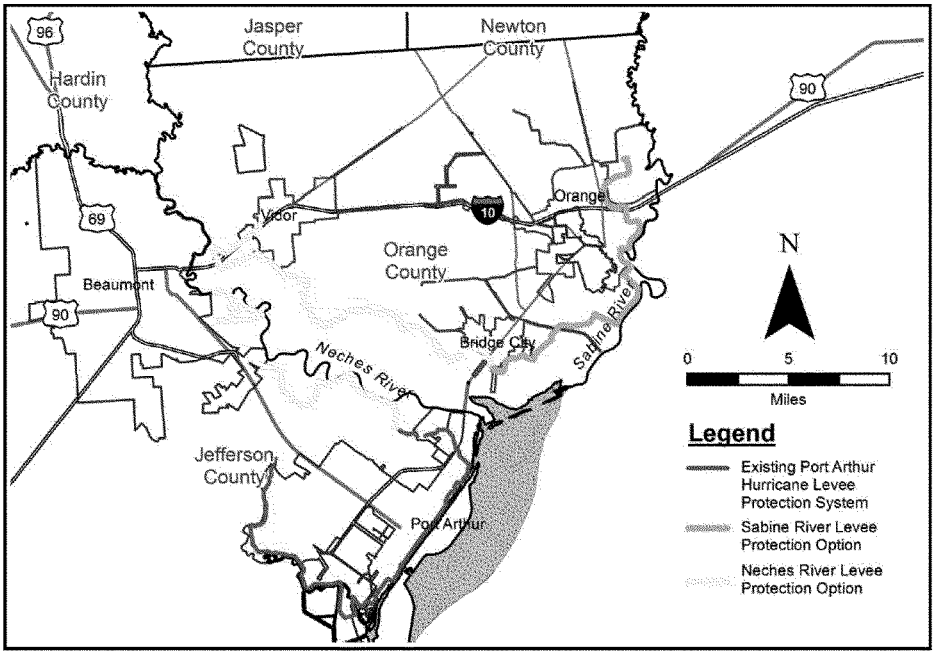

Figure 6-1: Levee Alignment to Provide Full County Protection on East and West Bank of Neches River (ref: Orange County Report)

6.1.1.2 Port Arthur HFPP Alignment

The Port Arthur HFPP is an established flood risk reduction system. No realignments are proposed at this time. A section of levee will be added to the system northwest of the far eastern end. Two areas of the current alignment should be investigated during the PED phase for possible re-alignment due to existing infrastructure. The two areas are near the Valero refinery and along the Sabine Neches Canal near the Port of Port Arthur facilities. This task is currently outside the scope of this study.

6.1.1.3 Freeport HFPP Alignment

The Freeport HFPP is an established flood risk reduction system. No realignments are proposed at this time. Notably, however, that part of the system along the Dow Barge Canal, which is approximately 13 miles, will effectively be rendered obsolete, as it will be cut off by the proposed navigation gate structure. One area of the current alignment (an approximate 1 mile section of the Old River South reach) should be investigated during the PED phase for possible re-alignment due to existing port and industry facilities. This task is currently outside the scope of this study.

6.1.2 Site Development

6.1.2.1 Orange-Jefferson County HFPP

Much of the areas traversed by the new levee system are highly or moderately developed, represented by industrial, residential, and commercial properties. The intent is to reduce flood-damage risk to vulnerable population and valuable assets, while at the same time minimize the environmental impacts; therefore, it is logical that levees and floodwalls would be constructed within and near sizably developed areas. The proposed CSRM alignment was appropriately routed with this in mind. Within developed areas, only a modest amount of clearing is anticipated. That said, several single-family homes, industrial and commercial buildings, structures, utilities (excluding pipelines), and pavements will have to be removed, relocated, or modified to provide necessary clearances and to construct the project. The number of affected structures was not counted for the Recommended Plan cost estimate. The default assumption however was that where a grouped number of structures or utilities would be adversely impacted by the construction of a levee, because of the embankment's large footprint, the more expensive floodwall structure, having a comparatively small footprint, would be built instead where reasonable for accommodation (assuming avoidance was not otherwise practical). This assumption was also made for situations in which there would be considerable impacts on sensitive environmental habitats. Assuming the more expensive floodwall structure option takes into consideration public acceptance and the political ramifications of the project where local public support for it is crucial.

The proposed Orange County reach alignment will cut through several forested areas that will require a lot of clearing and grubbing within the entire area of the temporary construction easements. In deriving the Recommended Plan cost the acreage of forests within the preliminary permanent easements was not estimated. Instead, a uniform amount of clearing, grubbing, and stripping was assumed per lineal foot of levee/floodwall construction and parametric cost estimates applied. The assumption was made that all cleared materials will be hauled to and disposed of at offsite locations.

After clearing and grubbing the area and appropriately addressing structures within the temporary construction easements, the foundation areas within the levee embankment footprint will be stripped to a depth of one-half foot. The subgrade will be excavated an additional 2.5 feet and will then be proof-rolled and scarified afterwards before receiving fill. For the floodwall footing, the area within its footprint will be stripped and excavated to the required footing depth.

6.1.2.2 Port Arthur and Vicinity CSRM

The improvements of the recommended plan for the existing system are to replace all floodwall sections, rebuild all closure structures within the system and modestly raise the levees in several

areas. Scour protection with reinforced-concrete pads is proposed along all floodwall. The levees will be raised by adding a fill lift atop the crown and interior-side slope. The completed improvements will be entirely within the existing perpetual easement. Where needed to accommodate construction activities however, additional temporary work area easements will be acquired. Because the existing system already is a developed project that is routinely maintained, no significant additional site development is anticipated to construct the improvements. The assumed construction operations will involve the stripping of surfaces to receive pavement and fill, modest excavations, removing road pavement (on the levee crown), placing concrete, placing select fill, constructing paved roadway, and turfing. These operations will be conducted in a developed environment.

6.1.2.3 Freeport and Vicinity CSRM

The improvements for the existing system include replacement of current floodwall, addition of several sections of new floodwall, areas of levee raises, new gated vehicular closure structures, a navigable gate structure and several drainage structures. The Recommended Plan for the Freeport CSRM component also includes the construction of a new navigation structure near the entrance of the Dow Barge Canal. The levees will be raised by adding a fill lift atop the interior-side slope. This will be done entirely within existing rights-of-way. Where needed to accommodate construction activities however, temporary work area easements beyond the perpetual easement will be acquired. Except for the proposed navigation gate structure, little additional site development will be necessary to construct the improvements because the project is already a developed project that is maintained.

Construction of the navigation gate structure will require the construction of a cofferdam and provision for allowing the continued passage of barge traffic. Consequently, a considerable amount of logistics coordination and accommodation will go into the construction of this feature. Selecting the site for the structure will require the deliberate assessment of possible locations that would be practical from construction, functional integrity, and operational perspectives given the constraints of available land area and maintaining navigation on the barge canal, and to a lesser extent, the characteristics of existing foundation soils. Significant site development will be required because the structure will be constructed in the dry. The structure location will be approximately 1 mile into the DOW Barge Canal from its entrance.

6.2 REAL ESTATE

6.2.1 General

For a feasibility study, USACE determines real estate requirements and associated cost based on the selected plan footprint and a gross appraisal. More exact real estate requirements are developed during the design phase following completion of the feasibility study.

According to Federal law, the non-Federal sponsor is responsible, within USACE guidance, to undertake (pay for) the required real estate actions. Real estate actions and acquisition required for project construction will begin prior to award of the individual construction contracts. The proposed Orange-Jefferson County CSRM will require pipeline and utility relocations, accommodation of existing roadways, and the removal of existing structures. USACE evaluates the compensable (or non-compensable) nature of the various utility relocations in conjunction with the sponsor via Attorney's Opinion of Compensability. It then assigns relocation costs when the utility ownership and real estate rights information is adequate for a compensability determination. Utility relocation design details are developed during the design phase. The associated project costs of pipeline and utility relocations and other infrastructure modifications were not considered for the alternative comparison stage while determining the Recommended Plan through the NED criteria, they have been subsequently added to the Recommended Plan cost. Pertaining estimates and details are contained in this chapter.

6.2.2 Orange-Jefferson County CSRM

In developing the recommended plan in Orange and Jefferson Counties, temporary construction easements and perpetual easements of uniform width were assumed for the new levees and floodwalls respectively. For the levees, a perpetual easement ranging from 101 feet to 150 feet was devised, variations in such easement requirements are due to the varying nature of the elevation of the flood risk reduction system and the existing natural ground. Easement assumes minimum 30-foot-wide work areas along each side of the levee embankment as measured from any feature of the proposed system for operations, maintenance, and monitoring. For the floodwalls, which have a smaller footprint than the levees, a uniform 78 foot wide easement was assumed for permanent use. The driving consideration on the floodwall permanent easement requirements are the features related to the foundation, which are likely to be piled and some of those piles will be angled away from the system centerline.

Further refinement of features will take place during the PED stage but the final-design structure templates implemented for most of the project will be the same as or smaller than those assumed, even when adding structure height to account for future sea-level rise, wave run-up, freeboard, and foundation settlement and consolidation (overbuilding of the levee embankment). There will be

instances too along the alignments where narrower-width work areas are necessary or preferred to minimize impacts on existing infrastructure, facilities, buildings, and environments or because of physical hindrances (e.g., bodies of water, soil conditions, and limited construction easement). Conceivably, there could be instances where the easements would need to be made wider, although this is not expected. As the project features are further developed and refined relative to the existing terrain and physical features, the construction easements will be appropriately tailored along the alignment.

For the navigation gate structures proposed to be built across Adams and Cow Bayous, temporary construction easements for staging areas and perpetual easements will need to be acquired.

It was also assumed that four (4) temporary staging areas will be needed to construct the Orange 3 reach.

6.2.3 Port Arthur and Vicinity HFPP

The construction activities to construct the proposed improvements can be performed entirely within the existing rights-of-way. This will ultimately depend however on how high the levees are incrementally raised to accommodate wave run-up, future sea-level rise, and the minimum freeboard requirement. Fourteen temporary staging areas totaling 33 acres were assumed to be needed for construction.

6.2.4 Freeport and Vicinity HFPP

Except for the navigation gate structure and the drainage overflow structure, most, if not all, of the construction activities to construct the proposed improvements can be performed entirely within the existing rights-of-way, depending on how high the levees are incrementally raised to accommodate wave run-up, future sea-level rise, and the minimum freeboard requirement. Six (6) temporary staging areas were assumed to be needed for construction. For the navigable gate structure, temporary construction easements for staging and a perpetual easement will need to be acquired.

6.3 RELOCATIONS

6.3.1 Pipelines

Due to the prevalence of the petrochemical industry within the study areas, the projects cross or parallel, or will cross or parallel numerous pipelines carrying various petroleum products. The proposed new systems also cross several other utility conduits and storm drains as well. All such conduits are generically referred to in this report as "pipelines". Plates C-69 through C-87 show the number of pipelines crossed.

In most instances, existing pipelines that will cross beneath or through a planned flood risk reduction system, or be close to it, require relocation. This is because most pipelines are buried at a relatively shallow depth when surcharge loading is not anticipated and leaving them in place could cause serious damage to and structural compromise of the levees. The structural integrity of the pipelines can also be adversely affected when putting a large surcharge load over them, as will access to the pipelines. The pipe strength may not be enough to withstand the added loading and pipe joints may be unable to accommodate movements resulting from foundation settlement. The foundation design for the floodwalls may also preclude allowing pipelines to remain in place. As a general rule, pipelines beneath flood risk reduction features such as levees and floodwalls should be avoided altogether, particularly in the case of pressure lines.

When developing the projects to a greater level of design detail/confidence, the necessity for pipeline relocations will be re-evaluated. It may be that some pipelines can be allowed to remain in place within the levee foundation. In assessing this, the following principal items will be considered:

- levee height
- duration of high water stages against the levee
- susceptibility to piping and settlement of levee and foundation soils
- type of pipeline (low- or high-pressure line, or gravity drainage line)
- depth of the pipeline
- feasibility of providing closure in event of ruptured pressure lines, or in the event of failure of flap valves in gravity lines during high water
- ease and frequency of required maintenance and access
- cost of acceptable alternative systems
- possible consequences of piping or failure of the pipe

Since all but a few of the pipelines crossed by the proposed new levee/floodwall systems carry petroleum products and are buried at a relatively shallow depth, and given that their present condition and strength are unknown, the presumption will be that virtually all these pipelines will have to be relocated. Supporting this premise is that significant settlement and consolidation of the compressible foundation from the added levee surcharge load is expected will take place, which undoubtedly will greatly disturb/stress the pipelines embedded within it. The bottom of the concrete footings of the floodwalls will also be set a few feet below the existing grade and in some instances, piles may have to be driven for the foundation. Leaving the pipelines in place only increases the risk that either the structures composing the HFPP or the pipeline will eventually be structurally compromised.

6.3.1.1 Pipelines Crossing Orange-Jefferson County CSRM

Relocations or modifications for the pipelines and utilities crossing the proposed Orange-Jefferson County CSRM alignment or near the alignment, and their associated costs, will be extensive. Essentially all the pipelines, if not all, will require relocation given their shallow burial depths and likely structural inadequacy to handle the greater overburden load, and because they will effectively serve as seepage conduits. Even under short-duration hydrostatic loading, seepage is a concern that needs to be examined. (Current requirement is that a steady-state seepage condition must be assumed for flood-damage reduction structures.)

Information on the pipelines crossing the Orange-Jefferson County alignment was obtained from an oil and gas GIS database maintained by the TRRC. This information included the pipeline's approximate location and orientation by coordinates, system and subsystem names, ownership, operator, diameter, product carried, and permit. However, it did not provide the pipeline depth. Because only a nominal amount of the Orange and Jefferson County project area is within USACE's regulatory domain, no information on pipeline depths was immediately available that might have been included in as-installed permit records. There was no other expedient vehicle by which the pipeline depths could be readily assessed. Most oil and gas pipelines though are typically buried at a depth of 3 to 6 feet, as reported by the industry.

6.3.1.2 Pipelines crossing Port Arthur and Vicinity and Freeport and Vicinity HFPPs

While a number of pipelines cross the Port Arthur and Freeport systems, very few pipeline and utility relocations or modifications are anticipated as being necessary for these systems. Where the recommended plan consists of levee raises, it is assumed that these pipeline crossings will not require relocation. Modest raising of the levees is not expected to have an appreciable effect on the pipelines. Pipelines crossing floodwall will require relocation in both areas.

6.3.2 Pipeline Relocation Method

All pipelines requiring relocation will be removed by mechanical excavation (i.e., trenching) and then reinstalled at a deeper depth by way of horizontal directional drilling, which is ideally suited for deep burial depths. Directional drilling is a reliable method of relocation and can be done prior to constructing the levee. From a geotechnical perspective, the pipeline needs to be installed deep enough beneath any of the system features to avoid stresses that could be induced from the constructed embankment subsidence. The required depth and minimum distances the pipeline entry and exit points should be from the levee/floodwall centerline will be investigated in PED as the project details are further developed. That said, it is expected that the relocated pipelines will have to be buried at a depth of at least 30 feet below ground at the structure centerline with entry and exit points at least 100 feet away from the centerline.

6.3.3 Road Crossings

Along existing and proposed alignment of system features are road crossings that would have to be relocated, raised and taken in account in estimates and design considerations. Details on such crossings are displayed in Table 6-1, Table 6-2, and Table 6-3. For the Orange 3 reach, the type of proposed crossing for each of the individual crossings is listed. The type of proposed crossing was determined by a cursory review in google earth imagery, which took into account several aspects of the crossing area. These items included type of road, assumed use of road, and the location of road in relation to existing infrastructure. The crossings for the Port Arthur system are all recommended to be improved to the same type of crossing as the existing, except for the removable panel crossings which will be replaced with gated structures. For the Freeport system, most crossings will be improved with the same type of crossing, except for several existing ramps of the DOW Barge Canal South and Old River South levees, which will require gated closures due to the recommended floodwall construction in the crossing areas. The type and number of crossings will be refined in the PED phase, currently only preliminary types and locations have been chosen.

Table 6-1: Orange 3 Road/Railroad Crossings

Name	Station	City	Crossing	Type of Proposed Crossing Structure
I-10 Underpass	-----	Orange	Roadway	Gate
N Farragut Ave	32+00	Orange	Roadway	Gate
E Park Road	114+00	Orange	Roadway	Gate
Pier Road	121+25	Orange	Roadway	Gate
Cypress Avenue	125+79	Orange	Roadway	Gate
Cypress Ave	137+24	Orange	Roadway	Gate
E Green Avenue	140+73	Orange	Roadway	Gate
Main Avenue	144+36	Orange	Roadway	Gate
Front Avenue	147+74	Orange	Roadway	Gate
Simmons Drive	151+78	Orange	Roadway	Gate
Railroad Access	152+27	Orange	Railroad	Gate
Access Road	153+67	Orange	Roadway	Gate
Polk Avenue	188+52	Orange	Roadway	Gate
Jackson Avenue	193+67	Orange	Roadway	Gate
Market Street	200+42	Orange	Roadway/Railroad	Gate
Moss Avenue	209+58	Orange	Roadway	Gate
Georgia Street	212+92	Orange	Roadway/Railroad	Gate
Facility Access Road	220+17	Orange	Roadway	Gate
Border Street	246+95	Orange	Roadway	Gate

Alabama Street	262+46	Orange	Roadway/Railroad	Gate
Facility Access Road	562+89	Orange County	Roadway	Gate
Facility Access Road	586+25	Orange County	Roadway	Gate
Facility Access Road	597+50	Orange County	Roadway	Gate
Facility Access Road	670+25	Orange County	Roadway	Ramp
Lakeshore Farm Road	697+73	Orange County	Roadway	Ramp
Gumhill Street	744+46	Bridge City	Roadway	Gate
Hideaway Street	757+77	Bridge City	Roadway	Ramp
Facility Access Road	837+10	Bridge City	Roadway	Gate
Old Ferry Road	943+90	Bridge City	Roadway	Gate
State Highway 87 (East)	977+78	Bridge City	Roadway	Gate
State Highway 87 (West)	978+27	Bridge City	Roadway	Gate
Facility Access Road	1119+98	Bridge City	Roadway	Gate
Facility Access Road	1132+85	Bridge City	Roadway	Ramp
Facility Access Road	1141+21	Bridge City	Roadway	Ramp
Gulf States Utilities Road	1148+70	Bridge City	Roadway	Ramp
Facility Access Road	1151+00	Bridge City	Roadway	Ramp
Facility Access Road	1157+17	Bridge City	Roadway	Ramp
Powerhouse Road	1166+90	Bridge City	Roadway	Ramp
Powerhouse Road	1194+61	Bridge City	Roadway	Ramp
Gulf States Utilities Road	1198+43	Bridge City	Roadway	Ramp
Facility Access Road	1215+75	Bridge City	Roadway	Gate
Facility Access Road	1218+12	Bridge City	Roadway	Gate
Bessie Heights Road	1329+42	Bridge City	Roadway	Ramp
Tanglewood Drive	1356+26	Bridge City	Roadway	Gate
Ivy Lane	1380+85	Bridge City	Roadway	Ramp
Tillie Smith Road	1389+84	Bridge City	Roadway	Ramp

Table 6-2: Port Arthur Existing Road/Railroad Crossings

Name	Station	Reach	Crossing	Type of Crossing Structure	Proposed New Crossing
Access Road	128+90	Reach 1	Roadway	Swing Gate	Gate
Rail Access	310+45	Reach 1	Railroad	Swing Gate	Gate
Access Road	345+22	Reach 1	Roadway	Swing Gate	Gate
Seawall Drive	515+89	Reach 2	Roadway	Ramp	Ramp
Seawall Drive	521+89	Reach 2	Roadway	Ramp	Ramp
Seawall Drive	529+50	Reach 2	Roadway	Ramp	Ramp
Seawall Drive	573+50	Reach 2	Roadway	Ramp	Ramp
Access Road	621+83.77	Reach 3	Roadway	Swing Gate	Gate
Rail Access	624+52.00	Reach 3	Railroad	Removable Panel	Gate
Access Road	640+43	Reach 3	Roadway/Railroad	Removable Panel	Gate-2
West Lakeshore Drive	642+39.48	Reach 3	Roadway	Removable Panel	Gate
Access Road	644+60.75	Reach 3	Roadway/Railroad	Removable Panel	Gate-3
Rail Access	646+09.82	Reach 3	Railroad	Removable Panel	Gate
Rail Access	646+86.15	Reach 3	Railroad	Removable Panel	Gate
Texaco Island Road	736+61	Reach 4	Roadway	Ramp	Ramp
Rail Access	769+71.86	Reach 4	Railroad	Swing Gate	Gate
Access Road	770+21.86	Reach 4	Roadway	Swing Gate	Gate
Access Road	771+80.11	Reach 4	Roadway	Swing Gate	Gate
Access Road	773+48.16	Reach 4	Roadway	Swing Gate	Gate
Access Road	777+76.15	Reach 4	Roadway	Swing Gate	Gate
Access Road	827+62.40	Reach 4	Roadway	Swing Gate	Gate
Access Road	829+86.52	Reach 4	Roadway	Swing Gate	Gate
Access Road	834+56.49	Reach 4	Roadway	Swing Gate	Gate
Access Road	845+65.85	Reach 4	Roadway	Swing Gate	Gate
Access Road	848+97.66	Reach 4	Roadway	Swing Gate	Gate
Access Road	858+53.70	Reach 4	Roadway	Swing Gate	Gate
Rail Access	871+88.90	Reach 4	Railroad	Swing Gate	Gate
Dowling Road	874+00	Reach 4	Roadway	Ramp	Ramp
Facility Access Road	983+78	Reach 5	Roadway	Ramp	Ramp

Facility Access Road	999+58	Reach 5	Roadway	Ramp	Ramp
Hwy 365	1453+10	Reach 5	Roadway	Swing Gate	Gate
Facility Access Road	N/A	PA Extension	Roadway	Ramp	Ramp
East Port Neches Avenue	N/A	PA Extension	Roadway	Ramp	Ramp
Access Road	N/A	PA Extension	Roadway	Ramp	Ramp

Table 6-3: Freeport Existing Road Crossings

Name	Station	Reach	Crossing	Type of Levee Crossing Structure	Proposed New Crossing
County Road 690B	201+12	Oyster Creek	Roadway	Ramp	Ramp
Duncan Drive	216+60	Oyster Creek	Roadway	Ramp	Ramp
Access Road	244+86	Oyster Creek	Roadway	Ramp	Ramp
Unnamed Road	283+99	Oyster Creek	Roadway	Ramp	Ramp
FM523	285+98	Oyster Creek	Roadway	Ramp	Ramp
Access Road	288+58	Oyster Creek	Roadway	Ramp	Ramp
Access Road	294+80	Oyster Creek	Roadway	Ramp	Ramp
Access Road	352+89	Oyster Creek	Roadway	Ramp	Ramp
Access Road	41+69	East Storm	Roadway	Ramp	Ramp
FM 332	81+26	East Storm	Roadway	Ramp	Ramp
Cone Island Road	111+71	East Storm	Roadway	Ramp	Ramp
Facility Road	247+50	Dow Barge Canal North	Roadway	Ramp	Ramp
Facility Road	269+76	Dow Barge Canal North	Roadway	Ramp	Ramp
Facility Road	265+33	Dow Barge Canal South	Roadway	Ramp	Ramp
Facility Road	274+58	Dow Barge Canal South	Roadway	Ramp	Ramp
Facility Road	305+34	Dow Barge Canal South	Roadway	Ramp	Gate
Facility Road	315+18	Dow Barge Canal South	Roadway	Ramp	Gate
South Avenue D	125+78	Old River North	Roadway	Ramp	Ramp
Midway Road	131+30	Old River North	Roadway	Ramp	Ramp
Access Road	155+61	Old River North	Roadway	Ramp	Ramp
Port Road	120+00	Old River South	Roadway	Swing Gate	Gate
Port Road	135+49	Old River South	Roadway	Swing Gate	Gate
Access Road	142+18	Old River South	Roadway	Ramp	Ramp

East Brazos Blvd	142+74	Old River South	Roadway	Ramp	Ramp
Access Road	160+78	Old River South	Roadway	Ramp	Ramp
Access Road	244+29	Old River South	Roadway	Ramp	Gate
Access Road	255+07	Old River South	Roadway	Ramp	Gate
Access Road	257+66	Old River South	Roadway	Ramp	Gate
Access Road	263+72	Old River South	Roadway	Ramp	Gate
Access Road	273+50	Old River South	Roadway	Ramp	Gate
Access Road	276+98	Old River South	Roadway	Ramp	Gate
Facility Road	21+49	South Storm	Roadway	Ramp	Ramp
Facility Road	26+15	South Storm	Roadway	Ramp	Ramp
Facility Road	27+33	South Storm	Roadway	Ramp	Ramp
Bryan Mound Road	41+39	South Storm	Roadway	Ramp	Ramp

7 STRUCTURAL

7.1 INTRODUCTION

This section discusses the structural data gathering efforts and engineering analyses for the Sabine to Galveston FIFR-EIS. A feasibility level of analysis was completed to come up with a conceptual design for the structural components of the proposed Orange-Jefferson, Port Arthur and Freeport CSRM's. The proposed Orange-Jefferson CSRM shown in Figure 7-1, the Port Arthur and Vicinity CSRM shown in Figure 7-2 and the Freeport and Vicinity CSRM shown in Figure 7-3 each contain lengths of floodwall proposed to be included in their alignments. The lengths of proposed features per area are included in Table 7-1. The total length of Orange 3 includes distances within the alignment for pump stations, road closure gates and navigation structures. The proposed Orange 3 Reach of the Orange-Jefferson CSRM crosses two existing navigation channels - Adams Bayou and Cow Bayou. Consequently, this requires closure at each bayou with a navigable gate structure. The recommended plan for the Freeport CSRM includes adding in a sector gate structure to cross the DOW Barge Canal, refer to Chapter 1 of the Engineering Appendix for more information. This feasibility document outlines the work accomplished for the preliminary analysis of the floodwall and the conceptual design of the navigable gate structures. For information on the drainage structures or pump stations see the Hydrology and Hydraulics section.

Figure 7-1: Orange-Jefferson CSRM – Overview Map

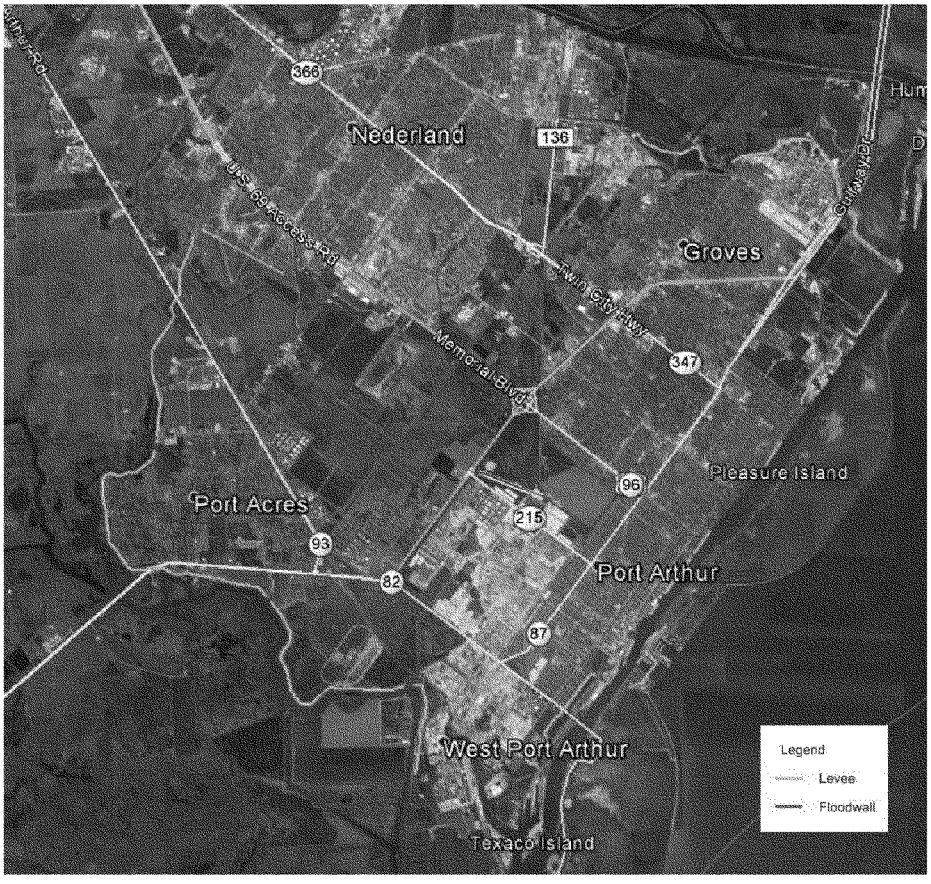

Figure 7-2: Port Arthur and Vicinity CSRM - Overview Map

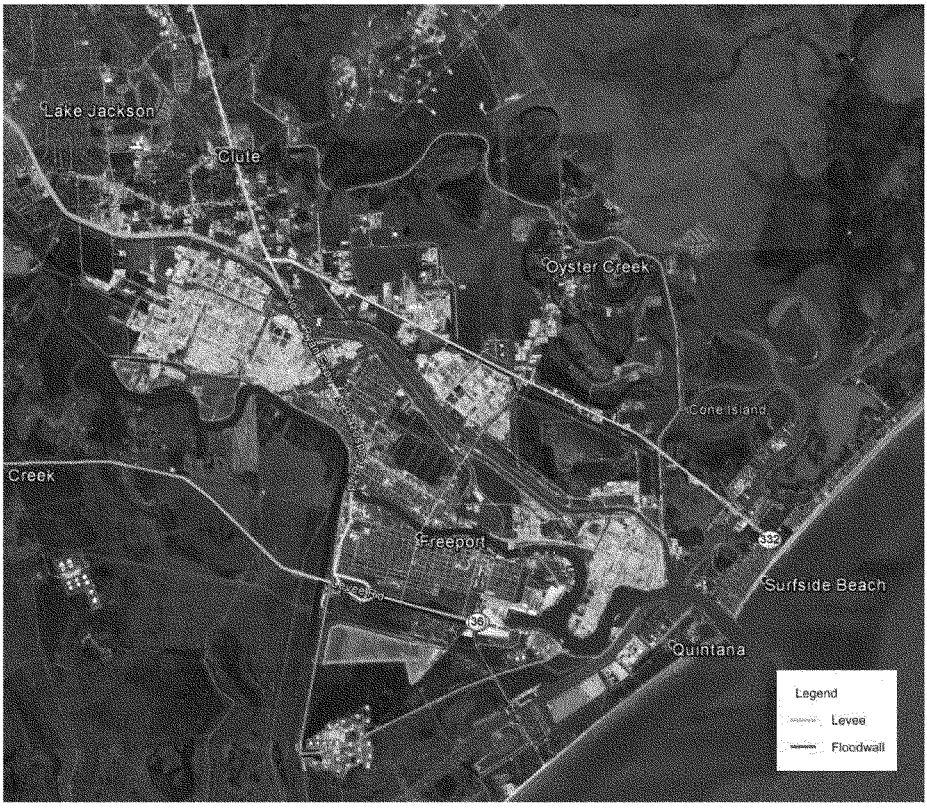

Figure 7-3: Freeport and Vicinity CSRM - Overview Map

Table 7-1: Approximate Lengths of Proposed Features per Area

Reach	Total Length (ft)	Length Of Features (ft)	
		Levee/Raise	Floodwall
Orange 3	141,064	82,169	56,755
Port Arthur	162,162	31,030*	30,090
Freeport	217,217	69,375	29,255
*Includes 'Port Arthur Addition'			

7.2 FLOODWALL

7.2.1 Assumptions

The floodwall will be designed as a reinforced concrete T-wall, which is assumed to be the most appropriate type of floodwall for the project area, due to levee elevation requirements and projected loadings. The T-wall type of floodwall also has no height limit and is the recommended type for areas with barge/boat impacts, which are possible in several areas with these proposed and existing levee systems. Floodwall in the Orange-Jefferson CSRM, as well as the Freeport and Port Arthur CSRM's is being designed to an average top elevation of all portions of floodwall in the Orange 3 alignment. The floodwall designed for the Orange 3 reach will be checked against the parameters for the existing systems (Port Arthur and Freeport) to validate using the same typical cross section for all locations which are proposed to be floodwall. The top elevation for construction includes added height for wave run-up and relative sea level rise, at the predicted 50 year intermediate level, on top of the modeled SWLs. To account for future sea level change up to the 100 year intermediate or 50 year high levels, the floodwall is being designed with enough structural capacity in its stem, base and foundation to account for any possible raise required. The average top elevation of floodwall in the Orange 3 reach was determined thru analysis of hydraulic factors, including SWL and wave run-up, during the plan optimization phase of the project. From these calculated heights, the weighted average was determined using the heights and their associated lengths of levee. This was completed for each of the RSLC scenarios considered in this study, 50 year intermediate, 100 year intermediate and 50 year high for the Orange 3 reach. The elevations have been rounded and are shown in Table 7-2.

Table 7-2: Floodwall Elevations for RSLC Scenarios - Orange 3

Orange 3 - Floodwall Elevation (weighted Avg)	
RSLC Scenario	Elevation (NAVD88)
50 Year Intermediate	15
100 Year Intermediate	17
50 Year High	17

*Ground El = 5

For cost estimating purposes, the stem height was varied according to the variations in natural ground elevations, with the base geometry, concrete thicknesses, and pile arrangement remaining the same. Preliminary design parameters for the floodwall are based on hydraulic loadings (surge, wave run-up, etc.) provided by H&H and generalized local soil conditions along the alignment of the levee provided by Geotechnical. The soil parameters from the area with the perceived worst soil conditions were used for the floodwall analysis. From the geotechnical investigations, sand

stratums were found in areas the floodwall traversed. The floodwall will utilize a steel sheet pile cutoff (PZ22) for the entire length of floodwall, due to the assumption that a coastal storm event in this area would achieve steady state conditions. The project areas are in a non-seismic zone; therefore, no seismic analysis was done.

For areas of the alignment which require a tie-in between the earthen levee and floodwall, the seepage cutoff steel sheet pile of the T-wall will extend into the earthen embankment a distance equal to or exceeding the design height of the earthen levee. This extension is assumed to be 20 feet, but will depend on heights of the levee adjacent to the floodwall.

7.2.2 Structural Analysis

The design process for the floodwall used several EMs and the HSDRRDG. The floodwall was designed according to EM 1110-2-2502, but EM 1110-2-2100 was utilized where it superseded the older guidance. The reinforced concrete was designed according to EM 1110-2-2104.

7.2.2.1 Design Parameters

- Natural ground elevation: EL 5.0'
- K_o: 0.8 (at-rest earth pressure coefficient)
- Cohesion = 0.4 ksf (foundation)
- Φ = 23 degrees, for drained condition
- Unit weight (soil), γ = 110 pcf
- Unit weight (concrete), γ = 150 pcf
- Unit weight (water), γ = 64.0 pcf
- Still-Water Level = EL +11 feet (provided by H&H)
- Wave data for design purposes not provided at this stage of the project
- Concrete: normal weight, f'c = 5ksi (w/c = 0.4)
- Reinforcing steel: ASTM A615, fy = 60 ksi

The natural ground elevation was established from LiDAR survey data for the area. The ground elevation used for the design is an average value for all locations of floodwall. The average ground elevation was derived from the available LiDAR survey data by creating a profile along the Orange 3 reach and calculating the average ground surface within all locations of floodwall. Geotechnical provided the foundation soil properties information (at-rest earth pressure coefficient, soil cohesion, phi angle, and unit weight) that was obtained through geotechnical investigations. The soil properties used for the design were from the area of floodwall with the perceived worst soil conditions (i.e. low cohesion value). (For more information on these input variables, including how they were derived, see the Geotechnical section of this appendix.) A higher unit weight of

water (64.0 pcf) was assumed t for the design due to the higher salinity of the water in this coastal location. The still-water level was calculated from modeling performed by H&H (see Chapter 2 of this appendix), but was determined to be the most cost effective plan through the economic analysis. For more information on the economic analysis, see the main report and Appendix C.

7.2.2.2 Load Cases and Factors

Load cases for the floodwall design, as shown in Table 7-3, are based on EM 1110-2-2100, EM 1110-2-2502 and the HSDRRDG, which provides several additional load cases. The load cases and their associated values shown in Table 7-3 consider the 50 year intermediate RSLC scenario, which is the level these levee systems would be constructed to. For design checks and to determine adequate structural capacity for a possible future raise, the same load cases and floodwall cross section dimensions were utilized with the 100 year intermediate and 50 year high RSLC water levels. The single load factor method, outlined in EM 1110-2-2104, was used to determine the factored moment and shear for the concrete structure. Where guidance overlapped, the more conservative approach was utilized for the design that would satisfy all applicable guidance.

Table 7-3: Floodwall Load Cases

Sabine to Galveston Floodwall Load Cases (Refer to EM 1110-2-2100, EM 1110-2-2502 Table 4-3, & HSDRRSDG)

Load Case No.	C1	C3	C4	C6*	C6**
Title	Surge Stillwater	Construction	Normal Operating	Wind	Stillwater to Top of Wall
Description	Backfill in place Water to stillwater Level (flood side) Waves excluded Uplift acting	Short Duration Loading Wind Included Construction Equipment Surcharge	Backfill in place Water at 10-yr return period level Uplift Acting	Backfill in place Water at usual (non-storm) level Wind on land side	Backfill in place Water to top of wall Level (flood side) Waves excluded Uplift acting
Load Case Classification	Unusual	Unusual	Unusual	Unusual	Extreme
Flood water Elevation	11.00	-----	7.00	-----	15.00
Wave Height	-----	-----	-----	-----	-----
Backfill Elevation - Flood Side	5.00	5.00	5.00	5.00	5.00
Backfill Elevation - Land Side	5.00	5.00	5.00	5.00	5.00
Surcharge	-----	5 k/ft, 40 mph wind speed	-----	140 mph wind speed	-----
Resultant Location (Min base in Compression)	75.0%	75.0%	75.0%	75.0%	Resultant within Base
Sliding FS Required	1.50	1.50	1.50	1.50	1.10
Flotation FS	1.20	1.20	1.20	1.20	1.10
Minimum Bearing Capacity FS	3.00	3.00	3.00	3.00	3.00

-Load Cases C1, C1a, C1b, C1c, C3 and C4 are from EM 1110-2-2100

*Load Case C5 is from EM 1110-2-2502, Table 4-3

**Load Case C6 is from New Orleans HSDRRSDG; values for sliding, resultant, flotation, and bearing from EM 1110-2-2100

***Information for wave load cases (C1a, C1b, C1c) not provided at this stage (will update design when values are provided by H&H)

7.2.2.3 Design

The floodwall cross-section, shown on Plate S-01, for the conceptual design (dimensions shown in Figure 7-4 and Figure 7-5) was generalized for all locations of floodwall. The floodwall is being designed to be adaptable to the 100 year intermediate or 50 year high RSLC levels from its proposed construction elevation for this study, which is the 50 year intermediate RSLC level. For purposes of this study, quantities for the cost estimate will utilize the recommended NED top of wall elevation, which is at the 50 year intermediate RSLC level. The design assumes a stem height of 14 feet, which includes the 50 year intermediate RSLC level (16 feet for the 100 year intermediate or 50 year high RSLC level), and a ground elevation of +5 feet NAVD 88. The top of wall height was established based on a SWL of 11 feet NAVD 88, and includes additional height provisions for wave run-up and intermediate sea level rise. The SWL is premised on the economic analysis results that establish the NED Plans. The thicknesses of the concrete base and stem were optimized in the design process to provide the most appropriate cross section. Cohesive soil, having low permeability, will be used to back fill the flood side of the walls to reduce the potential of seepage under the wall. This material will also be used to backfill the land side of the walls where a concrete splash apron will be constructed to prevent scour from wave overtopping. Because of the cohesive nature of soil to be used as backfill and assumed conservative value for the soil foundation material (C = 0.4 ksf), the strength mobilization factor was not applied in the design calculations.

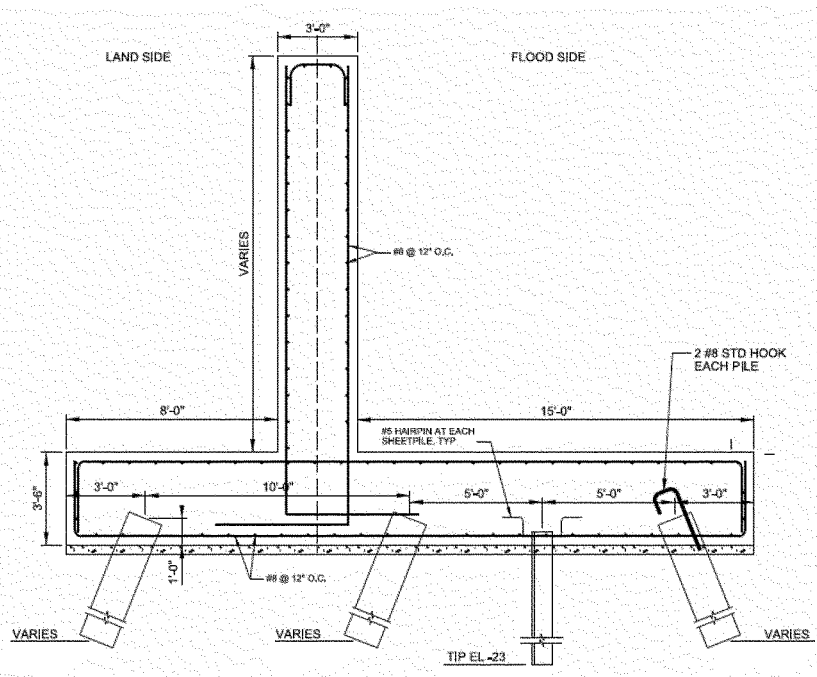

Figure 7-4: Floodwall - Conceptual Design Cross Section

Sabine to Galveston - Floodwall

Design Parameters

Floodwall dimensions (see figure)	
Top of Wall Elevation (100 Int, 50 High RSLC) =	17
Top of Wall Elevation (50 YR Int RSLC) =	15
Ground EL (flood side) =	5
Ground EL (land side) =	5
stem height=	16
stem width=	3
base width=	26
base height=	3.5
stem position on base =	9.50
heel length=	15.00
toe length=	8.00
EL, top of base=	1
EL, bottom of base=	-2.5

Design Parameters		
$\gamma_{saturated}$ (lb/ft^3) =	110	
$\gamma_{submerged}$ (lb/ft^3) =	46	
γ_{water} (lb/ft^3) =	64	
$\gamma_{concrete}$ (lb/ft^3) =	150	
K_a =	0.8	
Wind Velocity (mph) =	140	*Load Case 5

Load Factors (per EM 1110-2-2104, 3-3)	
Hydraulic =	1.3
Hydraulic (tension) =	1.65
Dead =	1.7
Live =	1.7
Wind =	0.75

$c_{undrained}$ (ksf) =	0.4	
$\phi_{undrained}$ =	0	
$N_{q,\ undrained}$ =	1.00	(EM 1110-2-2502, Table 5-1)
$N_{\gamma,\ undrained}$ =	0.00	(EM 1110-2-2502, Table 5-1)
$N_{c,\ undrained}$ =	5.14	(EM 1110-2-2502, Table 5-1)

$c_{drained}$ (ksf) =	0	
$\phi_{drained}$ =	23	
$N_{q,\ drained}$ =	8.66	(EM 1110-2-2502, Table 5-1)
$N_{\gamma,\ drained}$ =	4.82	(EM 1110-2-2502, Table 5-1)
$N_{c,\ drained}$ =	18.05	(EM 1110-2-2502, Table 5-1)

Figure 7-5: Input for Floodwall Analysis

Several stability analyses were performed in accordance with the guidance of EM 1110-2-2502. These included evaluations of overturning, sliding, and bearing capacity. Each of these stability checks has an associated factor of safety for different load cases that the floodwall shall be designed to meet, which is provided in Table 7-3. A summary of the design parameters and input values that were used in the stability analyses are shown in Figure 7-5.

Several areas of the existing systems, which were found to require a large earthen levee raise, do not have sufficient available space to construct the raise with earth fill. These sections of levee will require a small T-wall section of floodwall, which is shown in Figure 7-6.

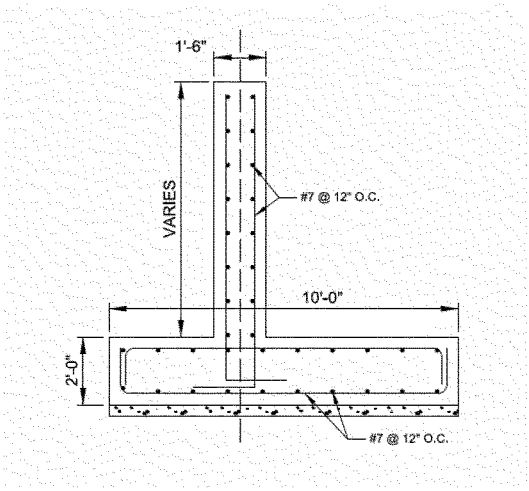

Figure 7-6: Floodwall - In Place of Earthen Levee Raise

7.2.3 Conclusions

More extensive soils investigations will need to be conducted during PED to provide better understanding of the foundation conditions for the various floodwall sections along the proposed Orange-Jefferson CSRM levee alignment, Port Arthur CSRM, and Freeport CSRM work areas. Analyses including, but not limited to, seepage, global stability, heave, and settlement, will be completed during the PED phase in accordance with applicable USACE engineering guidance.

Several sections of floodwall in the proposed alignment are near or along navigation channels; therefore marine vessels will be traveling near them. For those floodwalls that will be adjacent to the proposed navigation gates, a protective system consisting of timber piles will be installed to prevent vessel strikes (collisions) on the floodwalls during normal operations and during storms. The relative draft of a typical barge is 10 to 12 feet; therefore, with a top of wall surge loading at

elevation +15.00 feet NAVD 88, the fender system will have to be built to a height that would be sufficient to keep vessels from striking the floodwall. The proposed floodwall along the Channel to Orange will also be exposed to vessel strikes. Consequently, this area will have to be designed accordingly to account for the possibility of vessel strikes. This design will be completed in PED.

All floodwall locations were assumed to be constructed with protection against overtopping (scour pad) on the land side of the wall. Erosion protection (riprap) will be placed around floodwall-to-earthen levee tie-ins on both the flood and land sides of the levee and floodwall. All T-wall sections are assumed to require steel sheet piling for seepage cutoff. Analysis for seepage under floodwalls will be conducted during PED. For the existing levee systems, Port Arthur and Freeport, any sections of steel sheet pile I-wall are assumed to be cut to the appropriate elevation and incorporated into the new T-wall as seepage cutoff. For cost estimating purposes of this study, it is assumed that new seepage cutoff will be required for all locations of floodwall. Without conducting seepage analyses, the required depth of the seepage cutoff is unknown and therefore the current depth of the sheet pile has the possibility to not be sufficient for seepage cutoff.

During the design process, the floodwall was found to require piling due to the bearing stability check not meeting the minimum factor of safety for several load cases. As stated earlier, this assumption was made for the preliminary design. The conceptual design for the floodwall utilizes 16-inch square pre-stressed concrete piles for all locations, but it may be determined in future analyses that steel pipe, steel H-piles or auger cast piles are more suitable for certain floodwall locations. All areas of the alignment which are proposed to be floodwall should be analyzed to determine if piling is required. The additional soils investigations to be performed during PED will help to determine if floodwall locations will require piles and what type of piles are most suitable. The analyses for the piling design will be required during PED for all locations which are determined to require piles. Tests that will need to be performed during the PED phase for the piling design: *pile load tests,* which are intended to validate the computed capacity for a pile foundation and also to provide information for the improvement of design rational, and *field tests,* which are performed to verify or predict driving conditions and/or load capacity of service piles at the construction site. The preliminary configuration for the amount and spacing of the piles is 3 piles/row at 5-foot spacing. A pile group analysis will also need to be performed during PED to determine the most appropriate piling configuration.

For Still Water to Top of Wall loading (Load Case 6), the sliding stability check was found to not meet the minimum factor of safety. Consequently, the possibility of widening or sloping the base of the floodwall or providing a key in the base will need to be further explored during PED. The additional geotechnical investigations during PED will provide higher resolution of the in situ soils at the floodwall locations, which will yield a more accurate design. For the NED Plan however, the generalized floodwall cross section shown in Figure 7-4 was assumed to calculate quantities

for the cost estimate. Concrete strength utilized will be 5,000 psi, along with a water to cement ratio of 0.4. The assumption would be that a minimum of 4,000 psi concrete strength would be sufficient for the design, but with incorporation of the 0.4 w/c ratio, the 5,000 psi strength would likely be achieved. Therefore, for cost estimating purposes, 5,000 psi strength concrete will be utilized. Steel reinforcement for the floodwall was calculated to be #8 bars at 12 inches on center for the base and stem. Temperature and shrinkage reinforcement was required to be #8 bars at 12 inch centers for all sections of concrete. Due to the possibility of other load cases (i.e. the wave and barge impact load cases) increasing the calculated loads for the reinforcement, for cost estimating purposes, 150 pounds of steel reinforcement per cubic foot of concrete was assumed.

The Orange 3 reach floodwall design was used as the basis for the Freeport and Port Arthur levee systems. A design check was completed utilizing the NED elevations for the floodwall of each of the existing systems to validate the assumption of using the preliminary designed floodwall of the Orange 3 reach for the Freeport and Port Arthur areas. All areas of each systems alignment, Orange, Port Arthur and Freeport, were investigated to determine the largest section of floodwall that would be designed. The largest heights are shown in Table 7-4 for the Orange, Port Arthur and Freeport CSRM's. One area in Freeport has a recommended elevation of 26 feet NAVD88, this section of floodwall would be built on top of an existing levee embankment and therefore was not included in the table below. The stick up height of this section of floodwall would be approximately 7 feet, whereas other areas on the system have greater stick up heights.

Table 7-4: Maximum Floodwall Elevations for RSLC Scenarios

Orange - Floodwall Elevation		Port Arthur - Floodwall Elevation		Freeport - Floodwall Elevation	
RSLC Scenario	Elevation (NAVD88)	RSLC Scenario	Elevation (NAVD88)	RSLC Scenario	Elevation (NAVD88)
50 Year Intermediate	16	50 Year Intermediate	19.5	50 Year Intermediate	18.5
100 Year Intermediate	18	100 Year Intermediate	21.5	100 Year Intermediate	20
50 Year High	18.5	50 Year High	22	50 Year High	20.5
*Ground El = 5		*Ground El = 5		*Ground El = 7	

These section characteristics, which would be subjected to the largest hydraulic and soil loads, were checked against the conceptual floodwall design shown in Figure 7-4. When checking the higher loads, two load cases did not meet criteria for the sliding stability check and most load cases did not meet criteria for bearing capacity, which is similar to the conceptual floodwall design. Other aspects of the floodwall design, stem width, base height, etc., were the same as for the conceptual design. The check on the largest height of floodwall did yield a greater amount of reinforcement. The assumption stated previously to use more reinforcement for cost estimating purposes of this study should capture the extra reinforcement required for the larger heights of

floodwall. This process helped to confirm the assumption of utilizing the same floodwall cross section for all areas that are proposed to be floodwall.

For the existing levee systems, Port Arthur and Freeport, any floodwall is assumed to be replaced with reinforced concrete T-wall. The retrofitting of the existing floodwall was investigated and determined to not be feasible for current design guidelines due to excessive stick-up height of the I-wall in both Port Arthur and Freeport. The T-wall sections, in areas where marine vessel strikes are possible, are not designed for such occurrences. This constitutes the majority of floodwall on these existing levee systems, and therefore it was determined to assume replacement of all floodwall at this stage of the project.

7.3 NAVIGABLE GATE STRUCTURES

7.3.1 Concept Design

The navigable gate structures at Adams and Cow Bayous are proposed as a sector gate with adjacent vertical lift floodgates. The locations of these structures in relation to the alignment of the Orange-Jefferson CSRM are shown in Figure 7-7 and in Figure 7-8 for the Freeport and Vicinity CSRM. A navigable gate structure is also required near the entrance to the DOW Barge Canal in Freeport. This structure is also being proposed as a sector gate. The gate structures were modeled after the sector gate recently completed at the Caernarvon Canal as part of the New Orleans Hurricane and Storm Damage Risk Reduction System project work. To incorporate the information from this completed gate structure in New Orleans, the dimensions and quantities from the Caernarvon gate were adjusted to closer align with the width and size of the three navigable structures in this study. The structures will be built to the height of the adjacent floodwall of the levee system.

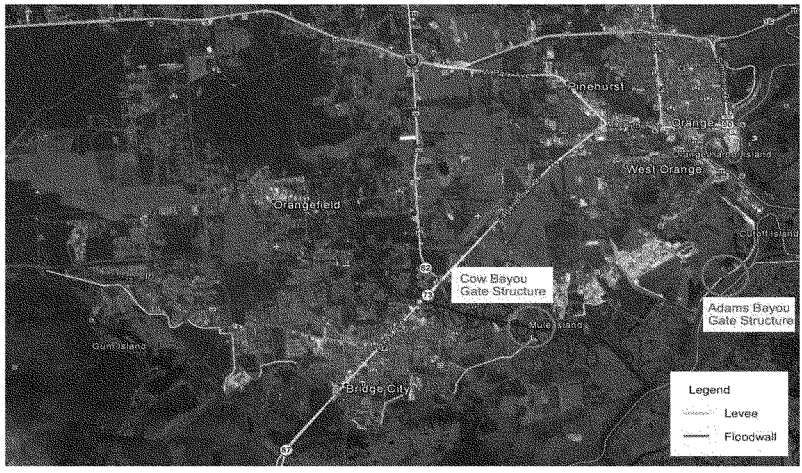

Figure 7-7: Orange–Jefferson CSRM Gate Structures Overview Map

Figure 7-8: Freeport and Vicinity CSRM - Gate Structure Overview Map

It is assumed that all sector gate structures will be constructed in line with the existing shipping channels, see Figure 7-9 for a photo of a similar sector gate structure.

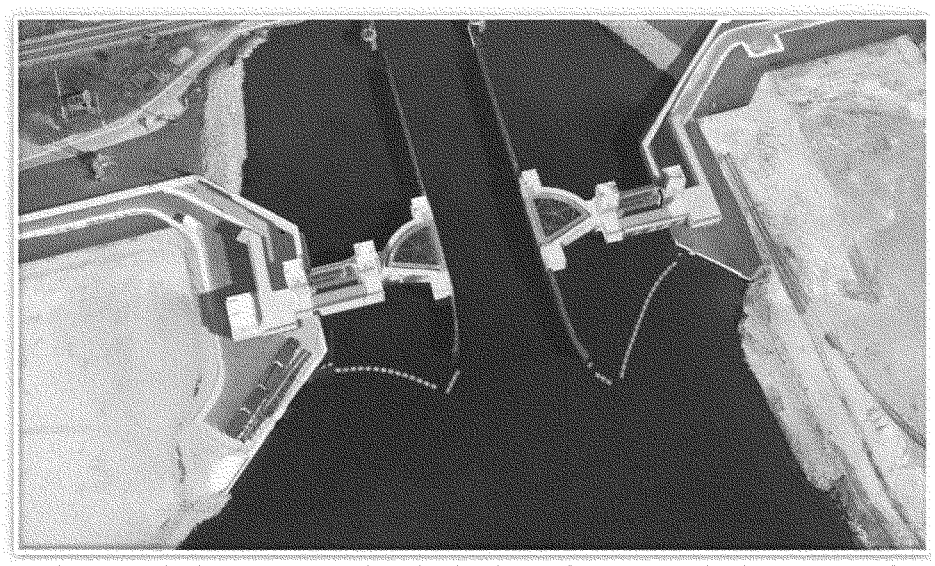

Figure 7-9: Aerial Photograph of Navigation Sector Gates with Adjoining Vertical Lift Gates

7.3.1.1 Adams Bayou

The Adams Bayou Gate Structure will be of the sector gate type with a navigable opening of 84 feet. With some limited data gathering, the channel is currently being utilized by 80 feet wide vessels. Due to the similarity between this structure and navigable lock type structures, EM 1110-2-2602 was referenced to determine an appropriate width for this size vessel. The 84 feet width was chosen to allow current vessels through the gate structure; by adding 4 feet to the navigable width of the gate opening to minimize damage to vessels and the gate structure walls. A structure this size will be large enough to accommodate single barges and other moderate draft vessels likely to use the waterway. The sill of the sector gate structure is assumed to be at a depth of 16 feet MLLW, which is the current maintained channel depth of 13 feet MLLW with an additional three feet for safe passage of vessels. For structural design purposes a sill elevation of -16 feet NAVD88 will be used.

Due to the narrowing of the bayou at the proposed crossing, an additional series of non-navigable flood gates are proposed to mitigate impacts to channel flow during normal upland rainfall events, as shown in Plate S-02. This gate will be a 30-foot-wide vertical lift gate positioned on the west side of the sector gate structure. Its sill depth is assumed to mirror the current channel depth near the banks of the bayou (approximately 8 feet). The size of the vertical lift gate was determined by calculating the normal channel flow with a rainfall event and providing enough open area through

the gate structures for this flow. For more information, see the Hydraulics and Hydrology section of this report. Because of the location where this structure is proposed to be sited, only one vertical lift gate is being proposed. On the east side of the channel, there is an abandoned placement area, which is assumed to be integrated into the proposed levee system. The vertical lift gate is proposed to be situated on the west side of the sector gate structure due to the pump station being located on the east side of the gate structure and the layout of the current placement area levee.

7.3.1.2 Cow Bayou

For the purpose of this study, the same sector gate proposed for Adams Bayou is proposed for the navigation structure at Cow Bayou due to similar site conditions at each proposed location (i.e., type of vessel usage, maintained channel width and depth). The sill of the sector gate structure is assumed to be at a depth of 17 feet MLLW, which is the current maintained channel depth of 14 feet MLLW with an additional three feet for safe passage of vessels. For structural design purposes a sill elevation of -17 feet NAVD88 will be used.

Two 60-foot-wide non-navigable vertical lift floodgates will flank the Cow Bayou sector gate structure, as shown on Plate S-03. These non-navigable floodgates are proposed to mitigate impacts to channel flow during normal upland rainfall events. The depth of the sill for the vertical lift gates is assumed to mirror the current depth of the channel near the banks of the bayou (approximately 8 feet). Cow Bayou is approximately 400 feet wide; therefore, a larger set of vertical lift gates will be required than for Adams Bayou to mitigate the impacts.

7.3.1.3 DOW Barge Canal

Located within the Freeport and Vicinity CSRM, the sector gate structure will be similar to the structures proposed at Adams and Cow Bayou in the Orange-Jefferson CSRM. No vertical lift floodgates will be required for this gate structure. The width of the navigable opening will be 74 feet due to a navigation constraint downstream of the gate location. Current infrastructure in the canal, which is approximately 70 feet in width, limits the width of barge vessels accessing the DOW Barge Canal. The 74 feet width was chosen to allow current vessels through the gate structure; by adding 4 feet to the navigable width of the gate opening to minimize damage to vessels and the gate structure walls. The sill of the sector gate structure is assumed to be at a depth of 17 feet MLLW. This depth includes the current GIWW channel depth near the entrance of the canal, which is 14 feet MLLW, and an additional three feet for safe passage of vessels. For structural design purposes a sill elevation of -17 feet NAVD88 will be used.

7.3.2 Conclusions

The gate structure analyses and design are beyond the scope of this study. Detailed design will be required for all aspects of the combined sector and vertical lift gate structures during PED. The gate design will utilize all applicable USACE engineering design guidance, specifically EM 1110-2-2602, as well as other guidance pertaining to concrete design, steel design, pile driving, etc. For the purpose of this study, only general concepts for these structures are provided, which are based on similar, previously constructed gates. All gate structures will be constructed within channels used for navigation; therefore, a cofferdam will have to be constructed to provide a dry construction area. The construction areas are currently assumed to be below the water table and would therefore require dewatering. It is assumed that the foundation soils are very soft at the proposed locations for the gate structures; therefore, the foundation will require strengthening with piles to form a stable foundation for supporting the gate structures. The piles are assumed to be pre-stressed concrete for cost estimating purposes of this study, but may consist of concrete piles, steel H-piles, or pipe; which will be determined during PED. Floodwall will be directly adjacent to these structures and tie in to the earthen levee sections. The gate structure monoliths and gates will be designed to be adaptable to RSLC, which will be to the 100 year intermediate level.

Due to the current active use of these channels, they will be required to remain operational and therefore will need some type of diversion channel during the gate construction to not inhibit industry from utilizing the channels. After construction is complete, during normal operations of the gate structures, the gate will remain open other than possible closure for maintenance practices or for an approaching storm event. Each of these possible closure activities would entail notification to all parties which utilize the channels from the local sponsor. The sector gate structures are not intended to inhibit use by any size vessel which currently utilizes the channels. The structures will not impose any draft, air-draft or vessel width restrictions for any vessel currently using the channels. In the event of a closure local industry would be properly notified to make preparations. The amount of notice has yet to be determined, but will be conveyed to local industry, when it has been defined.

7.4 EXISTING SYSTEMS

Existing levee systems consist of Port Arthur and Vicinity HFPP and Freeport and Vicinity HFPP. Both the Port Arthur and Freeport CSRM plans are to have their respective sections of floodwall replaced with reinforced concrete T-wall. A sector gate structure similar to what is planned for both Adams and Cow Bayous is being proposed approximately one mile into the DOW Barge Canal on the Freeport and Vicinity CSRM to alleviate numerous issues with the upper sections of the DOW Barge Canal levees. All road/railroad closure structures within floodwall sections of the alignments will be replaced.

7.4.1 Port Arthur and Vicinity CSRM

The Port Arthur and Vicinity CSRM is broken up into 5 reaches to separate the work areas of the 30 mile levee system, as shown in Figure 7-10. Only areas which contain structural components are outlined in this section. For further detail on the Port Arthur CSRM, see Chapter 1 of this appendix.

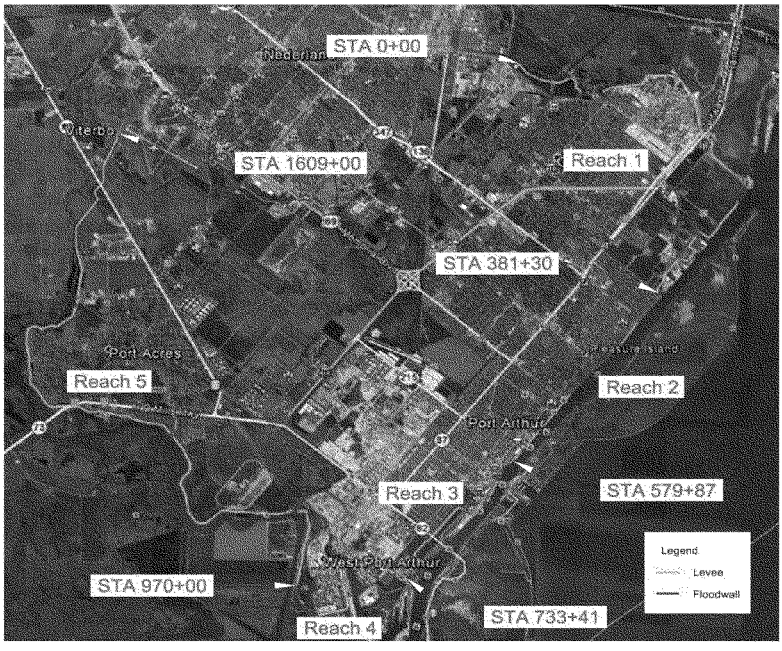

Figure 7-10: Port Arthur and Vicinity CSRM – Reaches

Within these reaches are numerous locations of floodwall, which includes T-wall, steel sheet pile I-wall, and concrete piling. The length of each type of floodwall within the levee system is listed in Table 7-5.

Table 7-5: Port Arthur and Vicinity CSRM – Existing Floodwall

Type	Length (ft)
Steel Sheet Pile I-wall	13,538
T-wall	12,923
Pre-stressed Concrete Piles	768
Braced Pre-stressed Concrete Piles	657
Total	27,886

These sections of floodwall do not currently contain any scour protection or protection from debris and vessel impacts. In order for this levee system to have sufficient capacity for the predicted RSLC and have the adaptability for future sea level changes, all areas of floodwall are proposed to be replaced with reinforced concrete T-wall. The lengths of new floodwall within each reach are listed in Table 7-6. The floodwall cross section, for purposes of this study, will be the same as what has been designed for the Orange 3 reach. See plates S-01 and S-05 for proposed cross sections of the floodwall on the Port Arthur CSRM.

Table 7-6: Port Arthur and Vicinity CSRM – Proposed New Floodwall

Reach	Length (ft)
1	690
2	10,940
3	7,030
4	9,790
5	1,640
Total	30,090

7.4.1.1 Reach 1 (STA 0+00 to 381+30)

This reach has 3 gated closure structures at Stations 128+90, 310+45, 345+22, which all contain sections of floodwall that include both T-wall and steel sheet pile I-wall. The Crane Bayou Pump Station, located at STA 306+00, contains a section of floodwall on its flood side. For the recommended plan, all sections of floodwall are proposed to be replaced with reinforced concrete T-wall. Locations and lengths of new floodwall are shown in Figure 7-11.

Figure 7-11: Port Arthur and Vicinity: Reach 1 – Overview Map

The closure structures will be demolished and new gated structures will be constructed, which will be adaptable to future sea level change. The closure structure replacements consist of 280 LF of floodwall. Approximately 410 LF of floodwall at the pump station will be placed a short distance to its flood side and pipe sleeves will be added in the floodwall for possible future expansion of the pump station.

7.4.1.2 Reach 2 (STA 381+30 to 579+87)

Reach 2 consists of 10,737 LF of floodwall and 3 pump stations within the alignment. Floodwall between Stations 381+30 and 579+87, ranges in stickup height from 6 to 10 feet. These existing floodwall sections include 10,471 LF of concrete T-wall and 266 LF of pre-stressed concrete piles. Pump Stations within this reach include Lake View, Del Mar and DeQueen. For the recommended plan, all floodwall in this reach is proposed to be replaced with concrete T-wall, which will be constructed to include RSLC and enough structural capacity for possible future raising due to RSLC. The recommended plan for this reach will consist of 10,940 LF of newly constructed floodwall, as shown in Figure 7-12.

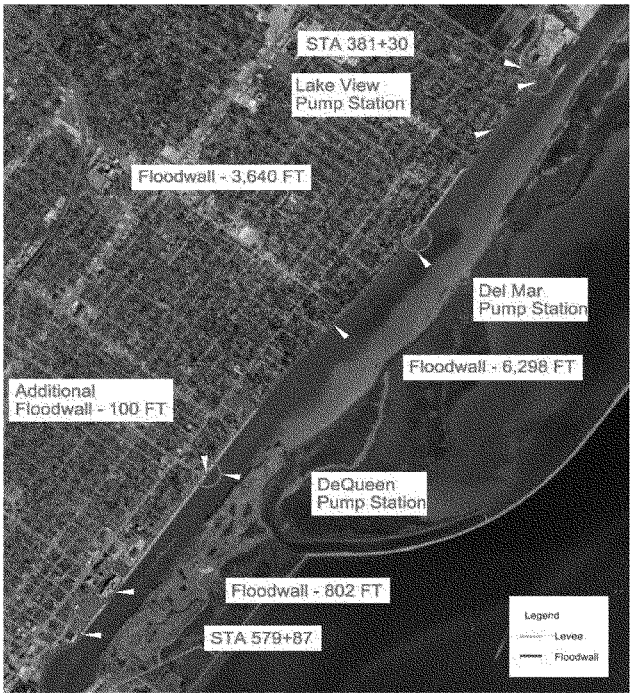

Figure 7-12: Port Arthur and Vicinity CSRM: Reach 2 – Overview Map

The existing T-wall will be demolished; the pre-stressed concrete piles will be saw cut to an elevation below the base of the new T-wall, with the area below the cut being left in place and the top portion being demolished. An additional length of floodwall, approximately 278 LF, will be added to the alignment for placing the floodwall in front of the pump stations, with the configuration shown in Figure 7-13. The added portions of floodwall to account for the extended sections around the pump stations have been included in the length stated previously. All floodwall in this reach will require construction from barges, due to limited available space on the interior of the floodwall.

Figure 7-13: Del Mar Pump Station – Floodwall Plan

7.4.1.3 Reach 3 (STA 579+87 to 733+41)

Reach 3 contains approximately 5,065 LF of floodwall. The floodwall of this reach consists of 5,134 LF of steel sheet pile I-wall, with approximately 471 LF of T-wall and ranges in height from 4 to 12+ feet. This reach contains 1 gated and 6 panel type closure structures, which will be replaced with gated closures. I-wall from STA 715+31 to 733+41, which has a stickup height of 10 to 12+ feet, has been analyzed for stability and shows significant crack development, marginal FOS for rotational stability and large deflections. There is a current high ground area, where the alignment passes through existing infrastructure (Port facility and dock) and poses a difficult task of constructing an adaptable levee or floodwall through this area. The alignment should be investigated for the possibility of being re-routed. This would allow for less difficult construction and provide a more robust and resilient section of levee. Performing this task is outside the scope of this study and will be completed during PED. To account for this scenario, the current section of high ground will be accounted for as new T-wall with drop-in panels.

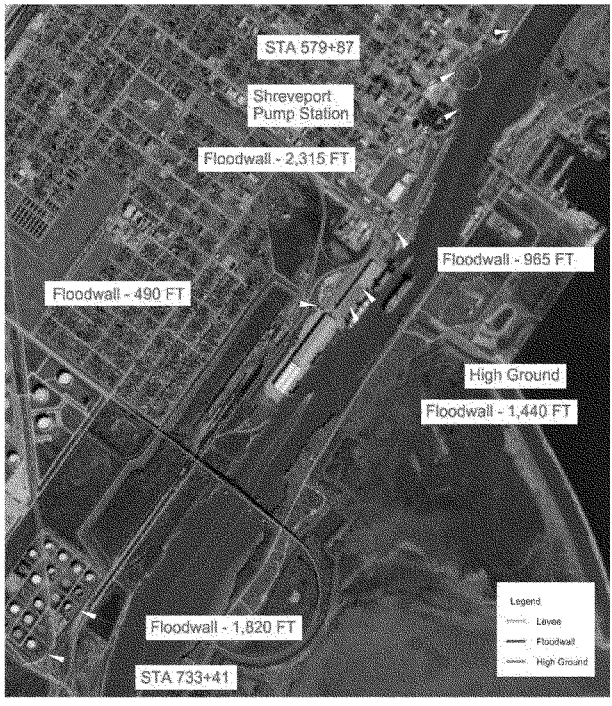

Figure 7-14: Port Arthur and Vicinity CSRM: Reach 3 – Overview Map

For the recommended plan, all existing floodwall in this reach is proposed to be replaced with concrete T-wall. Approximately 7,030 LF of floodwall, as shown in Figure 7-14, is proposed to be constructed in this reach. The existing sections of T-wall will be demolished. The steel sheet pile I-wall is proposed to be cut to a certain elevation that will be sufficient to be incorporated into the concrete T-wall as a seepage cutoff. For cost estimating purposes of this study, new steel sheet pile will be assumed to be placed in this section for seepage cutoff. The Shreveport Pump Station portion of floodwall will required that the floodwall be constructed a short distance in front of the pump station, in a similar manner to Figure 7-13. An approximate 800 LF section of floodwall will require its construction from barges. A section of T-wall near STA 733+41, approximately 100 LF in length, currently contains numerous pipe penetrations sleeved through the stem of the floodwall. A similar configuration will be designed during PED to permit the pipelines through the floodwall in a manner which will not hinder the levee systems performance, but for purposes of this study all pipelines are assumed to require replacement by the HDD method.

7.4.1.4 Reach 4 (STA 733+41 to 970+00)

Reach 4 contains approximately 9,404 LF of floodwall. The floodwall of this reach consists of 8,245 LF of steel sheet pile I-wall, 502 LF of cantilever concrete piles and 657 LF of braced concrete piles and ranges in height from 6 to 12+ feet. This reach also includes 12 gated closure structures, which will require replacement.

Floodwall from STA 762+87 to 872+70, near Valero refinery, contains a section of I-wall that has a stick-up height of 8 to 12+ feet. This I-wall section comprises both steel sheet pile and also a section of driven concrete piles which consist of cantilever and braced pre-stressed concrete piles. The steel sheet pile portion of this I-wall section has been analyzed for stability and shows significant crack development, marginal FOS for rotational stability and large deflections.

The section of levee from STA 930+00 to 1022+00 has a history of settlement, with some areas having as much as 3 feet of settlement from the end of construction into the early 1990s. To alleviate this issue, sections of the earthen embankment were brought back to grade with compacted earthen material. For the sections with more severe settlement, steel sheet pile was driven in the earthen embankment to bring the height of the levee back to grade and account for any future settlement. Sheet pile areas are shown in Figure 7-14, between STA 934+53 and 970+00. The two I-wall sections are approximately 1,410 and 1,745 LF in length and were constructed to a top elevation between 23.5 and 26.1 feet (msl).

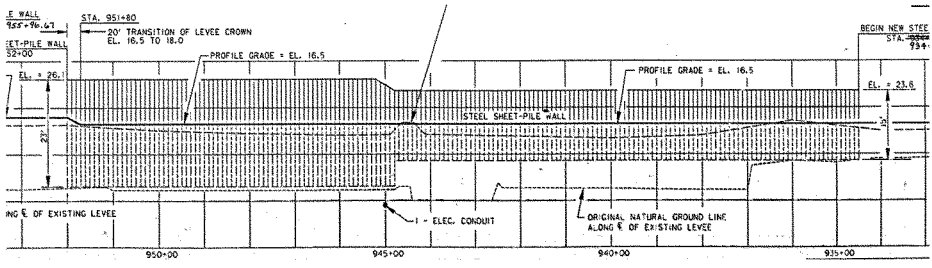

Figure 7-15: STA 934+53 I-Wall – As-built Profile

For the recommended plan, the steel sheet pile near the Valero refinery will be cut and left in place to be included as seepage cutoff in a pile founded T-wall, if found to be of sufficient depth for seepage cutoff. The type of piling, possibly auger cast piles, for the new floodwall through the Valero Refinery area should be thoroughly investigated during PED due to the current infrastructure. For this stage of the project, driven concrete piles are assumed. The pre-stressed concrete piles will be saw cut to an elevation below the base of the new T-wall, with the area below the cut being left in place and the top portion being demolished. Approximately 800 LF of

floodwall in this reach is assumed to be constructed from barges. Due to possible construction issues and very limited available space for construction due to current infrastructure, this section of floodwall should be investigated for re-routing of the alignment. This task is outside the scope of this study and should be completed during PED.

For the recommended plan, the steel sheet pile between stations 934+53 and 970+00 will be cut and left in place to be included as seepage cutoff in a pile founded T-wall, if found to be of sufficient depth for seepage cutoff. Due to the historical settlement issues, to decrease the weight of the levee, the earthen embankment through this area will be degraded to Elevation 10' and theT-wall will be placed onto the degraded levee section.

For cost estimating purposes of this study, new steel sheet pile will be assumed to be placed in all sections for seepage cutoff, due to unknown factors of the existing sheet pile. The total length of new floodwall for this reach is 9,790 LF, at three separate locations, as shown in Figure 7-16. All new floodwall is proposed to be reinforced concrete T-wall with a pile foundation.

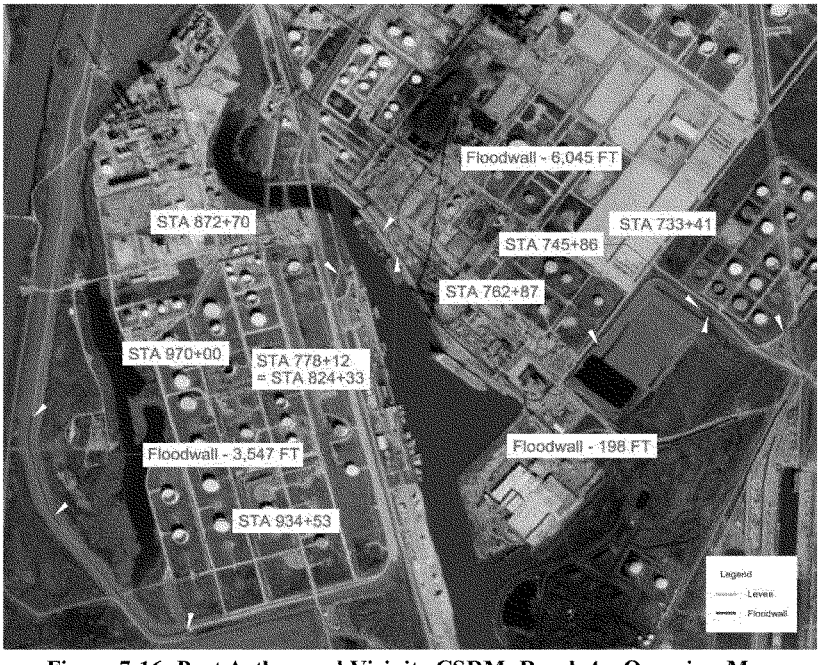

Figure 7-16: Port Arthur and Vicinity CSRM: Reach 4 – Overview Map

7.4.1.5 Reach 5 (STA 970+00 to 1609+00)

Reach 5 contains approximately 1,470 LF of floodwall, which is all of the reinforced concrete T-wall type. The floodwall sections are within three pump stations and one gated closure structure. The pump stations include Alligator Bayou, Lakeside and Port Acres. The closure structure is at Highway 365 (Station 1453+10) and has 115 LF of floodwall within the alignment. All sections of floodwall are to be replaced due to their current configuration not being adaptable to future sea level changes. For the recommended plan, these areas of floodwall are proposed to be replaced with reinforced concrete T-wall.

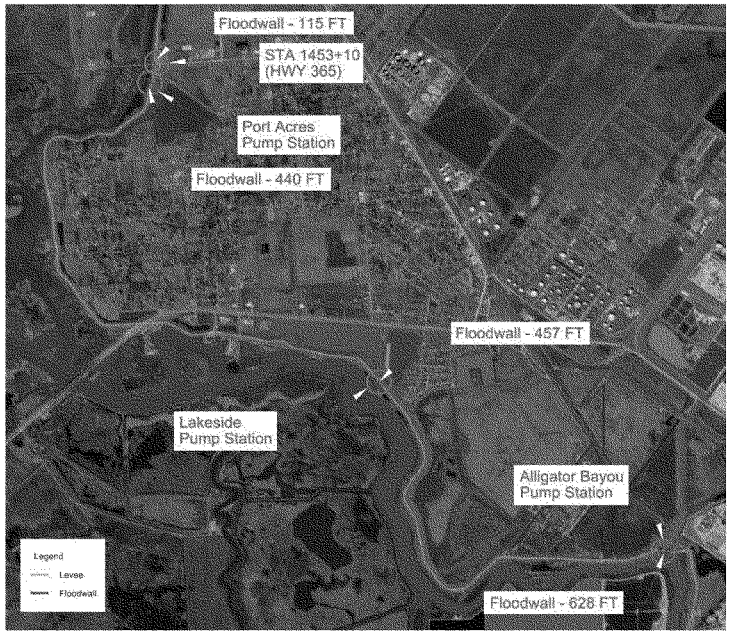

Figure 7-17: Port Arthur and Vicinity CSRM: Reach 5 – Overview Map

The length of floodwall to be constructed in this reach is approximately 1,640 LF. The lengths and locations of the new floodwall is shown in Figure 7-17.

7.4.2 Freeport and Vicinity CSRM

The Freeport and Vicinity CSRM is broken up into 8 reaches which comprises the 41 mile levee system. The reaches are shown in Figure 7-18. Due to the proposed sector gate structure in the DOW Barge Canal, the floodwall located within the DOW Barge Canal Turning Basin is not being considered for replacement. Only areas which contain structural components are outlined in this section. For further detail on the Freeport CSRM, see Chapter 1 of this appendix.

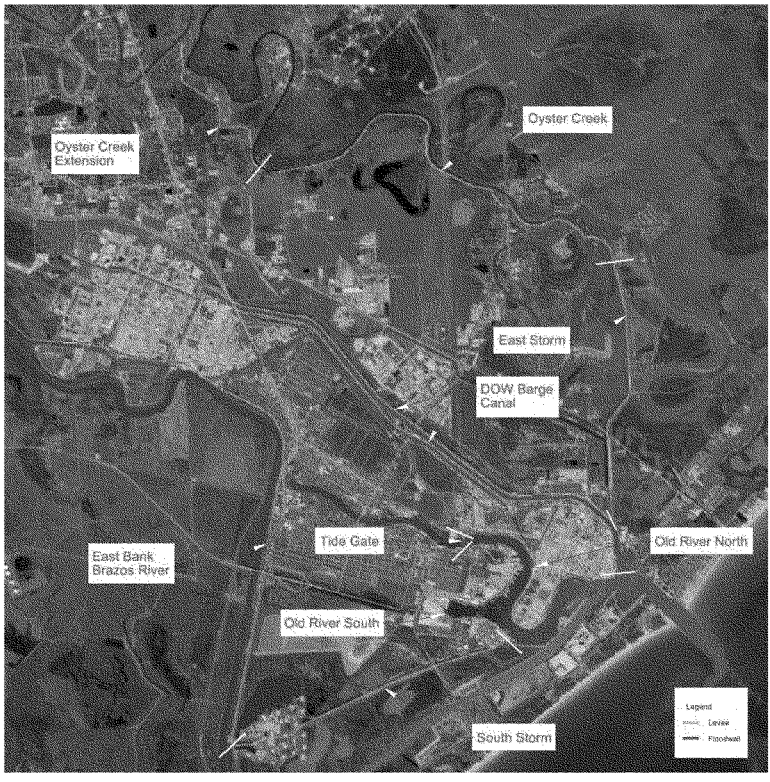

Figure 7-18: Freeport and Vicinity CSRM - Reaches

Within these reaches are numerous locations of floodwall, which includes T-wall, concrete capped steel sheet pile, concrete piling, concrete walls, concrete panel walls, and T-wall incorporated into a dock. The length of each type of floodwall within the levee system is listed in Table 7-7.

Table 7-7: Freeport and Vicinity CSRM – Existing Floodwall

Type	Length (ft)
Steel Sheet Pile I-wall	738
T-wall	3,528
T-wall (Dock Face)	3,432
Pre-stressed Concrete Piles	538
Concrete Wall	3,260
Concrete Panel Wall	273
Total	11,769

These sections of floodwall do not currently contain any scour protection or protection from debris and vessel impacts. In order for this levee system to have sufficient capacity for the predicted RSLC and have the adaptability for future sea level changes, all areas of floodwall are proposed to be replaced with reinforced concrete T-wall. The lengths of new floodwall within each reach are shown in Table 7-8. The floodwall cross section, for purposes of this study, will be the same as what has been designed for the Orange CSRM. See plates S-01 and S-06 for proposed cross sections of the floodwall on the Freeport CSRM.

Table 7-8: Freeport and Vicinity CSRM – Proposed New Floodwall

Reach	Length (ft)
Oyster Creek & Oyster Creek Extension	1,220
East Storm	320
DOW Barge Canal	3,190
Old River North	15,660
Tide Gate	580
Old River South	7,855
East Bank Brazos River	430
Total	29,255

7.4.2.1 Oyster Creek and Oyster Creek Extension

The Oyster Creek and Oyster Creek Extension reach has sections of floodwall in each of its alignments, as shown in Figure 7-19. Oyster Creek has approximately 985 LF of reinforced concrete T-wall and Oyster Creek Extension contains 235 LF of reinforced concrete T-wall. The recommended plan is to replace each of these two sections of floodwall with reinforced concrete T-wall, which will be designed to be adaptable to future sea level changes.

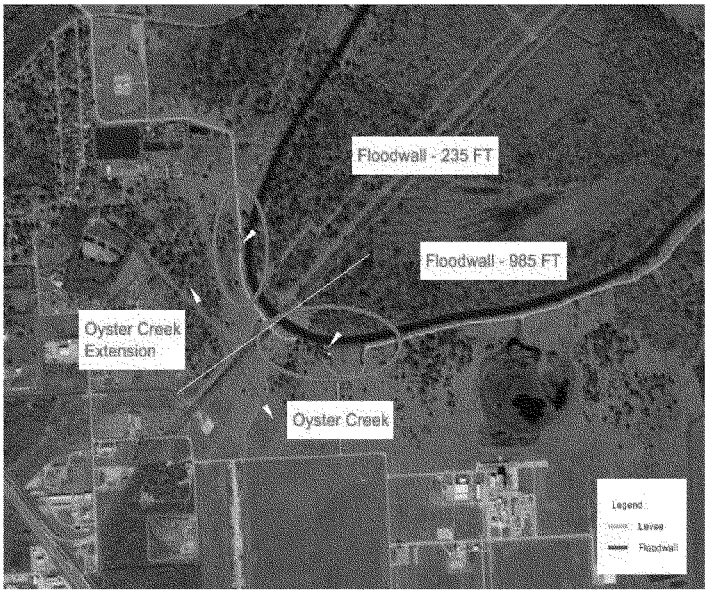

Figure 7-19: Oyster Creek and Oyster Creek Extension – Overview Map

7.4.2.2 East Storm

The East Storm levee reach currently does not contain a section of floodwall. The recommended plan includes adding approximately 320 LF of new T-wall to the earthen levee section, as shown in Figure 7-20.

Figure 7-20: East Storm - Overview Map

The proposed 1.5-foot levee raise cannot be accommodated through this area. The gravity drainage structure adjacent to the pump station inhibits raising of the levee through this area. Therefore a smaller T-wall (Figure 7-6) is being proposed through this section. The earthen levee section will be degraded and the T-wall placed to the land side of the crest of the levee.

7.4.2.3 DOW Barge Canal

The recommended plan for the DOW Barge Canal is to construct a gate structure in the canal, approximately one mile from the canal entrance. Due to the location of the gate structure, floodwall will need to be added to both sides of the gate structure and tie into the DOW Barge Canal levees. A portion of the DOW Barge Canal South levee crosses a water intake structure, as shown in Figure 7-21. This section of levee will require floodwall to be constructed through this area due to the location and design of the water intake structure. The levee through this area will be degraded and will require approximately 730 LF of new T-wall.

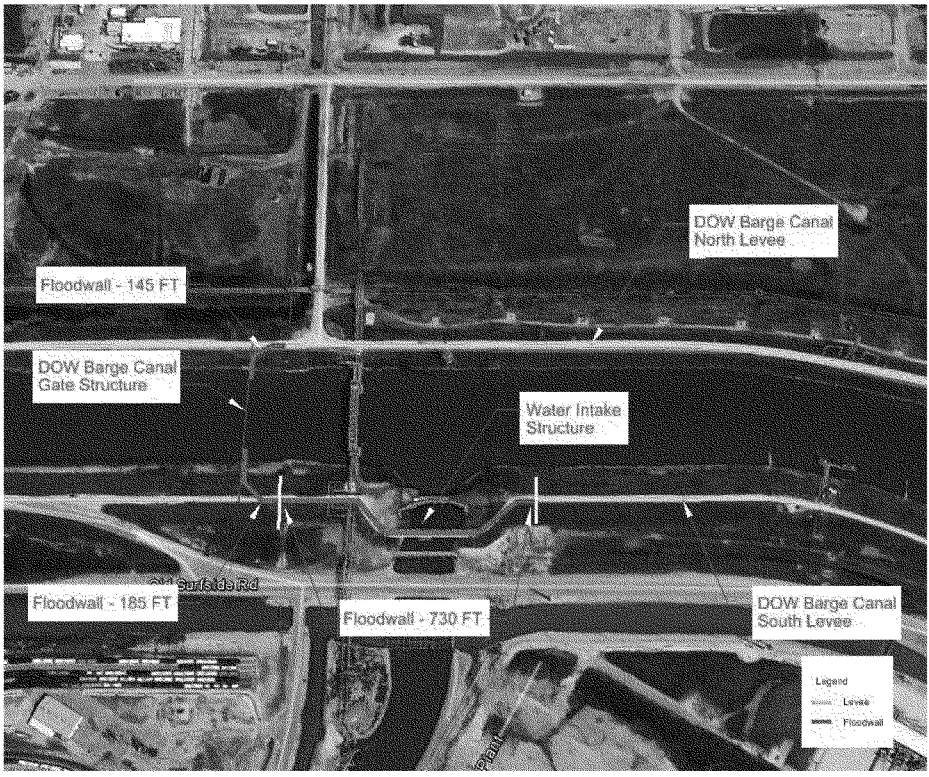

Figure 7-21: DOW Barge Canal – Overview Map

The southern end of the DOW Barge Canal levee requires a large raise due to the predicted hydraulic loadings. This area, as shown in Figure 7-22, has limited available space due to current infrastructure and cannot accommodate a large levee raise.

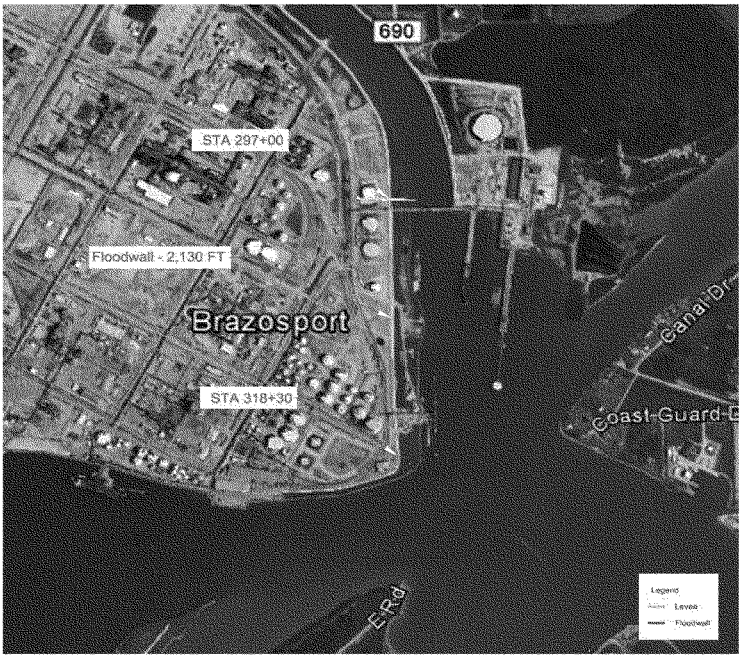

Figure 7-22: DOW Barge Canal – South End Overview Map

The recommended plan would entail constructing 2,130 LF of floodwall from STA 297+00 to 318+03, similar to the floodwall proposed in Figure 7-4. This area would require the use of a different type of pile, possibly auger cast piles. The type of pile most appropriate for this section should be investigated and determined during PED. For this study, the cost for the conceptual floodwall will be utilized, due to the predicted hydraulic loadings in this area

7.4.2.4 Old River North

The Old River North reach contains approximately 4,987 LF of existing floodwall. The floodwall of this reach consists of reinforced concrete T-wall, T-wall incorporated into a dock, steel sheet pile I-wall, concrete piles, concrete wall, and concrete panel walls. These sections range in stickup height from 4 to 6+ feet. This reach also contains what is referred to as the 'DOW Thumb', which has a large section of earthen embankment levee. The DOW Thumb area has shown susceptibility through updated modeling to large wave attack and overtopping from wave propagation along the adjacent deep draft navigation channel. The section of earthen embankment on the DOW Thumb also has a very low FOS for global stability.

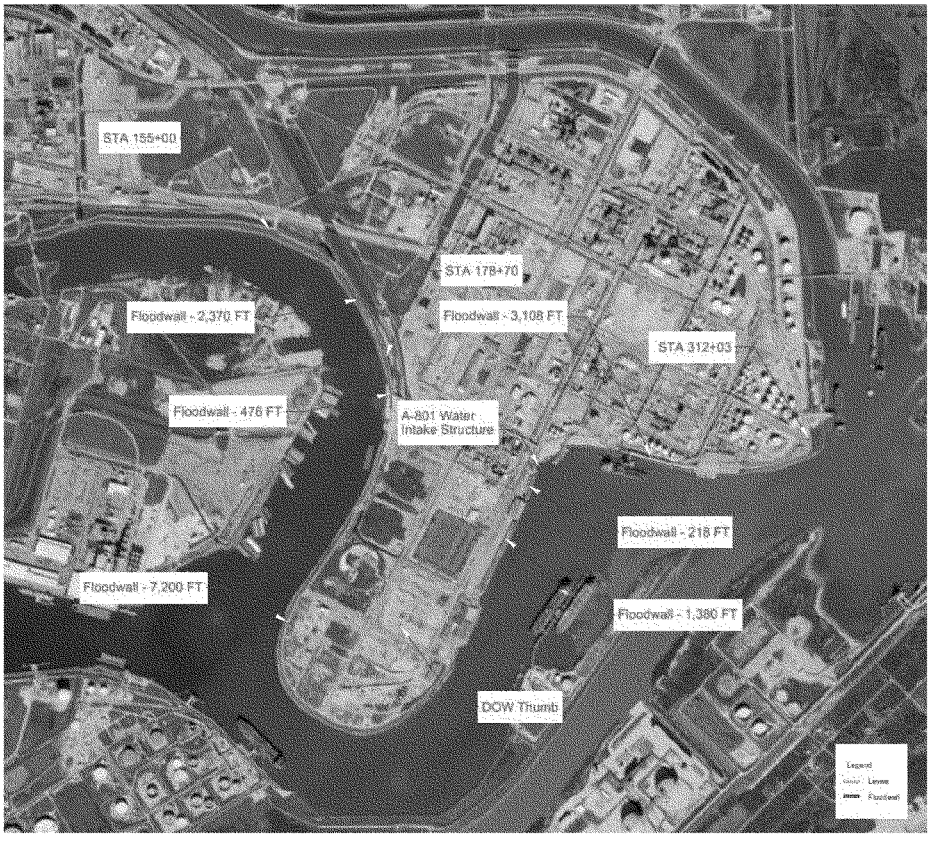

Figure 7-23: Old River North – Overview Map

For the recommended plan, all earthen embankment sections, as shown in Figure 7-23, between Stations 178+70 and 312+03, will be degraded and pile founded T-wall will be placed in these areas. This method will not reduce the FOS for global stability of the earthen embankment section of the DOW Thumb. To not reduce the FOS through this section of earthen embankment, the levee will be degraded to approximately elevation 11 and the T-wall in Figure 7-4 will be constructed in this area. The section of earthen embankment at STA 312+03 is being proposed to have new T-wall constructed due to limited availability of property through the area; this being port infrastructure currently adjacent to the existing levee. All existing floodwall sections in this reach will be replaced with new pile founded T-wall, as shown in Figure 7-23. Approximately 3,900 LF of floodwall will assume to be constructed from barges, due to limited available space for construction activities. The concrete piles will be saw cut to below the base of the new T-wall

and removed. The two sections of steel sheet pile I-wall, adjacent to the A-801 water intake structure, will be left in place. Through this area, the new floodwall will be constructed in front of the A-801 structure, but still provide access for local industry to pump water into their facilities. Approximately 2,370 LF of new T-wall will be added to the earthen levee section shown in Figure 7-23, between STA 150+00 and 178+70. The proposed 4-foot levee raise cannot be accommodated through this area. Therefore a smaller T-wall (Figure 7-6) is being proposed through this section. The earthen levee section will be degraded and the T-wall placed to the land side of the crest of the levee. The excavated material through this section will require environmental testing to determine if contaminants are present. If the material contains contaminants, it will be hauled to a hazardous material disposal site. All floodwall incorporated into docks will be reconstructed to current standards and designed to be adaptable to future RSLC, as well as including drop-in panels for industry access through the floodwall.

7.4.2.5 Tide Gate

The Tide Gate reach contains approximately 530 LF of existing floodwall. This floodwall consists of 362 LF of concrete capped steel sheet pile I-wall and 168 LF of concrete piles, as shown in Figure 7-24.

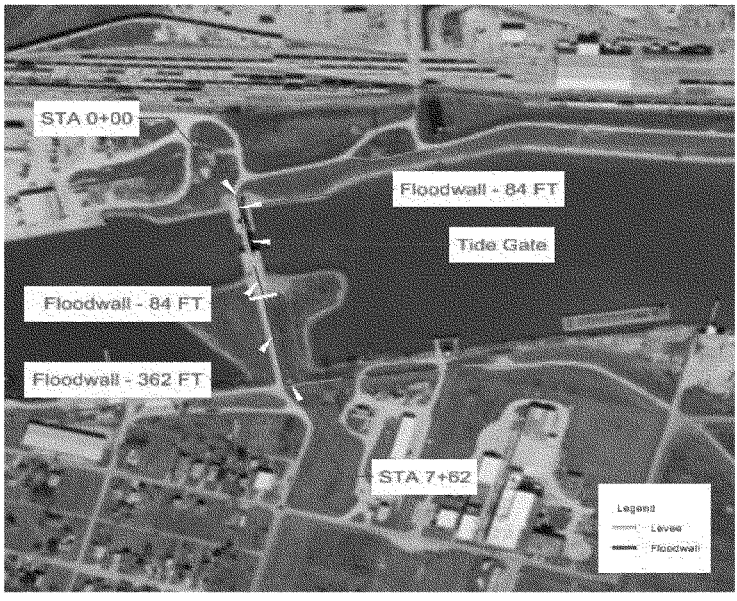

Figure 7-24: Tide Gate – Overview Map

The original levee through this area was earthen embankment, but it was later discovered that the very soft foundation material present in the Old River channel would not support the additional weight and the levee had settled. The concrete capped, steel sheet pile I-wall was added to alleviate the settlement issues. There are stability concerns for the I-wall section with water levels to design elevation or at top of wall. The concrete piles sections are at the same elevation as the steel sheet pile I-wall and are not adaptable to RSLC. For the recommended plan, the concrete cap of the floodwall be demolished, the steel sheet pile be cut and integrated into the newly constructed T-wall as a seepage cutoff, if found to be of sufficient depth. For purposes of this study, new sheet pile as seepage cutoff will be assumed to be required. The concrete piles will be saw cut to below the base of the new T-wall and left in place. The T-wall for this section will be pile founded due to the historical soft soil foundation in this area.

7.4.2.6 Old River South

The Old River South reach contains three sections of floodwall which total 4,600 LF. These sections consist of 310 LF of concrete capped steel sheet pile I-wall with two closure structures, 825 LF of floodwall incorporated into a dock, which is the Freeport Berth 7 dock, and 3,245 LF of concrete wall and concrete panels which encompasses the Port of Freeport Berth 1, 2, 3 and 5 dock. The concrete panels on this dock have been found to be structurally deficient for hydraulic loading, as well as the concrete wall which are part of the Berth 5 dock extension. For the recommended plan, all sections of floodwall are proposed to be replaced with reinforced concrete, pile founded T-wall, as shown in Figure 7-25. At the Port of Freeport dock area, the floodwall would be constructed in front of the current dock and backfilled to the existing grade of the docks. All of the construction activities for the Berth 1, 2, 3 and 5 dock area will be assumed to be from barges. The Berth 7 section of floodwall would be replaced with a post and panel concrete floodwall system. For purposes of this study, this section of wall will be accounted for as new T-wall. A new section of floodwall will be constructed on an earthen levee section. Approximately 3,475 LF of new T-wall will be added to the earthen levee section beginning at STA 278+54 and coming back towards the Berth 5 dock. Due to current infrastructure in this area of the Old River South reach, the proposed 3-foot levee raise does not have sufficient space available to be constructed another option must be considered. Therefore a small T-wall (Figure 7-6) is being proposed through this section. The earthen levee section will be degraded and the T-wall placed to the land side of the crest of the levee. The two closure structures will be replaced with swing gate closures.

Figure 7-25: Old River South – Overview Map

Although outside the scope of this study, the possibility of realigning the levee through the Port of Freeport area should be considered and investigated during PED.

7.4.2.7 East Bank Brazos River

This reach of levee contains a section of floodwall that was incorporated into a pump station, as shown in Figure 7-26. For the recommended plan, floodwall will be placed in front of the pump station, to the flood side, and will align into the earthen embankment of the system on each side of the pump station. Floodwall is assumed to be reinforced concrete T-wall. The floodwall will be constructed to the required NED elevation and backfill will be placed behind the wall to the current grade of the area around the pump station.

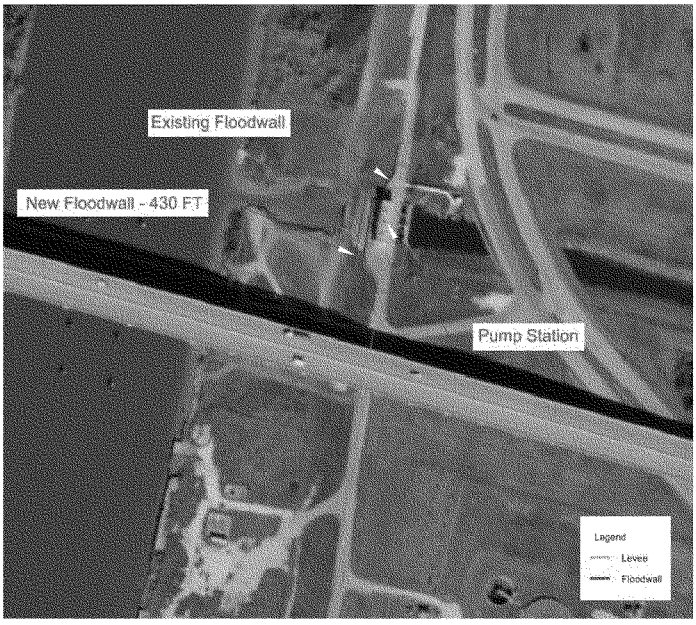

Figure 7-26: Pump Station – Overview Map

7.4.3 Conclusions

Similar to the methods and conclusions for the Orange CSRM floodwalls contained in Section 7.2.3, the floodwalls for both Port Arthur CSRM and Freeport CSRM will require further design and analysis during PED. The areas of the alignments which are currently floodwall are assumed to require new floodwall for this project. Analysis will need to be conducted to determine if all floodwall locations require pile foundations. The type of piles to be used for the floodwall should be investigated during PED, due to the extensive amount of infrastructure through the areas which are recommended to have floodwall constructed. A slope stability analysis should be completed during PED for areas which require the existing earthen embankment to be degraded for construction of a floodwall. This will help to determine the most appropriate elevation for the levee degrade.

7.5 OTHER STRUCTURAL COMPONENTS

Structural components of the Orange, Port Arthur and Freeport CSRM's which have not been discussed in this section include drainage structures, pump stations, and vehicular/railroad closure structures. These structures have been preliminarily analyzed elsewhere in this Engineering Appendix, but will require complete structural design during PED.

7.6 REFERENCES

USACE Engineer Manuals

- EM 1110-2-2100 - Stability Analysis of Concrete Structures, 1 December 2005
- EM 1110-2-2104 - Strength Design for Reinforced-Concrete Hydraulic Structures, 30 June 1992
- EM 1110-2-2502 - Retaining and Flood Walls, 29 September 1989
- EM 1110-2-2602 – Planning and Design of Navigation Locks, 30 September 1995

Other USACE Engineering Guidance

- Hurricane and Storm Damage Risk Reduction System Design Guidelines (HSDRRSDG) - Interim, June 2012

Drawings and Reports

- Flood Protection Planning Study Hurricane Flood Protection System, Orange County, Texas, December 2012.

8 HAZARDOUS AND TOXIC MATERIALS

A detailed discussion of HTRW and associated risk level definitions is provided in Appendix N of the FIFR-EIS.

8.1 ORANGE-JEFFERSON COUNTY CSRM

The Orange County levee and floodwall corridor (Orange 3 Reach) is approximately 26.7 miles in length from near the intersection of the Sabine River with Interstate 10, around the cities of Orange and Bridge City, Texas, and up to a point less than a mile southwest of FM 1135 where it intersects FM 105 (Orangefield Road) midway between Rose City and Bridge City. The corridor runs near numerous industrial facilities, including the Port of Orange, several shipbuilding yards, DuPont-Invista Sabine River Works, Lanxess Chemical Corporation, Firestone Polymers, and Chevron Phillips Chemical Company.

There are seven (7) major HTRW sites and facilities near or adjacent to the Orange County levee and floodwall alignment corridor identified from the research conducted. These sites consist of industrial facilities currently operating that are listed in databases identifying the generation, handling, or release of hazardous materials and waste. The largest of these, DuPont Chemical Corporation, maintains several large wastewater treatment and cooling ponds along the tentative alignment. The general HTRW risk for the levee alignment in Orange County is classified as *Low*, since no unresolved current or recent hazardous material releases were found, and no significant recent RCRA or CWA permit violations were identified. HTRW facilities in the area should be more thoroughly investigated with visual inspections and interviews with facility managers to confirm the potential HTRW risks along the levee alignment prior to construction or more detailed design.

The Jefferson Main reach levee and floodwall alignment corridor is approximately 14.3 miles in length around the City of Port Neches, Texas, and the ExxonMobil Chemical Plant in Beaumont, Texas. The corridor runs near seven (7) major petroleum and chemical facilities, including the ExxonMobil Chemical Plant, DuPont Chemical Corporation, and the Huntsman refinery, as well as numerous petroleum and chemical tank farms and loading facilities. There are numerous pipelines crossing the levee alignment in Jefferson County that transport hazardous materials for shipment or further processing. These pipeline crossings are identified as points of concern along the Recommended Plan alignment where special caution needs to be exercised during construction to avoid damage to the pipelines and release of hazardous materials into the environment.

Most of the refineries and chemical plants have had numerous Clean Air Act violations in the past or are currently in effect due to stack emissions. No currently active spills or land/water releases

of hazardous materials were found however. The Star Lake Canal, emanating from the Huntsman Refinery, runs adjacent to the Jefferson County alignment and is listed as an active NPL site due to past release of wastewater and storm runoff containing hazardous materials. This canal is scheduled for remediation by USEPA with the proposed removal of contaminated bottom sediments. Due to the presence of toxic sediments, this canal would be considered *High* risk; however, minor construction on the existing levee along the canal would not expose any sediments within the canal. Therefore, despite the large number of potential HTRW release facilities, the Orange-Jefferson CSRM project area is classified as generally *Low* risk for HTRW. The HTRW facilities in the area need to be more thoroughly investigated with visual inspections and interviews with facility managers to confirm the potential HTRW risks along the alignment corridor prior to construction or more detailed design. Coordination with USEPA remediation of the Star Lake Canal would also be required.

8.2 PORT ARTHUR AND VICINITY CSRM

The existing Port Arthur HFPP corridor is approximately 34.4 miles around the cities of Port Arthur and Groves, Texas. The corridor runs near five (5) major petroleum and chemical facilities, including the Texaco refinery, the Total-BASF refinery, the Valero refinery, and the Motiva Enterprises refinery, as well as numerous petroleum and chemical tank farms and loading facilities.

Most of the refineries and chemical plants have had numerous Clean Air Act violations in the past or are currently in effect due to stack emissions. No currently active spills or land/water releases of hazardous materials were found however. Despite the large number of potential HTRW release facilities, the Port Arthur CSRM project area is classified as generally *Low* risk for HTRW. The HTRW facilities in the area need to be more thoroughly investigated with visual inspections and interviews with facility managers to confirm the potential HTRW risks along the alignment corridor prior to construction or more detailed design. Although some large refineries and chemical plants are more than 0.25 mile from the project alignment, they could still affect the project corridor as a result of a major release.

8.3 FREEPORT AND VICINITY CSRM

The general risk level for the Freeport area is indicated as *Low* risk, since no current or recent unresolved RCRA or CWA releases were identified for any of the industrial facilities in the Freeport area. Many of the facilities have ongoing CAA violations due to stack emissions. The HTRW facilities in the area need to be more thoroughly investigated with visual inspections and interviews with facility managers to confirm the potential HTRW risks along the alignment corridor prior to construction or more detailed design.

9 COST ESTIMATES

This MII estimate was prepared for the Coastal Storm Risk Management and Ecosystem Restoration Feasibility Study on Sabine Pass to Galveston Bay, Texas. The study area encompasses six counties in southeast Texas. There are three structural components to this study. A proposed new levees and floodwalls that would comprise the Orange County Hurricane Flood Protection Project (HFPP), modifications to the existing Port Arthur HFPP including the "Port Arthur Extension" component", and Freeport HFPP. The estimate was divided into 3 construction contracts mirroring the three distinct geographical locations: Orange, Pt Arthur, and Freeport, Texas. The engineering design work is premised on a feasibility level of detail and analysis, consistent with the SMART planning process that is necessary to substantiate the Recommended Plan baseline cost estimate. Another key concept is to utilize existing information where applicable. Quantities and design features were developed by the Galveston District (SWG) Engineering Branch.

This estimate was prepared using the latest Unit Price Books and labor rates for fiscal year 2017 (October 2016). The estimate was divided into the three (3) geographic locations, with each location being subdivided into Non-Federal and Federal Costs. The costs were further organized in accordance with the work breakdown structure. The midpoint date of each account code for each of the construction contracts was provided by the project manager for developing the fully funded costs. The estimate was prepared in accordance with ER 1110-2-1302, dated 30 June 2016. The costs were escalated in accordance with the above Engineering Regulation and EM 1110-2-1304, dated 31 March 2016. All data was input into the Total Project Cost Summary Sheet (TPCS). The baseline estimate provides for all pertinent elements for a complete project ready for operations.

A formal Cost Risk Analyses was performed with the cooperation of the PDT and Cost Engineering Directory of Expertise (DX) of the Walla Walla District in July 2016. The risks were quantified and a cost risk model developed to determine a contingency at 80% confidence level (CL). The new contingencies along with the estimates were used for input in the TPCS. An ITR Certification for Cost Estimate was provided by Walla Walla District. The 50 year Operation and Maintenance estimate was prepared with an effective pricing date of October 2016.

ACCOUNT CODE 01 – LANDS AND DAMAGES: Cost for this Account Code was provided by SWG, Real Estate Division.

ACCOUNT CODE 02 -- RELOCATIONS: This account was separated into 3 different subgroups:

Pipeline: It was assumed that the relocation of the pipelines would be performed by directional drilling. Those costs were based on quotes from pipe suppliers, with the costs of hydrostatic testing, welding and layout, and making tie-ins based on quotes from pipeline contractors. Relocation work is assumed to take place prior to start of work on the project.

Pipeline Racks: This item refers to the need to modify existing pipelines racks to go over/through the new levee/floodwall. The quantities for the partial demolition and extension of pipeline racks were provided by SWG Structural Section.

Roads: Were it was decided that existing roads need to go over the new levee. The cost include demolition and removal of existing road. The construction of the new ramp and road on top of it.

ACCOUNT CODE 06 – FISH AND WILDLIFE FACILITIES (Mitigation):): There are four (4) proposed mitigation plans that are costed out in the Mii. They are:

Brackish Marsh - Mit 28 –Restore marsh by pumping shoaled material from Sabine-Neches Canal Section B into area of water (133.2 ac) and marsh (277.5 ac) near Old River Cove. Assume: 1) all costs of dredging are included in the cost estimate; 2) shoaled material is 20% sand, 80% clay/silt: 3) temporary containment berms and drainage structures constructed to contain material, and frequent movement of discharge point to control placement; 4) Target Year (TY)4-5, create 47 acres of sinuous circulation channels and ponds using marsh buggies to compress soil; 5) TY6 planting of spartina patens (4 in pots on 5 ft. centers) and degrade berm (to allow wide tidal access); 6) replanting 50% of patens plants in TY 7 where marsh did not take; 7) TY 8 remove any invasive plant species (assume 15% of planted area).

Brackish Marsh - Mit 29 –Restore marsh by pumping shoaled material from Sabine-Neches Canal Section B into area of water (106 ac) and marsh (83.5 ac) near Old River Cove). Assume: 1) all costs of dredging are included in the cost estimate; 2) shoaled material is 20% sand, 80% clay/silt: 3) temporary containment berm and drainage structures constructed to contain material, and frequent movement of discharge point to control placement; 4) TY4-5, create 26 acres of sinuous circulation channels and ponds using marsh buggies to compress soil; 5) TY6 planting of spartina patens (4 in pots on 5 ft. centers) and degrade berm (to allow wide tidal access); 6) replanting 50% of patens plants in TY 7 where marsh did not take; 7) TY 8 remove any invasive plant species (assume 15% of planted area).

Interim Marsh - Mit 31 –Restore marsh by pumping maintenance material from the Neches River Channel into area of water (151 ac) and marsh (221 ac) in Bessie Heights marsh. Assume: 1) all costs of dredging are included in the cost estimate; 2) shoaled material is 35% sand, 65% clay/silt: 3) temporary containment berm and drainage structures constructed to contain material, and frequent movement of discharge point to control placement; 3) TY4-5, create 53 acres of

sinuous circulation channels and ponds using marsh buggies to compress soil; 4) planting of spartina patens in TY6 (4 in pots on 5 ft. centers) and remove containment berm(to allow wide tidal access); 5) replanting 50% of patens plants in TY 7 where marsh did not take.

Fresh Marsh - Mit 52 –Restore marsh by pumping maintenance material from the Neches River Channel into area of water (63 ac) and marsh (144 ac) in Rose City marsh. Existing project maintenance cycle is 6-7 yrs. above station 422. Assume: 1) incremental cost of extra distance and pipe movement if quantities sufficient for 1 placement episode during regularly scheduled maintenance dredging; 2) shoaled material is 35% sand, 65% clay/silt: 3) temporary containment berm and drainage structures constructed to contain material (oil field roads encircle nearly all of area; levees could be constructed on roads), and frequent movement of discharge point to control placement ; 4) TY4-5, create 22 acres of sinuous circulation channels and ponds using marsh buggies to compress soil; 5) TY 6 planting of spartina patens (4 in pots on 5 ft. centers), and remove containment berms in TY 6 (to allow wide tidal access); 6) replanting 50% of patens plants in TY 7 where marsh did not take.

Quantities and design features were provided by SWG Planning, Environmental, & Regulatory Division. A yearly monitoring and report prepared of the overall condition of plantings and the marsh. This will be done for the every ten (10) year after construction for the duration of the project life.

ACCOUNT CODE 11 – LEVEES AND FLOODWALLS: SWG Geotech and Structural Engineering Section provided all quantities for the work. Each geographic area was considered a standalone feature and was provided its own folder. Under each folder construction items were divided into major cost categories.

LEVEE: It was assumed that material for construction of the earthen levees would be provided from commercial borrow pits. Quotes for delivery to the jobsite were obtained for each of the geographic locations. The material would require moisture control and the majority of this processing would be done at the borrow site processing area prior to bringing to the construction site. A dozer and tractor would process/perform moisture control work. Trucks will haul the material to the construction area. Dozers and roller will be used to spread and compact the material.

Levee to Floodwall tie-in would be done by placing riprap and filling the voids with grouted.

Other miscellaneous items included clearing, grubbing, and stripping the area; as well as Hydro seeding with mulch and fertilizer; scour protection of 6"reinforced concrete slab (3,000 psi) and reinforcement: 50 LB/CY. The Levee would be turfed from the toe of the levee to the other toe of

the levee, as well as any other disturbed areas. Sediment control during construction include silt fencing.

FLOODWALL: It was assumed that backfill for construction of the floodwall would be provided from commercial borrow pits. Quotes for deliver to the jobsite were obtained for each of the geographic locations. The material would require moisture control and the majority of this processing would be done at the borrow site processing area prior to bringing to the levee. A dozer and tractor would process/perform moisture control work. Trucks will haul the material to the construction area. Dozers and roller will be used to spread and compact.

Backfill - Spread and Compact Fill Material. Assumption: backfill, additional 4 ft. over wall heel and toe, levee -spread and compact, levee fill material, 95% compaction standard, 12" lift

Other folders included are: Sheet Pile Cutoff using PZ-22 steel sheet piles, 22'; Structure Concrete Piles: using 16" square prestressed concrete piles (PCP), 64' long, with 3 piles every 5'; and Concrete. The concrete folder has: reinforced slabs, reinforced walls, and stabilization slab (4").

Reinforced concrete Slab (Heel & Toe) of 5,000 psi, slab on stabilization slab, placed in

Reinforced concrete Wall (5,000 psi), wall placed on slab, placed in 40' monoliths

Concrete Stabilization Slab (3,000 psi), slab on grade.

Other miscellaneous items included clearing, grubbing, and stripping the area; as well as hydro seeding with mulch and fertilizer; scour protection of 6"reinforced concrete slab (3,000 psi) and reinforcement: 50 LB/CY.

At the existing HFPP at Port Arthur and Freeport, demolition of the existing floodwall needed to occur prior to construction of the new floodwall. Therefore a folder entitled "Demo" was included. In that folder (as applicable to the site) are the cost for the demolition of the existing T-wall, I-wall, Riprap, Granite blocks, and timber piling.

The estimates were based on standard operating practices for the Galveston District which assumed conventional contracting practices of large business IFB's.

Labor rates and overhead costs were adjusted to reflect Region 6. Soil characteristics were provided by SWG, Engineering Division, Geotechnical and Structures Section.

ACCOUNT CODE 13 – PUMP STATIONS: The cost for the different pump stations were developed using the latest table, from Jacksonville District, entitled Total CFS vs Cost per cfs based on historic pricing.

ACCOUNT CODE 15 – FLOODWAY CONTROL-DIVERSION

STRUCTURE: The cost of the navigation control structures were derived from cost from New Orleans District for similar work on the Caernarvon sector gate.

ACCOUNT CODE 30 -- ENGINEERING AND DESIGN: The cost for this account was developed using the guidelines provided in the TPCS, with the agreement of the cost engineer and the project manager. In addition, the costs for survey and soil borings were provided by SWG, General Engineering Section and Geotechnical & Structures Sections in Engineering & Construction Division.

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

10 BACKGROUND INFORMATION

The following information below was used in the plan formulation process to identify the tentatively selected plan (TSP) described in the Draft Report. The Draft Report was presented to the public on September 11, 2015. The information below is the same information presented in the Draft Report and does not reflect changes to the TSP recommendation that occurred after the publication of the Draft Report. The information is included to inform the reader of the planning process as it had been conducted up to publication of the Draft Report. After the release of the Draft Report, the team refined the design of the TSP with additional engineering and environmental investigations. This information is presented in the sections above. Based on feasibility level of design and based on comments received following publication of the Draft Report, portions of the TSP was modified. For the full details of the additional planning efforts, a brief description of those modifications is included in the main report.

10.1 DESCRIPTION OF TSP PROJECTS

10.1.1 Orange-Jefferson CSRM Project

10.1.1.1 Orange 3 Reach

The proposed Orange 3 reach is a levee/floodwall flood protection system that will serve to reduce the flood-damage potential from storm surge to much of the southern half of Orange County along the Sabine River and Bessie Heights Marsh (see Plate G-1). As conceived, the structures comprising the system will be built to an elevation capable of handling an 11-foot storm surge. At this time, there is no provision in the concept features assumed in developing the TSP project costs that accounts for future relative sea level rise, waves on top of the surge level, and additional minimum freeboard for wave overtopping. Therefore, the structure heights to accommodate this surge likely will end up being designed several feet higher than the heights assumed for the optimization analysis. (For the optimization analysis, it was assumed that sea-level rise, wave run-up, and overtopping could be uniformly applied across the system without affecting the TSP outcome.)

Orange 3 begins at I-10 at its northeast end, about 1.75 miles west of where the highway crosses the Sabine River. From there, the alignment roughly parallels the Sabine River to the south and then to the southwest to an industrial canal 1.65 miles northeast of the mouth of Cow Bayou. Along this reach, the alignment crosses Adams Bayou, which is used for navigation. There, the alignment turns sharply to the northwest, going up to a point near the south corner of the Du Pont Sabine River Works plant. From this point, the alignment runs southwesterly to Bridge City, crossing Cow Bayou along the way, which is also used for navigation. The alignment then wraps around Bridge City to the south, turning northwesterly along the north side of the Bessie Heights

Marsh to an end point less than a mile southwest of FM 1135, where it intersects FM 105 (Orangefield Road). Along this reach, the system will protect an electrical power-generating plant. In total, the length of the system will be approximately 27.1 miles, 21.1 miles of which will consist of earthen levee and 6.1 miles of concrete floodwall. The proposed alignment crosses several secondary roads, State Highway 87, Adams and Cow Bayous, an industrial canal, power plant intake canal, and floodplains where the foundation conditions are poor. It also crosses numerous pipelines and utilities, industrial facilities, commercial properties, residential areas, and sensitive environmental habitats. Consequently, there are going to be several challenges in implementing this reach of the project that will add considerably to its construction cost.

Orange 3 reduces the flood-damage potential from storm surge within the Cities of Orange, West Orange, Pinehurst, Bridge City, and Orangefield. It also protects petrochemical plants and Entergy Texas Inc. Sabine (Power) Plant, Bridge City.

10.1.1.2 Jefferson Main Reach

The proposed Jefferson Main reach is an earthen levee/concrete floodwall protection system that will serve to reduce the flood-damage potential from storm surge along the northeastern boundary of Jefferson County defined by the Neches River (see Plate G-1). As conceived, the structures comprising the system will be built to an elevation capable of handling an 11-foot storm surge. At this time, there is no provision in the concept features assumed in developing the TSP project costs that accounts for future relative sea level rise, waves on top of the surge level, and additional minimum freeboard for wave overtopping. Therefore, the structure heights to accommodate this surge likely will end up being designed several feet higher that the heights assumed for the optimization analysis.

The alignment begins near the northeastern terminus of the existing Port Arthur and Vicinity HFPP where it will tie into high ground. It runs west-northwest generally along the west bank of the Neches River, nearly 11.0 miles, to a point on the north side of the Du Pont Beaumont Works Industrial Park in Nederland. Because industrial facilities to be protected front the river, approximately 3.1 miles of the system will consist of floodwall. The alignment crosses industrial plants and must provide for access to several docking facilities along the river. It circumvents a large upland wetland area, thereby avoiding adverse impacts to the wetland.

10.1.1.3 Beaumont "A" Reach

The proposed Beaumont "A" reach is an earthen levee/concrete floodwall protection system that will serve to protect ExxonMobil's Beaumont Chemical Plant (see Plate G-1). This 3.6-mile-long system, consisting of 1.1 miles of levee and 2.5 miles of floodwall, was envisioned to supplant the

existing flood-protection system surrounding the plant to provide a level of protection that reduces the flood-damage risk against a 12-foot surge. It has been discovered since this alternative was forwarded to be included in the TSP as a project reach however that the recently industry-built barrier is approximately 3 to 4 feet higher than that being proposed based on the SWL alone. The proposed alignment generally follows the existing barrier alignment. When storm surge from Hurricane Ike inundated the plant in 2008, the plant was 6 to 10 feet under water. This resulted in a shutdown of the plant for more than a month. To prevent future damages from storm surge, ExxonMobil Corporation replaced its former levee system, making the barrier more robust and providing a higher level of protection.

10.1.2 Port Arthur and Vicinity CSRM Project

10.1.2.1 Port Arthur 8- to 10-foot I-Wall One-Foot Raise

The TSP for reconstruction and resiliency features for the existing HFPP in this reach was selected to be the one-foot raise plan. A one-foot raise will require 7,500 LF of 15-foot-wide by 6-inch thick concrete scour pad along with removing the excess stick-up height from the existing I-wall and adding erosion protection to reduce the likelihood of a brittle failure if the system's capacity is exceeded. This plan includes adding capacity to the system in this reach by addressing low areas of the levee system, raising 2,000 LF of levee one foot, and providing overtopping erosion protection at areas subject to excessive erosion.

10.1.2.2 Port Arthur Closure Structure

The TSP for reconstruction and resiliency features for the existing HFPP at the closure structure is the one-foot raise plan. The replaced closure structure gate structure is proposed to be 12 feet high by 30 feet wide. In addition to replacing the structure, 2,300 LF of 100-foot-wide by 6-inch thick concrete scour pad will be constructed, one on each side of the structure, to provide erosion protection to reduce the likelihood of a brittle failure if the system's capacity is exceeded and 12,000 LF of levee will be raised one foot.

10.1.2.3 I-Wall near Valero

The TSP for reconstruction and resiliency features for the existing HFPP at the I-wall near the Valero refinery is additional structural support and a one-foot raise. Construction of 5,000 LF of 15-foot-wide by 6-inch thick concrete scour pad and a batter piling and waler system with a one-foot raise will provide additional system capacity, assure the wall's structural integrity, and provide erosion protection to reduce the likelihood of a brittle failure if the system's capacity is exceeded. In conjunction with these reinforcement and resiliency measures, an additional 3,000 LF of adjacent levee will be raised one foot.

10.1.2.4 Port Arthur Tank Farm

The TSP for reconstruction and resiliency features for the existing HFPP at the I-wall near the Tank Farm is additional structural support and a one-foot raise. Construction of 1,800 LF of 15-foot-wide by 6-inch thick concrete scour pad and a batter piling and waler system with a one-foot raise will provide additional system capacity, assure the wall's structural integrity, and provide erosion protection to reduce the likelihood of a brittle failure if the system's capacity is exceeded. In conjunction with these reinforcement and resiliency measures, an additional 7,000 LF of adjacent levee will be raised one foot.

10.1.3 Freeport and Vicinity CSRM Project

10.1.3.1 South Storm Levee Raise

The South Storm Levee was determined not to be an economically viable option.

10.1.3.2 Freeport Dock Floodwall Raise

The TSP for reconstruction and resiliency features for the existing HFPP at the Freeport Dock floodwall is a reconstruction of the existing wall/drop in panel system. The construction will include 3,000 LF of floodwall to meet all USACE requirements for a wall/drop-in panel system for a port facility.

10.1.3.3 Tide Gate One-Foot Raise

The TSP for reconstruction and resiliency features for the existing HFPP at the I-wall located at the Tide Gate is a complete reconstruction of the I-wall and extension of the reconstructed floodwall to replace two (2) additional sections of floodwall at a one-foot raise in system capacity. Construction will consist of 700 LF of floodwall, 11 feet high, along with 2,000 LF of levee raised one foot.

10.1.3.4 Old River at Dow Thumb

The TSP for reconstruction and resiliency features for the existing HFPP along the Dow thumb levee reach is a one-foot raise in system capacity. Construction will include 4,000 LF of 15-foot-wide by 6-inch thick concrete scour pad along with 3,000 LF of levee raised one foot and 14,500 LF of high performance turf reinforcement mattress (HPTRM). Additional material will be added in order to "level up" the low spots of this reach of levee, which, in conjunction with the erosion protection, will to reduce the likelihood of a brittle failure if the system's capacity is exceeded.

10.1.3.5 Dow Barge Canal Protection

The TSP for reconstruction and resiliency features for the existing HFPP at the Dow Barge Canal levee is a closure structure and pump station constructed at the junction of the North Barge Canal and East Storm Levee across the barge canal to the South Barge Canal Levee. This structure will allow barge traffic to pass during routine operations and will have a pumping capacity of 2,000,000 gpm. The structure will be approximately 500 feet in length with two (2) sector gates to provide for an 80-foot-wide navigable opening. Tidal circulation will be maintained by two (2) sluice gates, each approximately 15 feet wide. The structure's final configuration will match the proposed level of protection for the system.

10.1.3.6 East Storm Levee Raise

The TSP for reconstruction and resiliency features for the existing HFPP at the East Storm Levee is a one-foot raise in system capacity. Construction includes 13,115 LF of levee raised one foot along with HPTRM installation for erosion protection.

10.1.3.7 Oyster Creek Levee Raise

The TSP for reconstruction and resiliency features for the existing HFPP at the Oyster Creek Levee reach is a one-foot raise in system capacity along with extending an elevation to account for changes in surge loading. Construction will include 3,500 LF of a 3-foot levee raise and 10,000 LF of a one-foot levee raise for a total raised distance of 13,500 LF. The construction procedure will include stripping, removal and replacement of a 12-foot-wide asphalt road, placement of compacted fill, and turfing.

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Time: 2:00:50 PM
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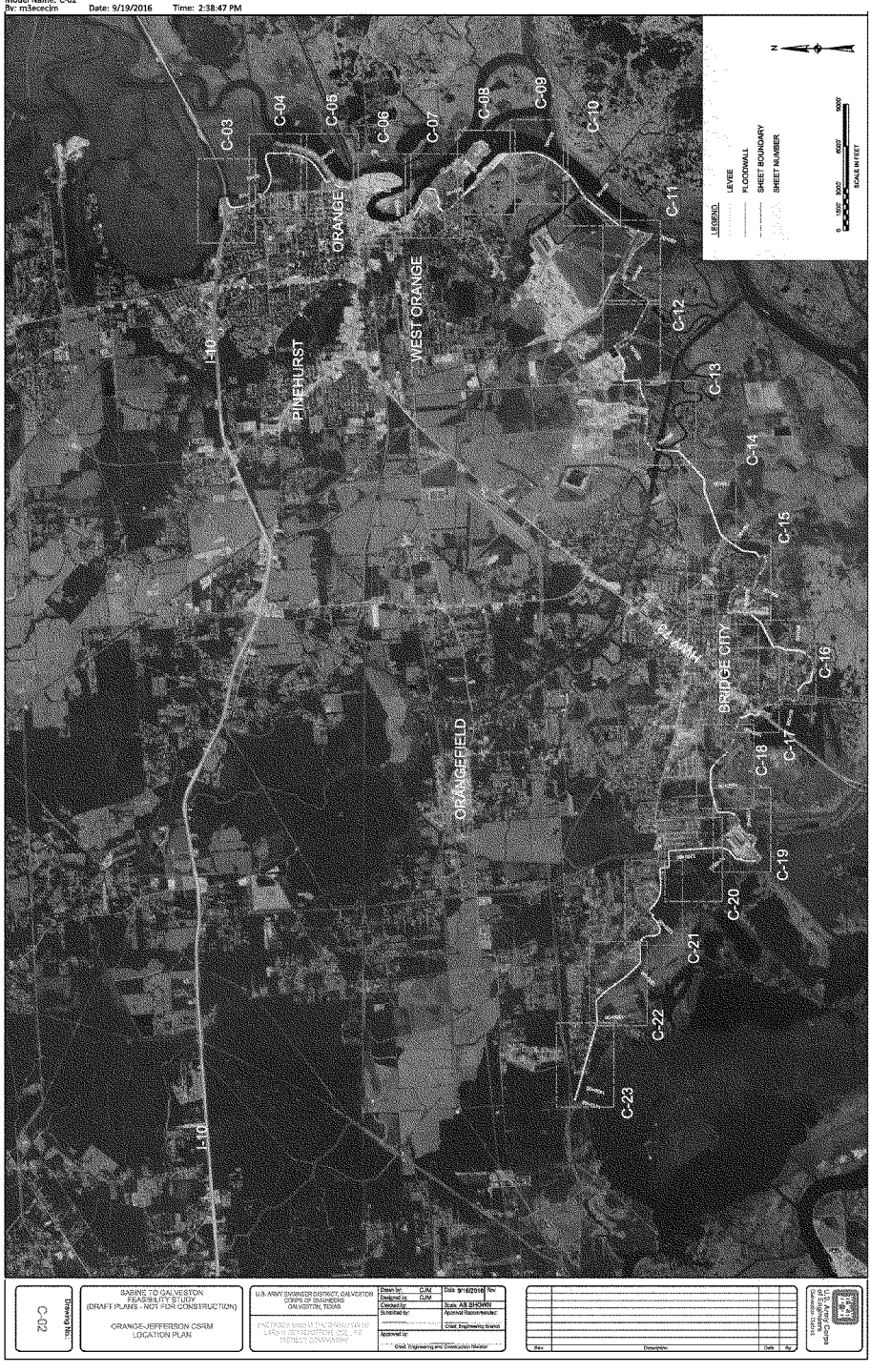
WEST ORANGE
PINEHURST
ORANGEFIELD
BRIDGE CITY
I-10
LEGEND
LEVEE
FLOODWALL
SCALE IN FEET
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM
OVERVIEW MAP
C-01
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division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C-03
C-04
C-05
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C-17
C-18
C-19
C-20
C-21
C-22
C-23
ORANGE
WEST ORANGE
PINEHURST
ORANGEFIELD
BRIDGE CITY
I-10
LEGEND
LEVEE
FLOODWALL
SHEET BOUNDARY
SHEET NUMBER
SCALE IN FEET
Drawing No.: C-02
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM
LOCATION PLAN
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Date: 9/16/2016
Checked by:
Scale: AS SHOWN
Submitted by:
Approved by:
Chief, Engineering and Construction Division
Chief, Engineering Branch
Rev.
Description
Date
By

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DRAINAGE STRUCTURE
PUMP STATION
ROAD/RAILROAD GATE
LEVEE
TOE
CREST
FLOOD SIDE SLOPE
LAND SIDE SLOPE
FLOODWALL
STEM
SCALE IN FEET
0+00
10+00
20+00
FLOODWALL
ELEV X.X X 120' BOX CULVERTS
TRANSITION
ELEV X.X X 120' BOX CULVERTS
ROAD/RAIL ROAD GATE
ROAD/RAIL ROAD GATE
PROVIDE LETTER OF PROVISIONAL PUMP AND BLOCK GATE
C-03
SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM PLAN - STA 0+00 TO STA 29+00
U.S. ARMY CORPS OF ENGINEERS GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev.
Description
Date
By

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Drawing No.:

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FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ORANGE-JEFFERSON CSRM
PLAN - STA 25+00 TO STA 92+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

RECOMMENDED FOR APPROVAL BY:
DANIEL SEPULVEDA, SAM, P.E.
STRUCTURAL ENGINEER

Drawn by:	CJM	Date: 6/18/2016
Designed by:	CJM	
Checked by:		Scale: AS SHOWN
Submitted by:		Approval Recommended:
		Chief, Engineering Branch
Approved by:		
		Chief, Engineering and Construction Division

Rev.	Description	Date	By

U.S. Army Corps of Engineers
Galveston District

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100+00
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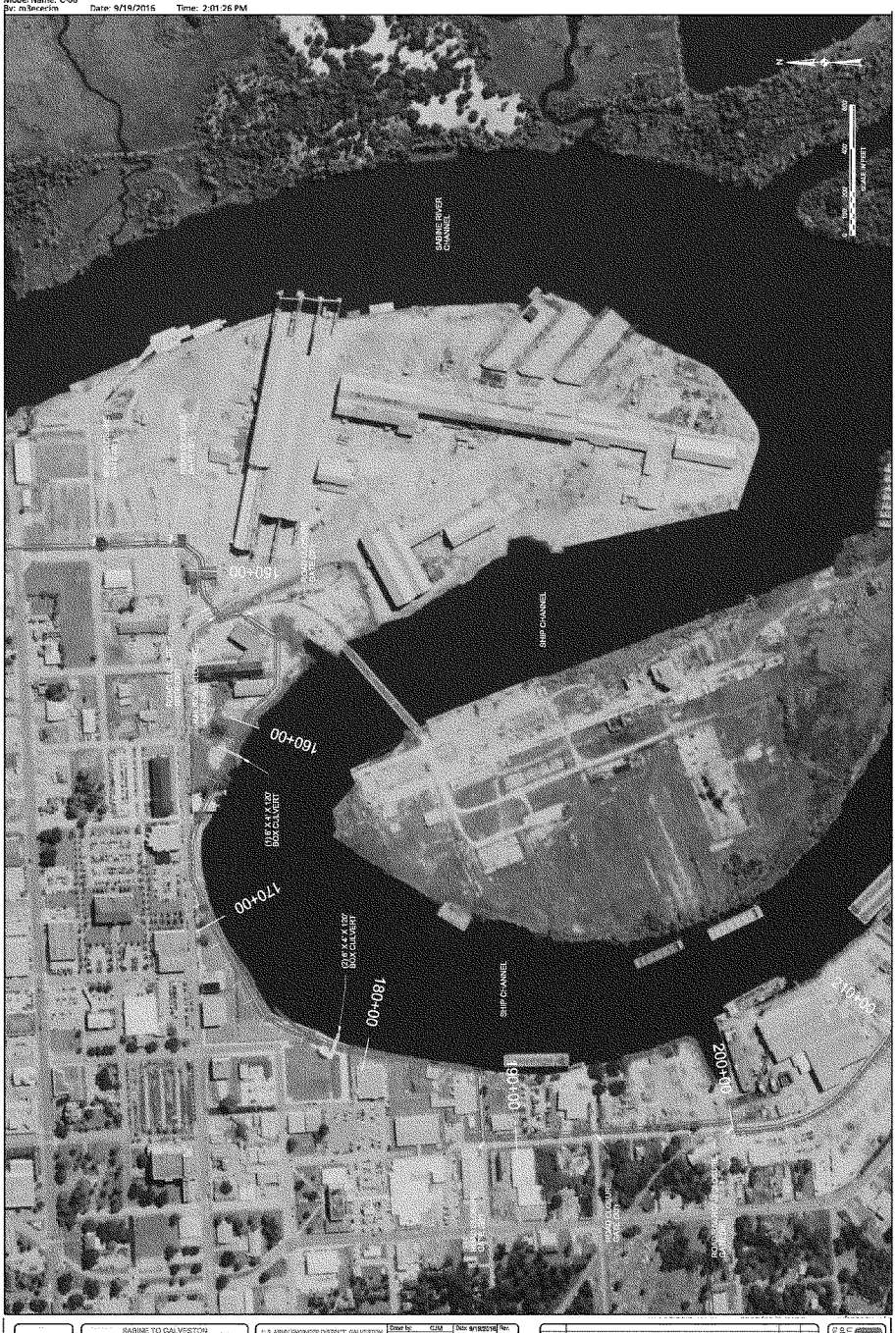
PUMP STATION #2
EXISTING STRUCTURE
TO BE INCORPORATED
INTO PROJECT
(ADD PUMPING CAPACITY)
SABINE RIVER
CHANNEL
ROAD CLOSURE
GATE (TYP)
RAISE TO ELEVATION
+16.0 NAVD 88
EXISTING
GROUND
EXISTING
GROUND
EXISTING
GROUND

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-06
By: mlecerin Date: 9/19/2016 Time: 2:01:26 PM



C-06
Drawing No.:

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ORANGE-JEFFERSON CSRM
PLAN - STA 143+00 TO STA 209+60

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE SUPERVISION OF:
CARLA SUTHERLAND, P.E.
PROJECT ENGINEER

Drawn by:	CJM
Designed by:	CJM
Checked by:	
Submitted by:	
Approved by:	
Chief, Engineering and Construction Division	

Date: 9/19/2016 Rev.
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch

Rev.	Description	Date	By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-07
SABINE RIVER CHANNEL
240+00
230+00
250+00
260+00
270+00
280+00
220+00
210+00
SABINE TO GALVESTON FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM
PLAN - STA 209+00 TO STA 280+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Date: 9/19/2016
Checked by:
Scale: AS SHOWN
Submitted by:
Approved/Recommended:
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division
C-07
Drawing No.

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-08
By: mbeverlin Date: 9/19/2016 Time: 2:01:42 PM
SABINE RIVER CHANNEL
SABINE RIVER CHANNEL
ORANGE MUNICIPAL SLIP
280+00
290+00
300+00
310+00
320+00
330+00
LEVEE TO FLOODWALL TRANSITION
LEVEE TO FLOODWALL TRANSITION
LEVEE TO FLOODWALL TRANSITION
D-17 X W-8 X 67 SHEET PILES
SCALE IN FEET
N
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM
PLAN - STA 280+00 TO STA 327+00
Drawing No.:
C-08
U.S. ARMY CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Created by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev.
Description
Date
By
U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 52G - Orange levee system.tc.dgn
Model Name: C-09
By: mlecrecim Date: 9/19/2016 Time: 2:01:52 PM

C-09

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ORANGE-JEFFERSON CERM
PLAN - STA 327+00 TO STA 369+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division

Date: 9/19/2016 Rev.
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch

Rev Description Date By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-10
By: mtescrim Date: 8/19/2016 Time: 2:02:00 PM

C-10

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ORANGE-JEFFERSON CSRM
PLAN - STA 369+00 TO STA 423+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PRELIMINARY AND NOT APPROVED BY HIGHER REVIEW AUTHORITY. DO NOT USE FOR CONSTRUCTION

Drawn by:	CJM	Date: 8/19/2016
Designed by:	CJM	
Checked by:		Scale: AS SHOWN
Submitted by:		Approval Recommended:
		Chief, Engineering Branch
Approved by:		
		Chief, Engineering and Construction Division

Rev.	Description	Date	By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 52G - Orange levee system.tc.dgn
Model Name: C-11
By: mkevecim
Date: 9/19/2016
Time: 2:02:08 PM
430+00
440+00
450+00
460+00
470+00
480+00
490+00
500+00
510+00
LEVEE TO TIE INTO EXISTING HIGH GROUND
TIE-IN AT EL 8.0 FT NAVD88
TIE-IN AT EL 8.0 FT NAVD88
SCALE IN FEET
C-11
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM
PLAN - STA 423+00 TO STA 519+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Rev
Description
Date
By
Drawing No.
U.S. Army Corps of Engineers
Galveston District

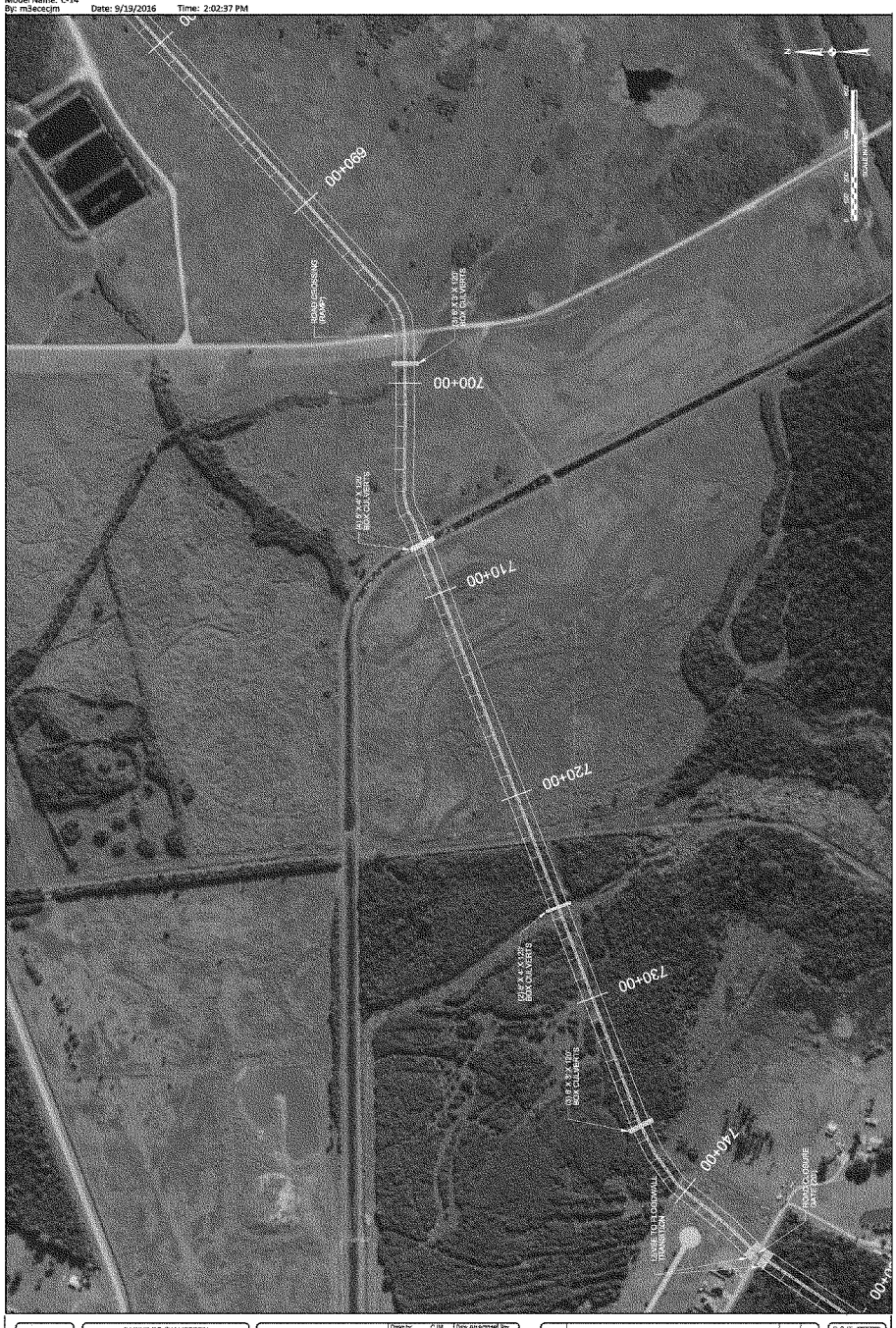
File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-12
By: m3ecascm Date: 9/19/2016 Time: 2:02:18 PM

520+00
530+00
540+00
550+00
560+00
570+00
580+00
590+00
600+00
8'-0" X 8'-0" BOX CULVERTS
LEVEE TO FLOODWALL TRANSITION
ROAD CLOSURE GATE (07)
LEVEE TO FLOODWALL TRANSITION
ROAD CLOSURE GATE (07)
ROAD CLOSURE GATE (07)
LEVEE TO FLOODWALL TRANSITION
ROAD CLOSURE GATE (07)
91.5Ø DIAMETER HDP
LEVEE TO FLOODWALL TRANSITION
ROAD CLOSURE GATE (07)
LEVEE TO FLOODWALL TRANSITION
ROAD CLOSURE GATE (07)
ROAD CLOSURE GATE (07)
91.5Ø DIAMETER HDP
LEVEE TO FLOODWALL TRANSITION
ROAD CLOSURE GATE (07)
ROAD CLOSURE GATE (07)

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 52G - Orange levee system.tc.dgn
Model Name: C-13
By: m3ecejm Date: 9/19/2016 Time: 2:02:27 PM

600+00
610+00
620+00
630+00
640+00
650+00
660+00
670+00
680+00
LEVEE TO FLOODWALL TRANSITION
LEVEE TO FLOODWALL TRANSITION
12'-6" X 3' FLOODWALL
12'-6" X 3' FLOODWALL
12'-6" X 3' FLOODWALL
12'-6" X 3' FLOODWALL
10'-0" X 10'-0" RCP CULVERTS
10'-0" X 10'-0" RCP CULVERTS
10'-0" X 10'-0" RCP CULVERTS

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-14
By: m3eccjm Date: 9/19/2016 Time: 2:02:37 PM



Drawing No.: C-14

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ORANGE-JEFFERSON CSRM
PLAN - STA 680+00 TO STA 745+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

RECOMMENDED FOR APPROVAL BY:
LACEY MATHERNE, COL, E.N.
DISTRICT COMMANDER

Drawn by:	CJM	Date: 9/19/2016
Designed by:	CJM	
Checked by:		Scale: AS SHOWN
Submitted by:		Approval Recommended:
		Chief, Engineering Branch
Approved by:		
	Chief, Engineering and Construction Division	

Rev.	Description	Date	By

U.S. Army Corps of Engineers
Galveston District

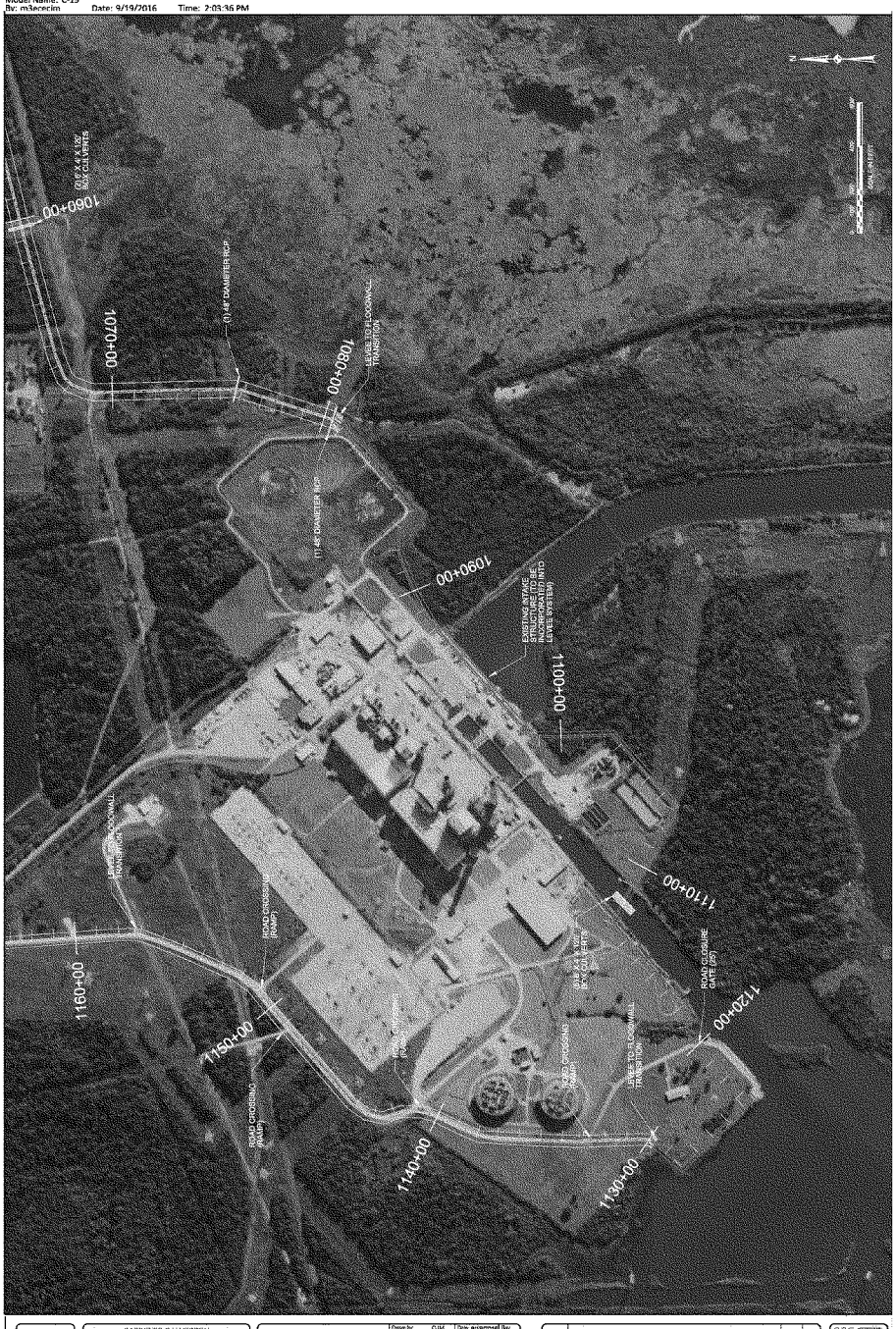
File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 52G - Orange levee system.tc.dgn
Model Name: C-15
By: m3ecezcm
Date: 9/19/2016
Time: 2:02:48 PM
740+00
760+00
780+00
800+00
820+00
840+00
860+00
880+00
910+00
930+00
950+00
ROAD CROSSING RAMP
ROAD CROSSING RAMP (DATE TBD)
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM
PLAN - STA 746+00 TO STA 868+06
C-15
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev
Description
Date
By

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-16
By: mSeaGrim
Date: 9/19/2016
Time: 2:09:01 PM
870+00
880+00
890+00
900+00
910+00
920+00
930+00
940+00
950+00
960+00
970+00
(6) 13'-6" x 10'-0" BOX CULVERTS
(6) 13'-6" x 10'-0" BOX CULVERTS
(6) 13'-6" x 10'-0" BOX CULVERTS
(6) 13'-6" x 10'-0" BOX CULVERTS
(6) 13'-6" x 10'-0" BOX CULVERTS
(6) 13'-6" x 10'-0" BOX CULVERTS
(6) 13'-6" x 10'-0" BOX CULVERTS
FLOODWALL TRANSITION
FLOODWALL TRANSITION
FLOODWALL TRANSITION

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-17
By: m3ecejm Date: 9/19/2016 Time: 2:03:14 PM

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 52G - Orange levee system.tc.dgn
Model Name: C-18
By: m3eacrcin
Date: 9/19/2016
Time: 2:03:25 PM
1060+00
1010+00
1020+00
1030+00
1040+00
1050+00
1060+00
107
EXIST TOP OF ROADWAY
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM
PLAN - STA 1000+00 TO STA 1060+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawing No.:
C-18

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 52G - Orange levee system.tc.dgn
Model Name: C-19
By: mlacercim Date: 9/19/2016 Time: 2:03:36 PM



File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-20
By: m3ecectin Date: 9/19/2016 Time: 2:03:47 PM

Drawing No.: C-20

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ORANGE-JEFFERSON CSRM
PLAN - STA 1160+00 TO STA 1205+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE SUPERVISION OF:
DANIEL JOHNSTON, COL, U.S.A.
DISTRICT COMMANDER

Drawn by:	CJM	Date: 9/19/2016
Designed by:	CJM	
Checked by:		Scale: AS SHOWN
Submitted by:		Approval Recommended:
		Chief, Engineering Section
Approved by:		
		Chief, Engineering and Construction Division

Rev.	Description	Date	By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 52G - Orange levee system.tc.dgn
Model Name: C-21
By: mleeccim Date: 9/19/2016 Time: 2:04:00 PM

Drawing No.: C-21

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ORANGE-JEFFERSON CSRM
PLAN - STA 1205+00 TO STA 1282+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

Drawn by:	CJM	Date: 9/19/2016
Designed by:	CJM	
Checked by:		Scale: AS SHOWN
Submitted by:		Approval Recommended:
		Chief, Engineering Branch
Approved by:		
		Chief, Engineering and Construction Division

Rev.	Description	Date	By

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-22
By: m3eceem
Date: 9/19/2016
Time: 2:04:11 PM
1290+00
1300+00
1310+00
1320+00
1330+00
1340+00
1350+00
CMP 4 x 4 SBT BOX CULVERTS
DRIVEWAY CROSSING (PAVED)
N
SCALE IN FEET
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
ORANGE-JEFFERSON CSRM
PLAN - STA 1282+00 TO STA 1354+00
U.S. ARMY CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Quantities by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering and Construction Division
Chief, Engineering Branch
Rev.
Description
Date
By
C-22
Drawing No.

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 S2G - Orange levee system.tc.dgn
Model Name: C-23
By: m3ceccim Date: 9/19/2016 Time: 2:04:22 PM

C-23

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ORANGE_JEFFERSON CSRM
PLAN - STA 1354+00 TO STA 1410+64

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

Drawn by:	CJM	Date: 9/19/2016
Designed by:	CJM	
Checked by:		Scale: AS SHOWN
Submitted by:		Approval Recommended:
		Chief, Engineering Branch
Approved by:		
		Chief, Engineering and Construction Division

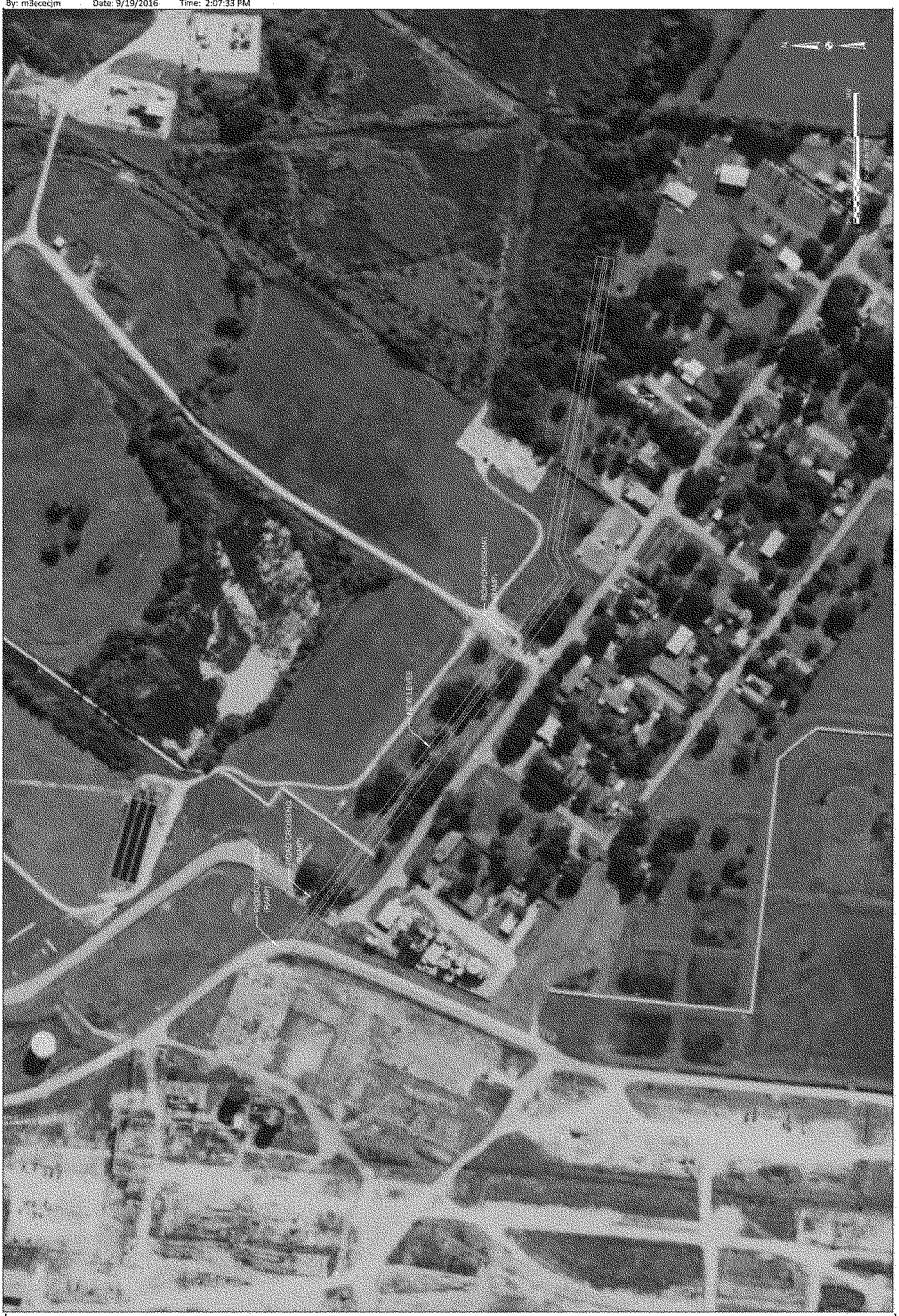
Rev. | Description | Date | By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-24
By: mbeard
Date: 9/19/2016
Time: 2:06:29 PM
LEGEND
LEVEE
FLOODWALL
REACH 1 - STA 0+00 TO 381+00
REACH 2 - STA 381+00 TO 579+47
REACH 3 - STA 579+47 TO 723+41
REACH 4 - STA 723+41 TO 970+00
REACH 5 - STA 970+00 TO 1065+00
N
0
1000'
2000'
4000'
8000'
SCALE IN FEET
PORT ARTHUR
LOUISIANA
TEXAS
REACH 1
REACH 2
REACH 3
REACH 4
REACH 5
Sheet No.
C-24
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
PORT ARTHUR AND VICINITY CSRM
OVERVIEW MAP
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by:
CLM
Date: 9/19/2016
Designed by:
C-SP
Checked by:
Scale: AS SHOWN
Submitted by:
Approved by:
Chief, Engineering Branch
Chief, Engineering and Construction Division
No.
Description
Date
By
Project Name
SABINE TO GALVESTON
FEASIBILITY STUDY
Contract Number
W912HN-15-D-0001
Task Order
0004

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-25
By: mbeckcim
Date: 9/19/2016
Time: 2:07:19 PM
C-25
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
PORT ARTHUR AND VICINITY CSRM
LOCATION PLAN
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE SUPERVISION OF
JARED R. BECKCIM, P.E.
ASSISTANT DISTRICT ENGINEER
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/15/2016
Scale: AS SHOWN
Approval Recommended
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev.
Description
Date
By
LEGEND
LEVEE
FLOODWALL
SHEET BOUNDARY
SHEET NUMBER
SCALE IN FEET
N
C-26
C-27
C-28
C-29
C-30
C-31
C-32
C-33
C-34
C-35
C-36
C-37
C-38
C-39
C-40
C-41
C-42
C-43

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-26
By: m3ectcjm Date: 9/19/2016 Time: 2:07:33 PM



Drawing No. C-26

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

PORT ARTHUR AND VICINITY CSRM
PORT ARTHUR ADDITION

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF:
LIEUTENANT COLONEL CHRISTOPHER W. POPE
DISTRICT COMMANDER

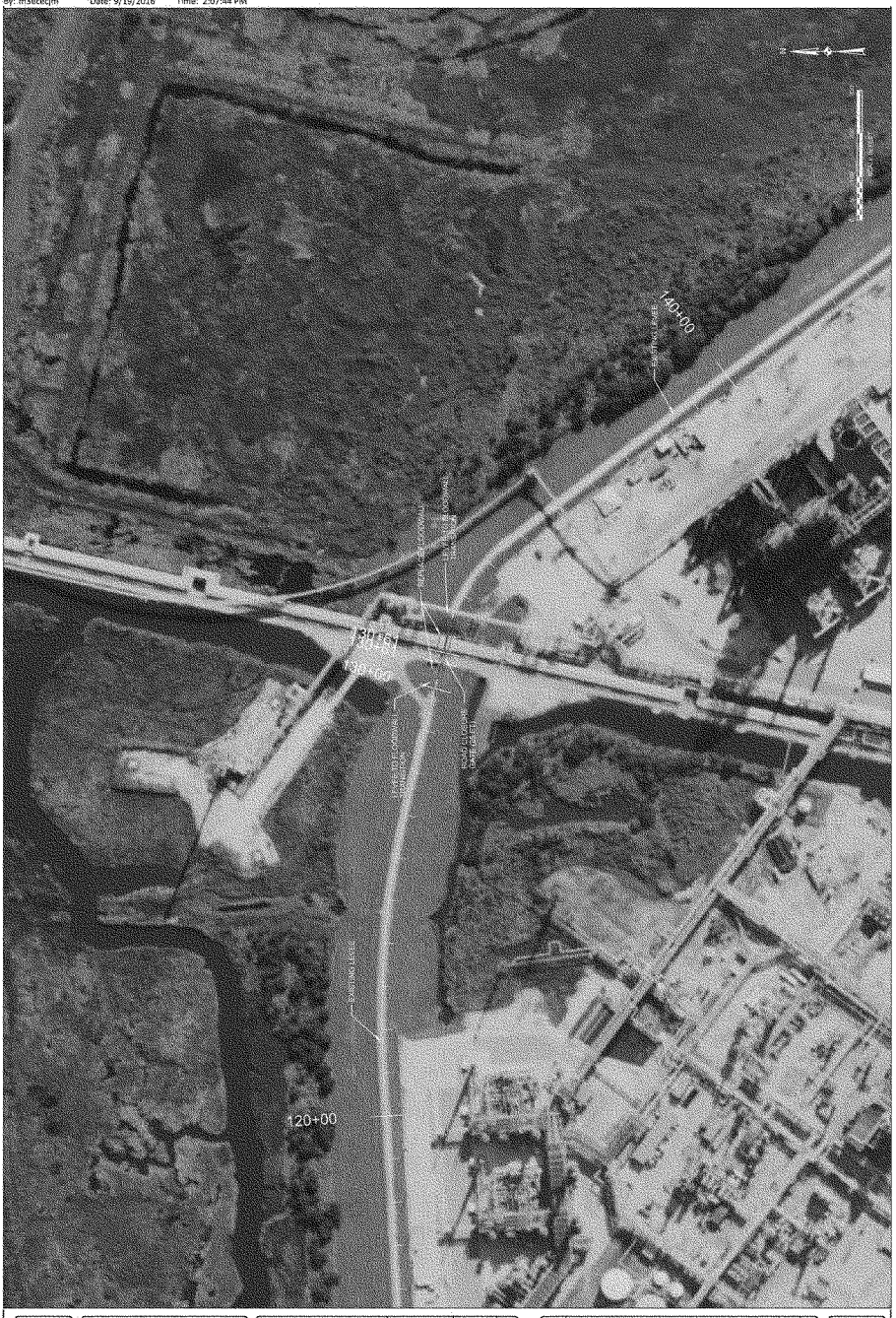
Drawn by: CJM Date: 9/19/2016
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division

Scale: AS SHOWN
Approved/Recommended:
Chief, Engineering Branch

Rev.	Description	Date	By

US Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sri\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-27
By: m3cecjm Date: 9/19/2016 Time: 2:07:44 PM



C-27
Drawing No.

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

PORT ARTHUR AND VICINITY CSRM
PLAN - STA 130+81

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF:
LIEUTENANT COLONEL P.E.
DISTRICT COMMANDER

Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Date: 9/15/2016
Scale: AS SHOWN
Approved Recommended:
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division

Rev. | Description | Date | By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-28
By: mkreacim
Date: 9/19/2016
Time: 2:07:55 PM
300+00
310+00
320+00
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
PORT ARTHUR AND VICINITY CSRM
PLAN - STA 290+00 TO 320+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF
DANIEL DECOSTANZA, CPE, PE
PROJECT ENGINEER
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/15/2016
Scale: AS SHOWN
Approval Recommended
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev.
Description
Date
By
C-28
Drawing No.

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-29
By: m3eceoim Date: 9/19/2016 Time: 2:08:05 PM

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-30
By: mbecnel
Date: 9/19/2016
Time: 2:08:23 PM
380+00
390+00
400+00
SABINE RIVER
INTRACOASTAL WATERWAY (DEEP DRAFT)
SABINE RIVER
INTRACOASTAL WATERWAY (DEEP DRAFT)
SABINE RIVER
INTRACOASTAL WATERWAY (DEEP DRAFT)
HIGH USE ROAD
HIGH USE ROAD
HIGH USE ROAD
Drawing No.
C-30
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
PORT ARTHUR AND VICINITY TSRM
PLAN - STA 380+00 TO 408+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF
LAREN BRIGHTWELL, P.E.
DISTRICT ENGINEER
Drawn by: CJM
Date: 9/16/2016
Designed by: CJM
Checked by:
Scale: AS SHOWN
Submitted by:
Approval Recommended
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division
No.
Description
Date
By
Sabine to Galveston
Coastal Storm Damage Reduction Feasibility Study

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-31
By: mbecsim Date: 9/19/2016 Time: 2:08:39 PM

Drawing No. C-31	SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)	U.S. ARMY ENGINEER DISTRICT, GALVESTON CORPS OF ENGINEERS GALVESTON, TEXAS	Check by: CJD Date: 9/15/2016 Rev. Designed by: CJM Checked by: Scale: AS SHOWN Submitted by: Agency Recommended Chief, Engineering and Construction Division Approved by: Chief, Engineering and Construction Division	Rev. Description Date By
	PORT ARTHUR AND VICINITY CSRM PLAN - STA 409+00 TO 459+00	PREPARED UNDER THE DIRECTION OF: [illegible]		

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-32
By: m3excecim Date: 9/19/2016 Time: 2:08:55 PM
450+00
460+00
470+00
480+00
490+00
500+00
REPLACE FLOODWALL
SABINE NECHES WATERWAY (DEEP DRAFT)
REPLACE FLOODWALL
REPLACE FLOODWALL
SABINE PASS WATERWAY (DEEP DRAFT)
REPLACE FLOODWALL
EXISTING LEVEE
SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)
PORT ARTHUR AND VICINITY CSRM PLAN - STA 456+00 TO 509+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON CORPS OF ENGINEERS GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev. Description Date By
Drawing No. C-32

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-33
By: mSeverin Date: 9/19/2016 Time: 2:09:12 PM

C-33

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

PORT ARTHUR AND VICINITY CSRM
PLAN - STA 505+00 TO 549+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE SUPERVISION OF
COL JOHN M. VEITENHEIMER, COL, USA
DISTRICT COMMANDER

Drawn by: CJH Date: 9/15/2016 No.
Designed by: CJH
Checked by:
Scale: AS SHOWN
Submitted by: Approval Recommended
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division

No. Date Description By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-34
By: mkocsis Date: 9/19/2016 Time: 2:09:28 PM

C-34

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

PORT ARTHUR AND VICINITY CSRM
PLAN - STA 545+00 TO 593+00

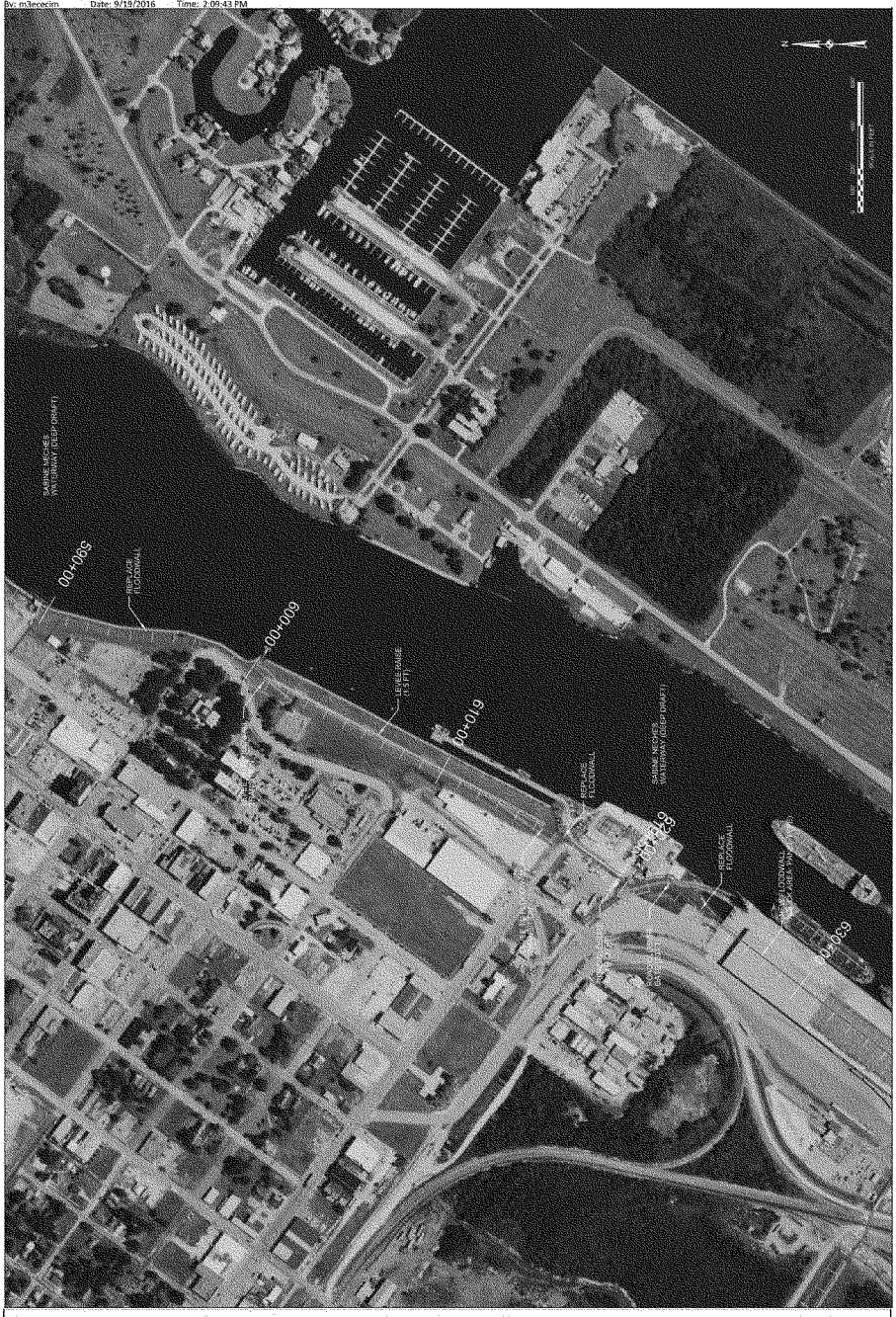
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

Drawn by: CJM Date: 9/19/2016
Designed by: CJM Rev.
Checked by: Scale: AS SHOWN
Intended by: Approval Recommended:
Civil Engineering Branch
Approved by:
Chief, Engineering and Construction Division

No. Revision Date By

Sheet Number

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-35
By: m3nocim Date: 9/19/2016 Time: 2:09:43 PM



Drawing No.: C-36

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

PORT ARTHUR AND VICINITY CSRM
PLAN - STA 930+00 TO 830+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

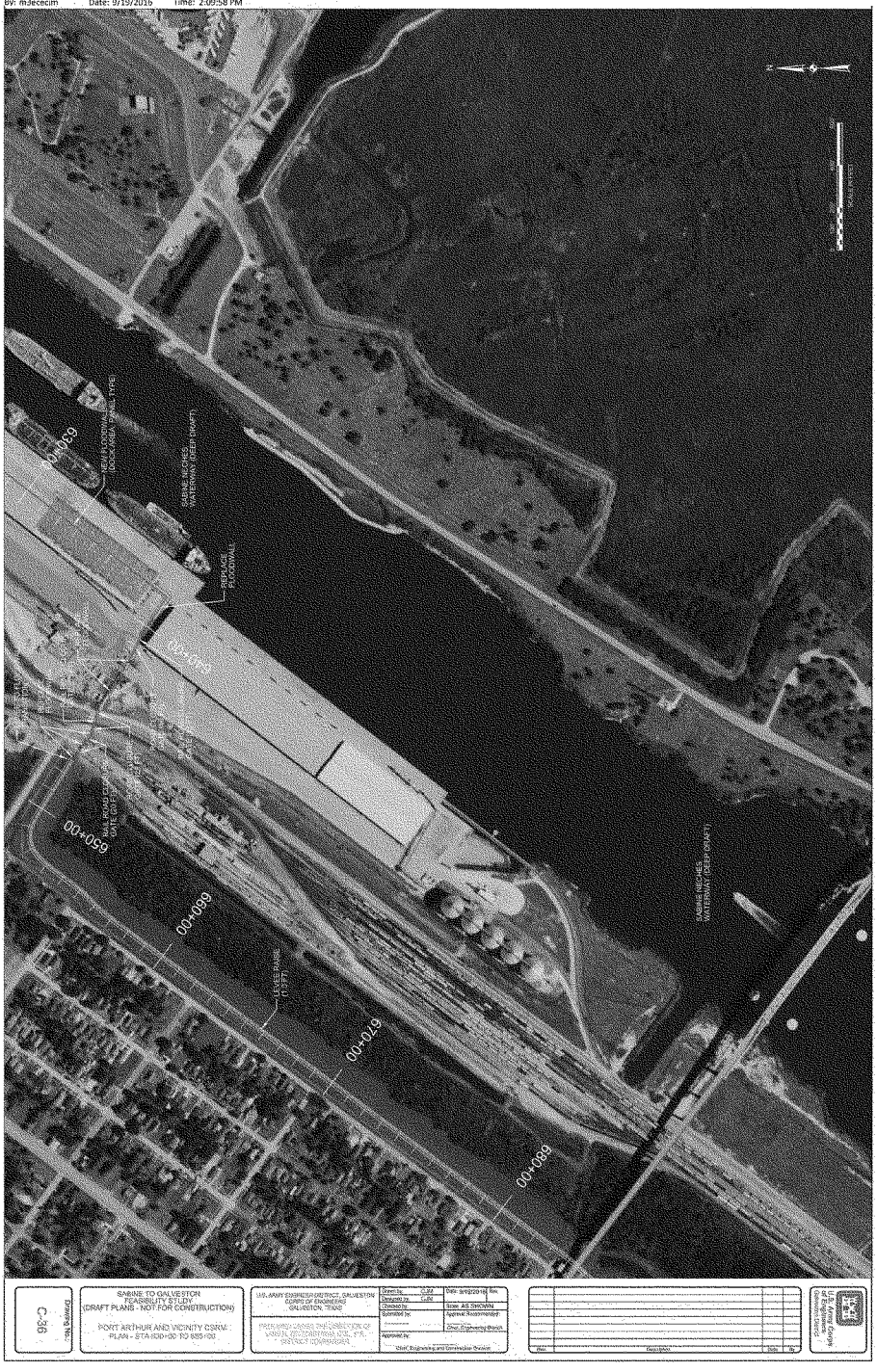
PREPARED UNDER THE DIRECTION OF
LINDA S. CHRISTOPHERSON, P.E.
DISTRICT COMMANDER

Drawn by:	CJW	Date: 9/19/2016
Designed by:	CJW	
Checked by:		Scale: AS SHOWN
Submitted by:		Approval Recommended
		Chief, Engineering Division
Approved by:		
		Chief, Engineering and Construction Division

Rev. | Description | Date | By

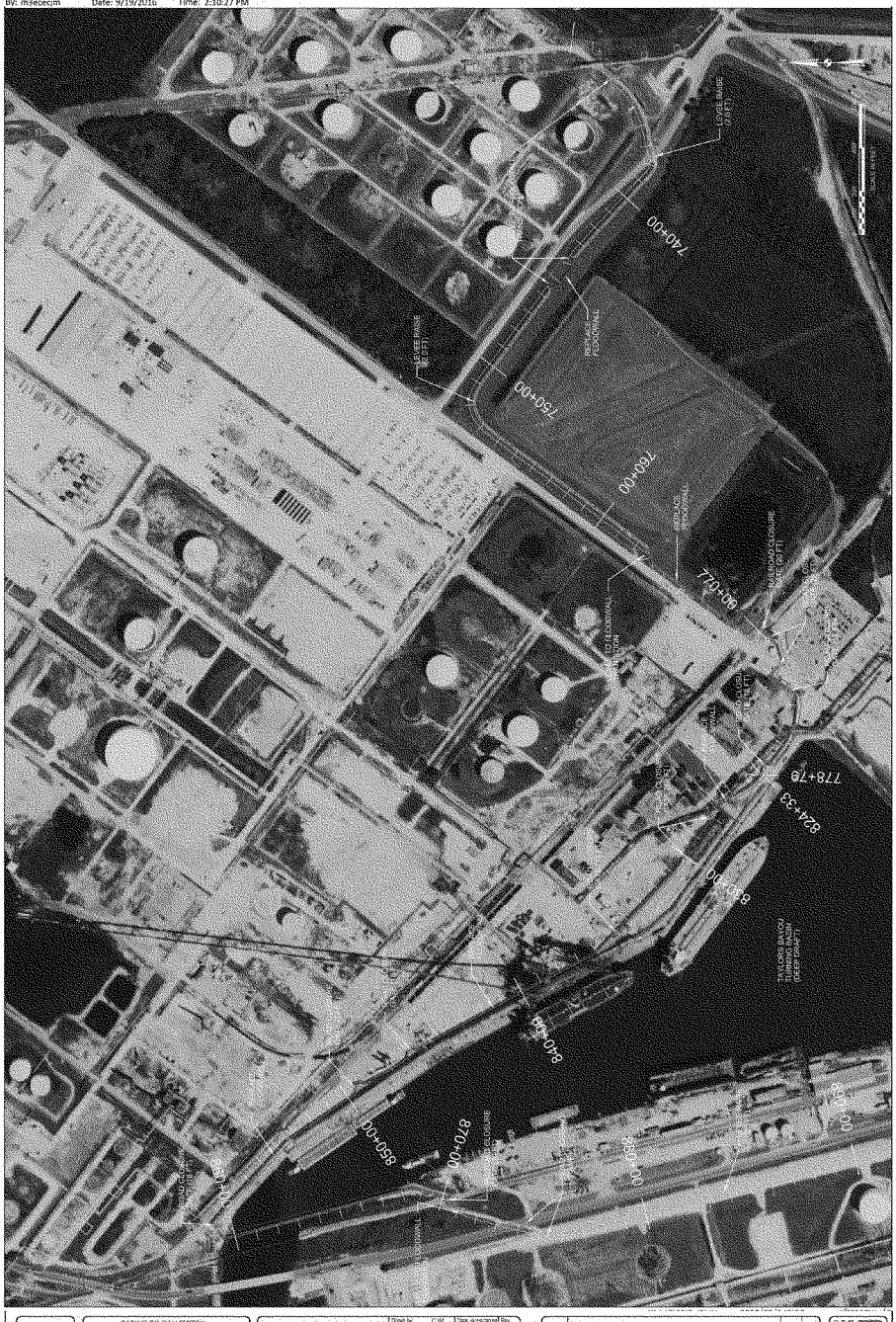
U.S. Army Corps of Engineers
Construction Series

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-36
By: mdecincim Date: 9/19/2016 Time: 2:09:58 PM


00+089
00+059
00+099
00+019
00+088
ABANDONED
ABANDONED
ABANDONED

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-37
By: mkeaggin Date: 9/19/2016 Time: 2:10:12 PM
SABINE PASS TO GALVESTON BAY WATERWAY (DEEP DRAFT)
SABINE PASS TO GALVESTON BAY WATERWAY (DEEP DRAFT)
SABINE PASS TO GALVESTON BAY WATERWAY (DEEP DRAFT)
SABINE PASS TO GALVESTON BAY WATERWAY (DEEP DRAFT)
690+00
700+00
710+00
720+00
730+00
740+00
SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)
PORT ARTHUR AND VICINITY (SABINE PLAN - STA 685+00 TO 734+00)
C-37
U.S. ARMY ENGINEER DISTRICT, GALVESTON CORPS OF ENGINEERS GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended
Chief, Engineering Division
Chief, Engineering and Construction Division
Rev.
Description
Date
By
U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-38
By: mSecrcm Date: 9/19/2016 Time: 2:10:27 PM



Drawing No. C-38	SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)	U.S. ARMY ENGINEER DISTRICT, GALVESTON CORPS OF ENGINEERS GALVESTON, TEXAS	Drawn by: CJM Designed by: CJM Checked by: Submitted by: Approved by: Chief, Engineering and Construction Division	Date: 9/19/2016 Rev. Scale: AS SHOWN Approval Recommended: Chief, Engineering Branch
	PORT ARTHUR AND VICINITY CSRA PLAN - STA 734+00 TO 880+00	PREPARED UNDER THE DIRECTION OF: LANE N. ARTHUR, COL, USA DISTRICT COMMANDER		

Rev.	Description	Date	By

U.S. Army Corps of Engineers Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-39
By: mSawyer.jm Date: 9/19/2016 Time: 7:10:42 PM

C-39

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

PORT ARTHUR AND VICINITY CORE
PLAN - STA 889+00 TO 999+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

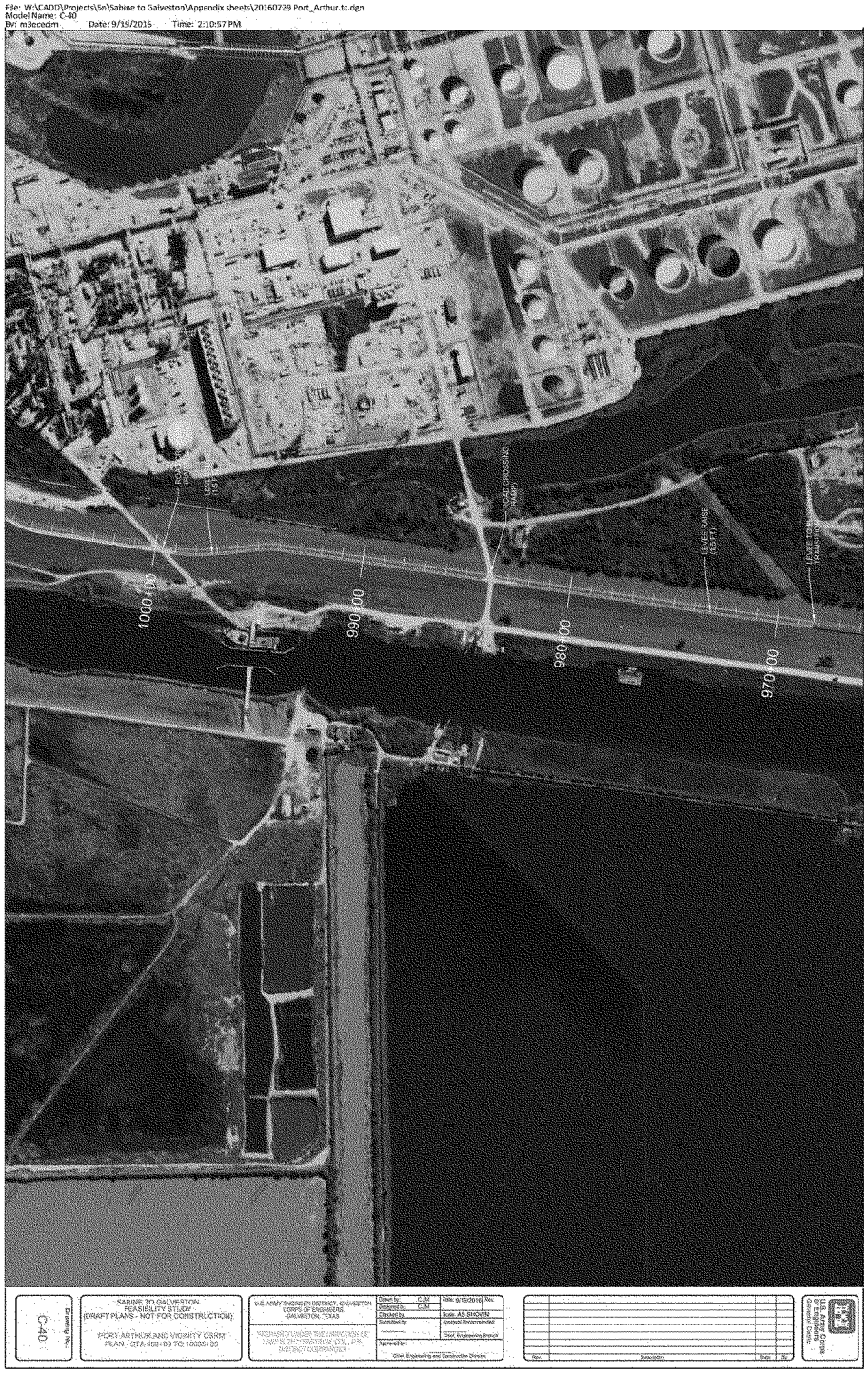
PREPARED UNDER THE SUPERVISION OF
[illegible]

Drawn by: CJDJ
Designed by: CJDJ
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division

Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended
Chief, Engineering Branch

Rev. Description Date By

U.S. Army Corps of Engineers
Galveston District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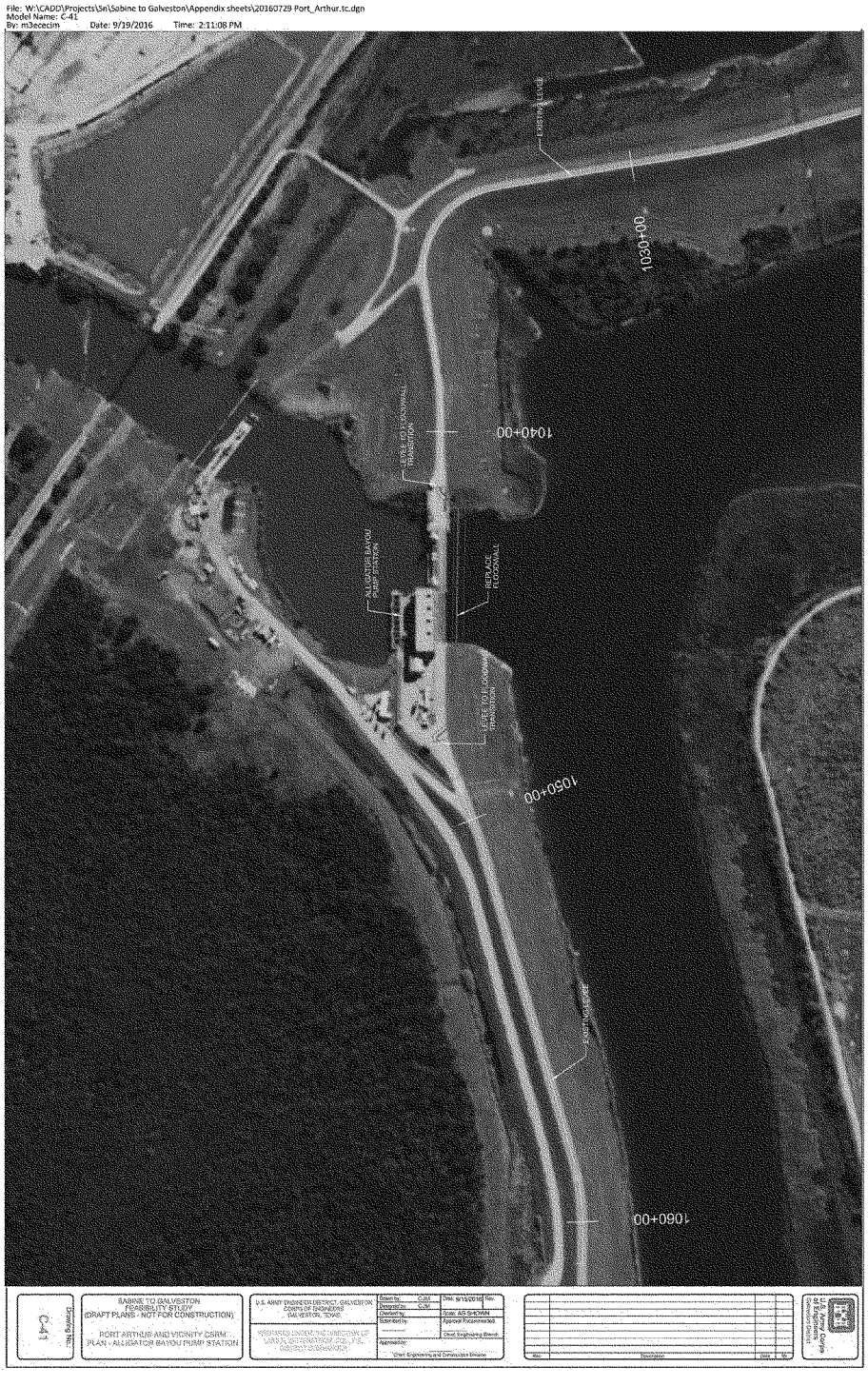
Model Name: C-40
By: mjacocm
Date: 9/19/2016
Time: 2:10:57 PM
1000+00
990+00
980+00
970+00
C-40
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
PORT ARTHUR AND VICINITY CSRM
PLAN - STA 969+00 TO 1000+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Chief, Engineering and Construction Division
Chief, Engineering Branch
No.
Revision
Date
By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Model Name: C-41
By: m3ecccm
Date: 9/19/2016
Time: 2:11:08 PM
EXISTING LEVEE
1030+00
1040+00
1050+00
1060+00
ALLIGATOR BAYOU PUMP STATION
REPLACE EXISTING CULVERTS
REMOVE EXISTING CULVERTS
REPLACE EXISTING CULVERTS
REPLACE EXISTING LEVEE
EXISTING LEVEE
C-41
SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)
PORT ARTHUR AND VICINITY CSRM PLAN - ALLIGATOR BAYOU PUMP STATION
U.S. ARMY ENGINEER DISTRICT, GALVESTON CORPS OF ENGINEERS GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF:
CHIEF, ENGINEERING AND CONSTRUCTION DIVISION
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved:
Date: 9/15/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev
Description
Date
No.
U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-42
By: m3eceejm Date: 9/19/2016 Time: 2:11:18 PM

C-42

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS – NOT FOR CONSTRUCTION)

PORT ARTHUR AND VICINITY CSRM
PLAN - LAKESIDE PUMP STATION

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

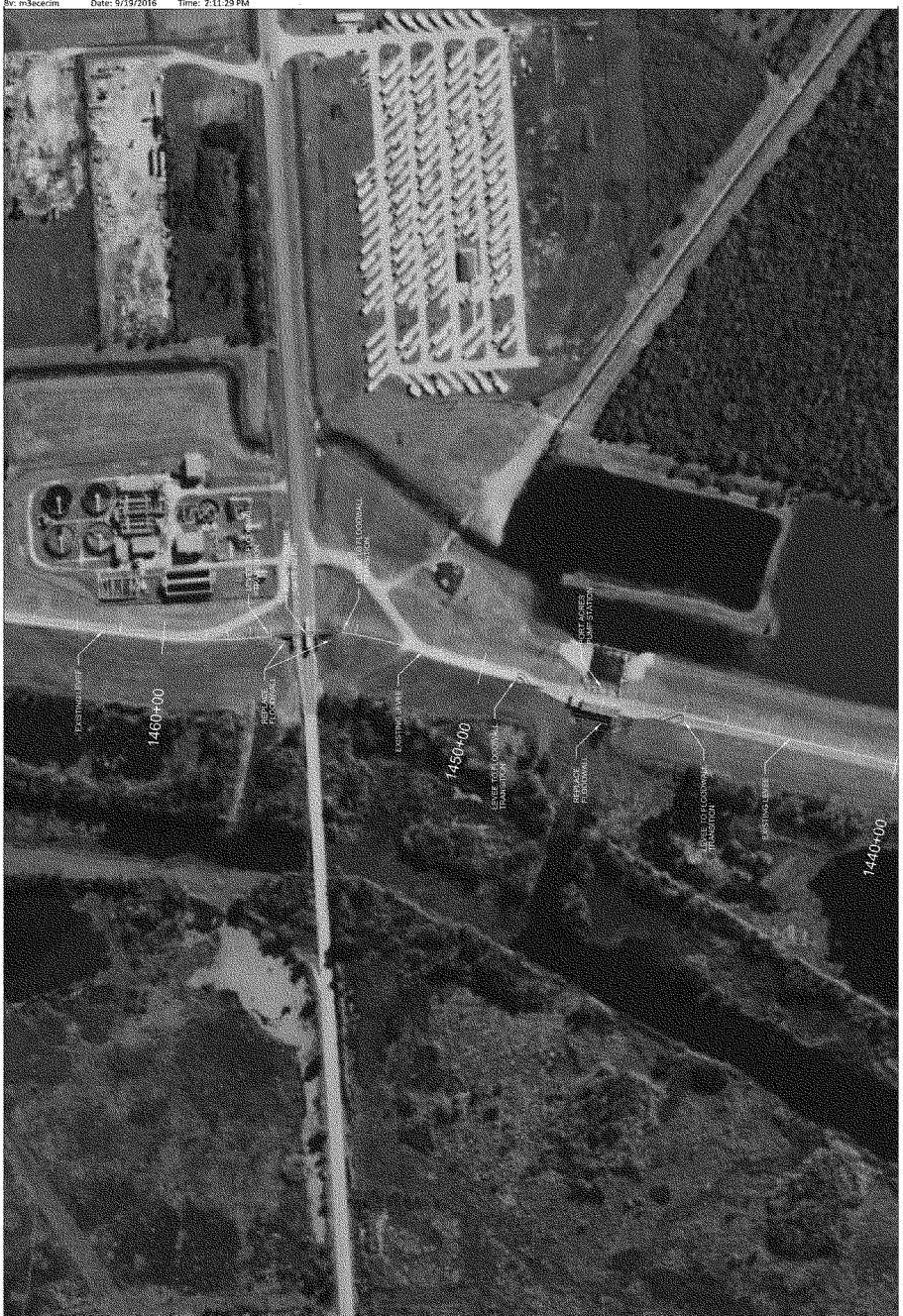
PREPARED UNDER THE DIRECTION OF:
WITH THE RECOMMENDATION OF:
APPROVED FOR:

Drawn by:	CJM	Date: 9/19/2016
Designed by:	CJM	
Checked by:		Scale: AS SHOWN
Submitted by:		Approval Recommended:
		Chief, Engineering Branch
Approved by:		
		Chief, Engineering and Construction Division

Rev.	Description	Date	By

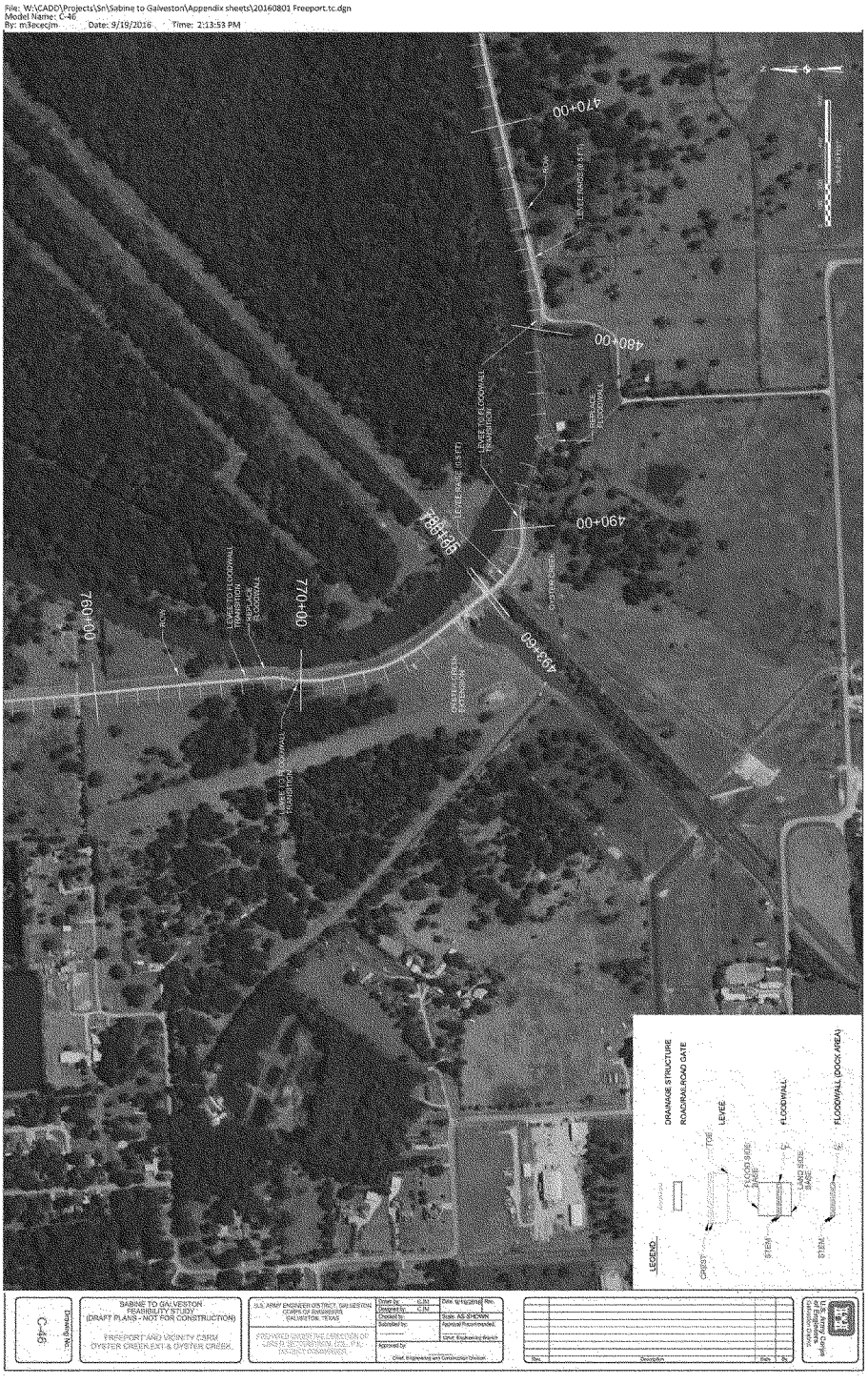
U.S. Army Corps of Engineers
Construction Division

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160729 Port_Arthur.tc.dgn
Model Name: C-43
By: m3acecim Date: 9/19/2016 Time: 2:11:29 PM


1460+00
1450+00
1440+00
EXISTING LEVEE
EXISTING LEVEE
EXISTING LEVEE

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
Model Name: C-44
By: m3eceqm
Date: 9/19/2016
Time: 2:12:48 PM
LEGEND
OYSTER CREEK EXTENSION
OYSTER CREEK
EAST STORM
DOW BARGE CANAL NORTH
DOW BARGE CANAL TURNING BASIN
DOW BARGE CANAL SOUTH
OLD RIVER NORTH
TIDE GATE
OLD RIVER SOUTH
SOUTH STORM
EAST BANK BRAZOS RIVER
NORTH WAVE BARRIER
SOUTH WAVE BARRIER
SCALE IN FEET
C-44
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VELASCO CANAL
OVERVIEW MAP
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: C-M
Designed by: C-M
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approved for Construction
Chief, Engineering and Construction Division
Chief, Engineering and Construction Division
Rev.
Description
Date
By

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
Model Name: C-45
By: m3ocecim Date: 9/19/2016 Time: 2:13:31 PM
LEGEND
LEVEE
FLOODWALL
SHEET BOUNDARY
SHEET NUMBER
SCALE IN FEET
C-45
SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AREA CIVIL WORKS LOCATION PLAN
U.S. ARMY CORPS OF ENGINEERS GALVESTON, TEXAS
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division
U.S. Army Corps of Engineers Galveston District


File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
Model Name: C-46
By: m3excejm Date: 9/19/2016 Time: 2:13:53 PM
760+00
770+00
780+00
790+00
400+00
410+00
420+00
430+00
440+00
450+00
460+00
470+00
480+00
490+00
LEGEND
DRAINAGE STRUCTURE
ROAD/RAILROAD GATE
LEVEE
FLOODWALL
FLOODWALL (DOCK AREA)
CREST
TOE
STEM
BASE
Drawing No. C-46
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY CANAL
OYSTER CREEK EXT & OYSTER CREEK
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF:
Drawn by: GJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering and Construction Division
Chief, Engineering Branch
Rev.
Description
Date
By
Drawing approved for public release; distribution is unlimited.

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
Model Name: C-47
By: m3eceicm Date: 9/19/2016 Time: 2:14:15 PM
400+00
410+00
420+00
430+00
440+00
450+00
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY (SWM)
OYSTER CREEK
PLAN - STA 400+00 TO STA 470+00
C-47
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Sheet Id: C_M
Designed by: CJM
Drawn by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev. Description Date By
U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
Model Name: C-48
By: m3eccicm
Date: 9/19/2016
Time: 2:14:34 PM
LEVEE RAISE (0.5 FT)
REPLACE DRAINAGE STRUCTURE
380+00
390+00
400+00
ROW
LEVEE RAISE (0.5 FT)
REPLACE DRAINAGE STRUCTURE
370+00
360+00
350+00
ROW
LEVEE RAISE (0.5 FT)
REPLACE DRAINAGE STRUCTURE
LEVEE RAISE (0.5 FT)
N
SCALE: 1" = 1,000'
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY CSRM
OYSTER CREEK
PLAN - STA 347+00 TO STA 405+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
RECOMMENDED FOR APPROVAL BY:
CHIEF, PLANNING DIVISION
DISTRICT ENGINEER
Drawn by: C.J.M
Designed by: C.J.M
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division
Date: 9/19/2016
Rev.
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Description
Date
By
Drawing No.
C-48
US Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport tc.dgn
Model Name: C-49
By: mseecain Date: 9/19/2016 Time: 2:14:53 PM

C-49

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

FREEPORT AND VICINITY (SEMS)
OYSTER CREEK
PLAN - STA 277+00 TO STA 377+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

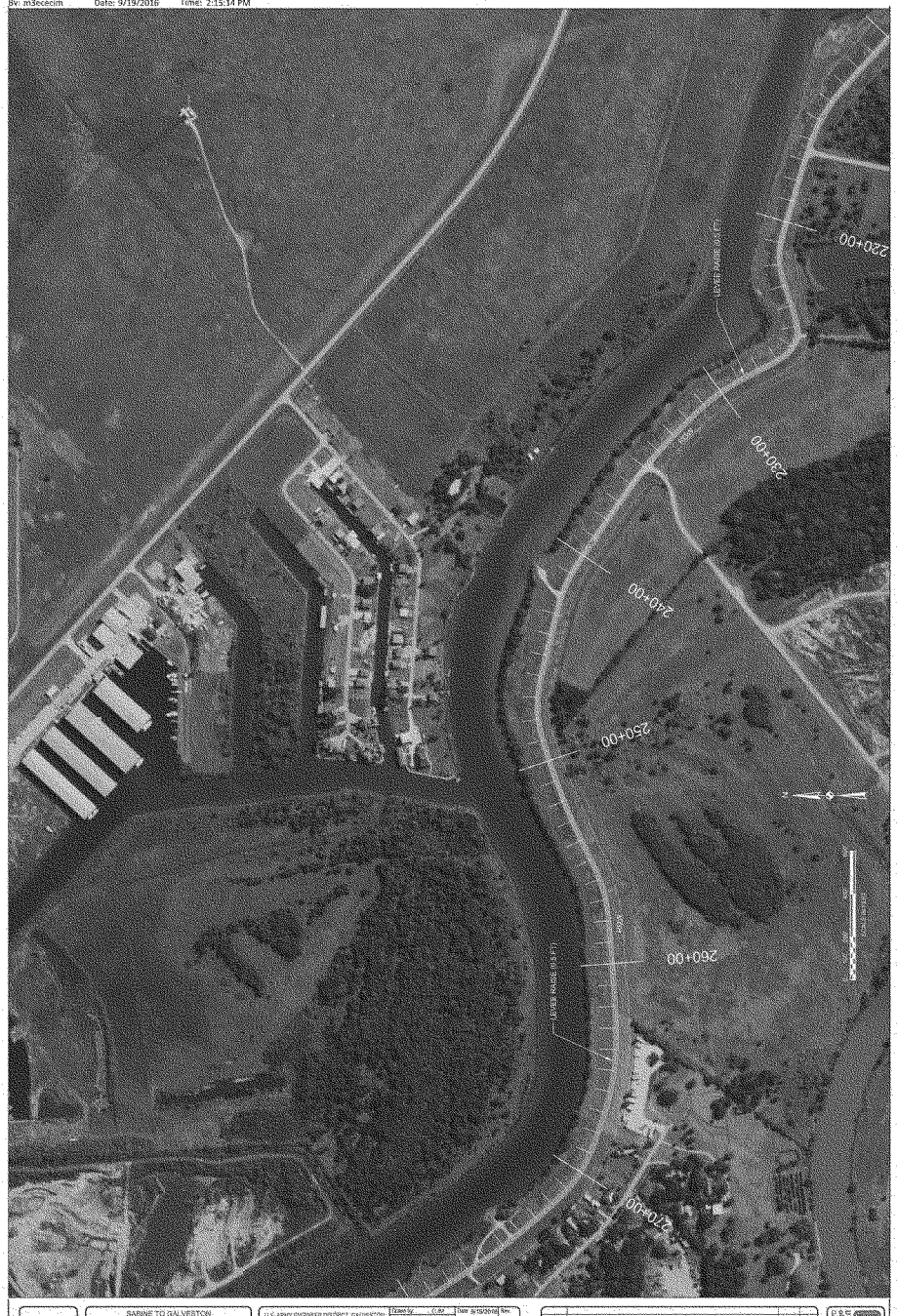
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division

Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch

Rev. Description Date By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\SN\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
Model Name: C-50
By: mSececim Date: 9/19/2016 Time: 2:15:14 PM



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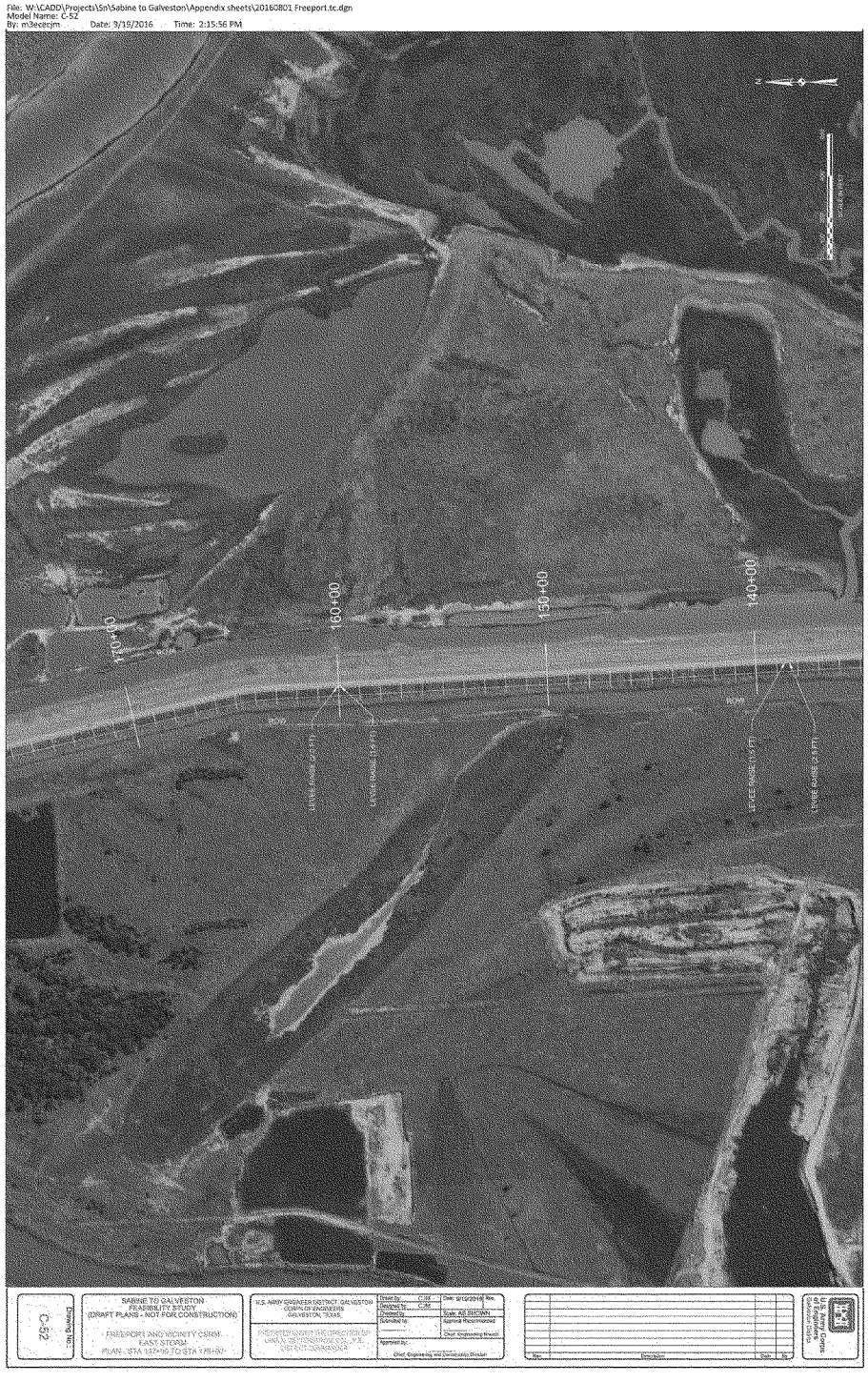
Model Name: C-51
By: rn3cecim Date: 9/19/2016 Time: 2:15:37 PM

180+00
190+00
200+00
200+00
210+00
220+00
FREEPORT HARBOR CHANNEL
OYSTER CREEK
FREEPORT
OLD FREEPORT
OLD FREEPORT
OLD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Model Name: C-52
By: mbecerjm Date: 9/19/2016 Time: 2:15:56 PM
170+00
160+00
150+00
140+00
C-52
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY CSRM
EAST STORM
PLAN - STA 137+99 TO STA 175+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF:
DAVID R. STEPHENSON, CCM, P.E.
DISTRICT COMMANDER
Chief, Engineering and Construction Division
Chief, Engineering and Planning Branch
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended
Date
Description
Mark
By

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
Model Name: C-53
By: m3ececjm
Date: 9/19/2016
Time: 2:16:15 PM
130+00
120+00
110+00
100+00
C-53
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY OSHM
60ft STORM
75+00 - STA 85+00 TO STA 137+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJH
Designed by: CJH
Checked by:
Submitted by:
Approved by:
Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended
Chief, Engineering Branch
Chief, Engineering and Construction Division
U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport tc.dgn
Model Name: C-54
By: mSeccim Date: 9/19/2016 Time: 2:16:35 PM

C-54

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

FREEPORT AND VICINITY CSRM
FAST STORM
PLAN - STA 57+00 TO STA 95+00

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE SUPERVISION OF:
KAREN OSTERHERM, PGS, PE
DISTRICT COMPLIANT

Approved by:
Chief, Engineering and Construction Division

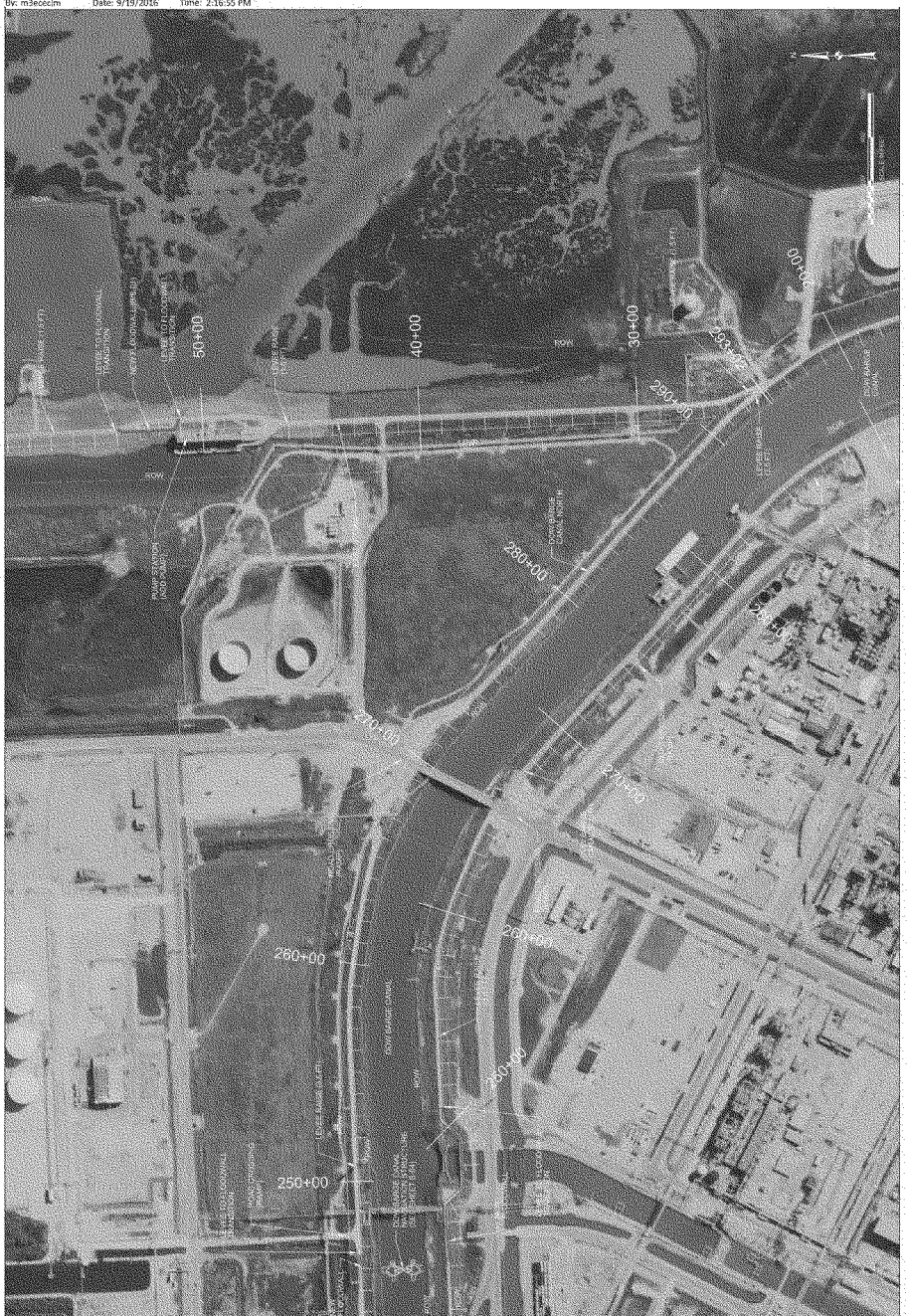
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:

Date: 9/15/2016 Rev.
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Division

Rev.	Description	Date	By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
Model Name: C-55
By: m3ececim Date: 9/19/2016 Time: 2:16:55 PM



C-55

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

FREEPORT AND VICINITY CSRM
EAST STORM AND DOW BARGE CANAL

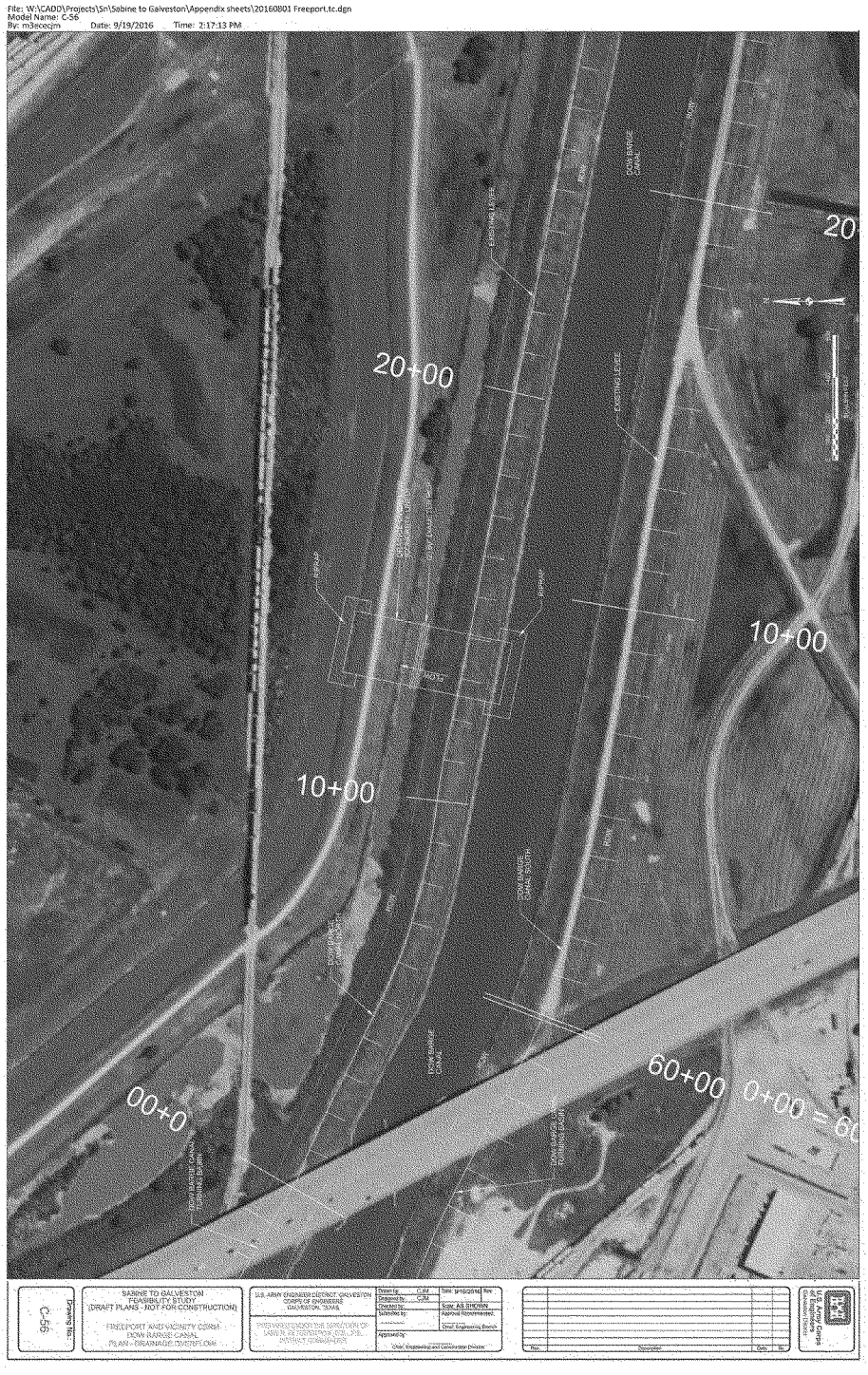
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE SUPERVISION OF
DAVID B. STEINMAN, P.E., BCE
DISTRICT ENGINEER

Drawn by:	CJH	Date: 9/19/2016
Designed by:	CJH	
Checked by:		Scale: AS SHOWN
Submitted by:		Approve Recommended
		Chief, Engineering Branch
Approved by:		
		Chief, Engineering and Construction Division

No.	Description	Date	By

U.S. Army Corps of Engineers
Galveston District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20+00
10+00
10+00
60+00
0+00 = 6
00+0
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY CEMA
DOW BARGE CANAL
PLAN - DRAINAGE OVERFLOW
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE SUPERVISION OF
LAUREN M. FERGUSON, P.E., CFM
DISTRICT ENGINEER
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division
Date: 9/15/2016
Scale: AS SHOWN
Approval Recommended
Chief, Engineering Branch
Rev.
Description
Date
By
U.S. Army Corps of Engineers
Galveston District
Drawing No.
C-56

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Model Name: C-57
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Drawing No. C-57

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

FREEPORT AIR VICINITY CERM
FREEPORT HARBOR CHANNEL AND OLD RIVER NORTH

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division

Date: 9/19/2016 Rev.
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch

Rev. Description Date By

U.S. Army Corps of Engineers
Galveston District

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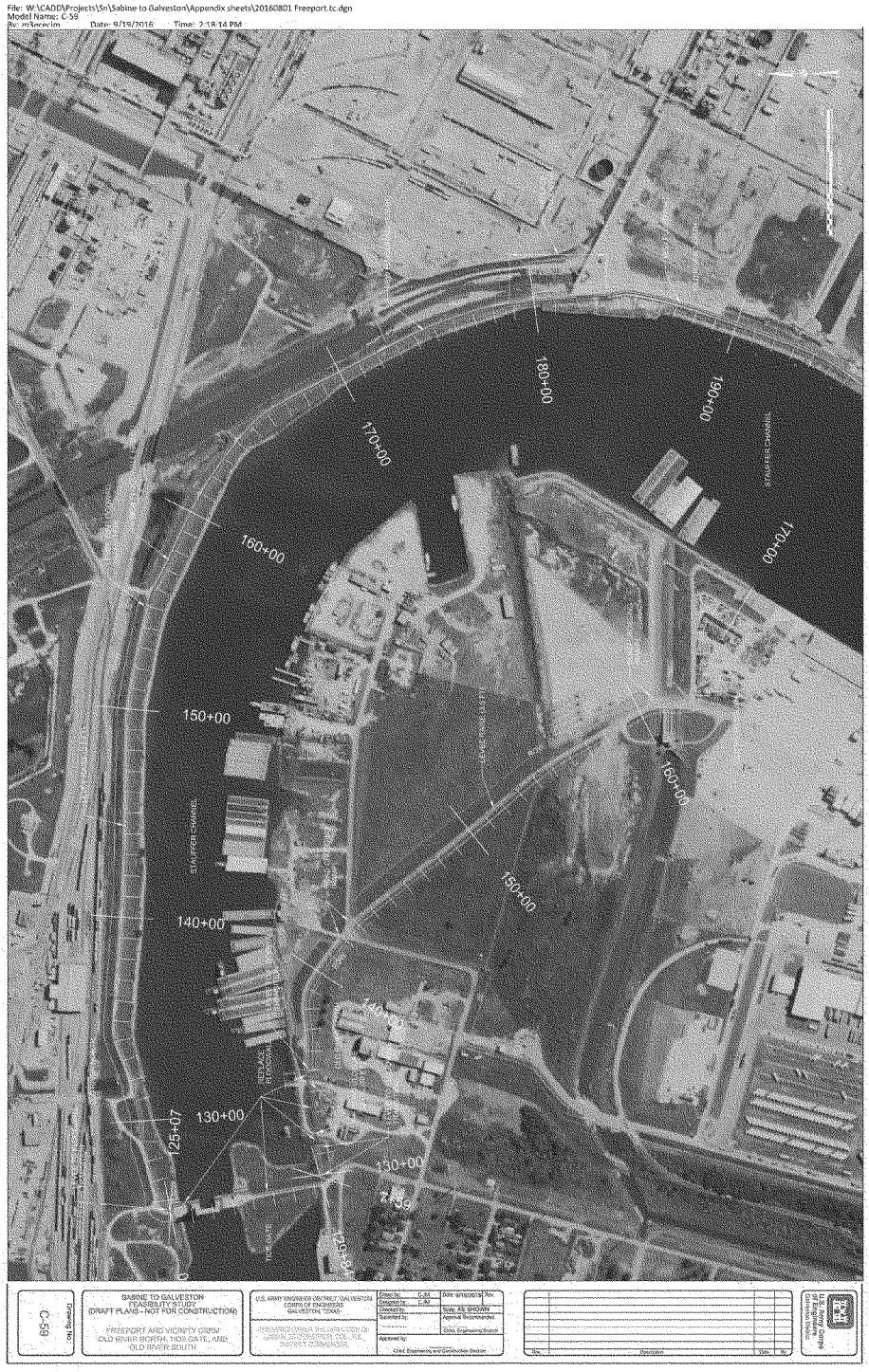
300+00
290+00
280+00
270+00
260+00
250+00
240+00
230+00
220+00
210+00
200+00
190+00
67+45
80+00
50+00
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY CSRM
OLD RIVER NORTH
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawing No.
C-58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By: mkeevan
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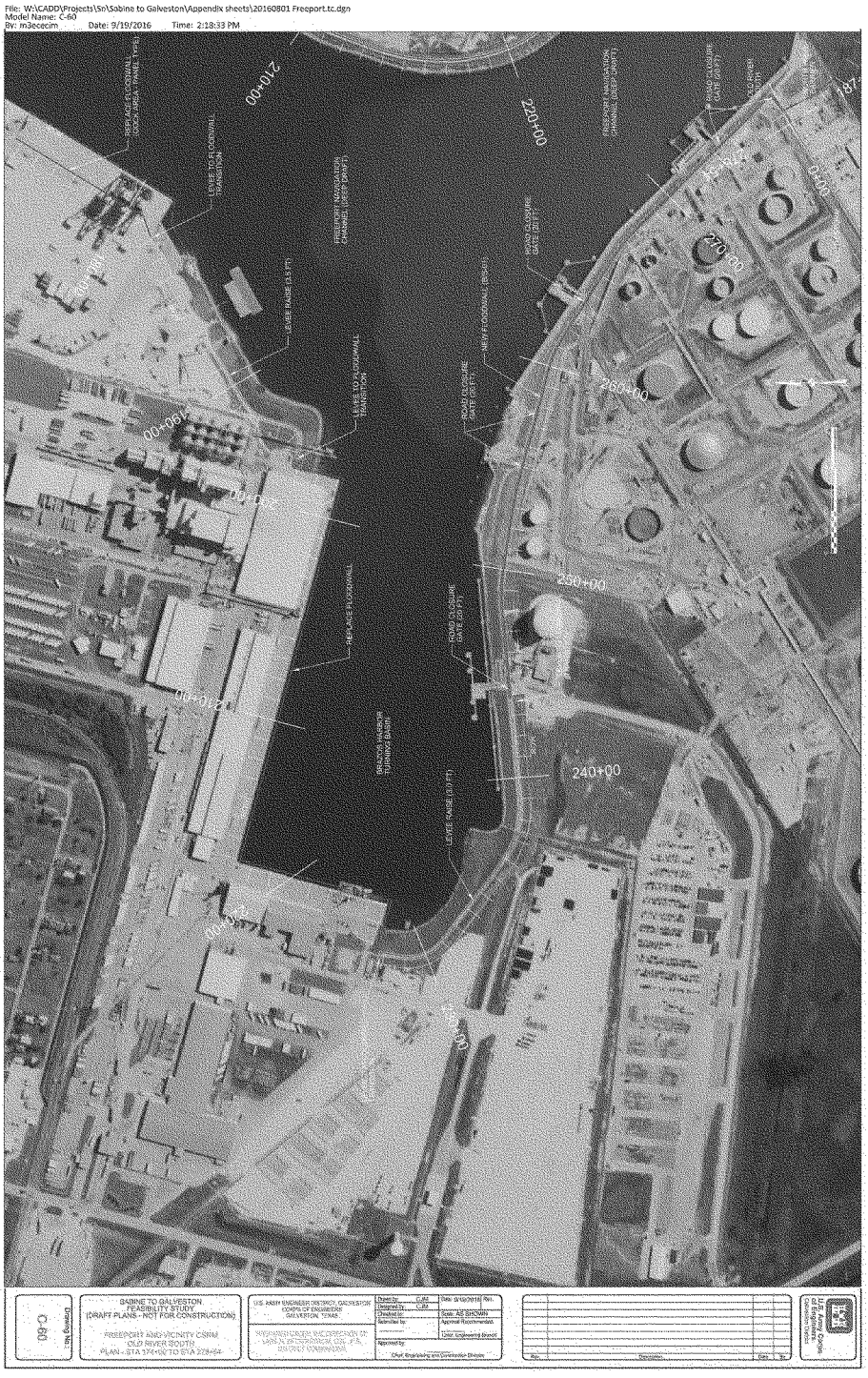
180+00
190+00
170+00
160+00
150+00
140+00
130+00
125+07
STAFFER CHANNEL
OLD RIVER SOUTH
OLD RIVER NORTH
65-3
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY CBRM
OLD RIVER NORTH, YOS GATE, AND
OLD RIVER SOUTH
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: C.M.
Date: 9/19/2016
Rev.
Recommended by: C.M.
Checked by:
Note: AS SHOWN
Submitted by:
Approval Recommended:
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division
U.S. Army Corps of Engineers
Galveston District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220+00
230+00
240+00
250+00
260+00
270+00
280+00
290+00
300+00
310+00
320+00
330+00
340+00
350+00
360+00
370+00
380+00
390+00
400+00
410+00
420+00
430+00
440+00
450+00
460+00
470+00
480+00
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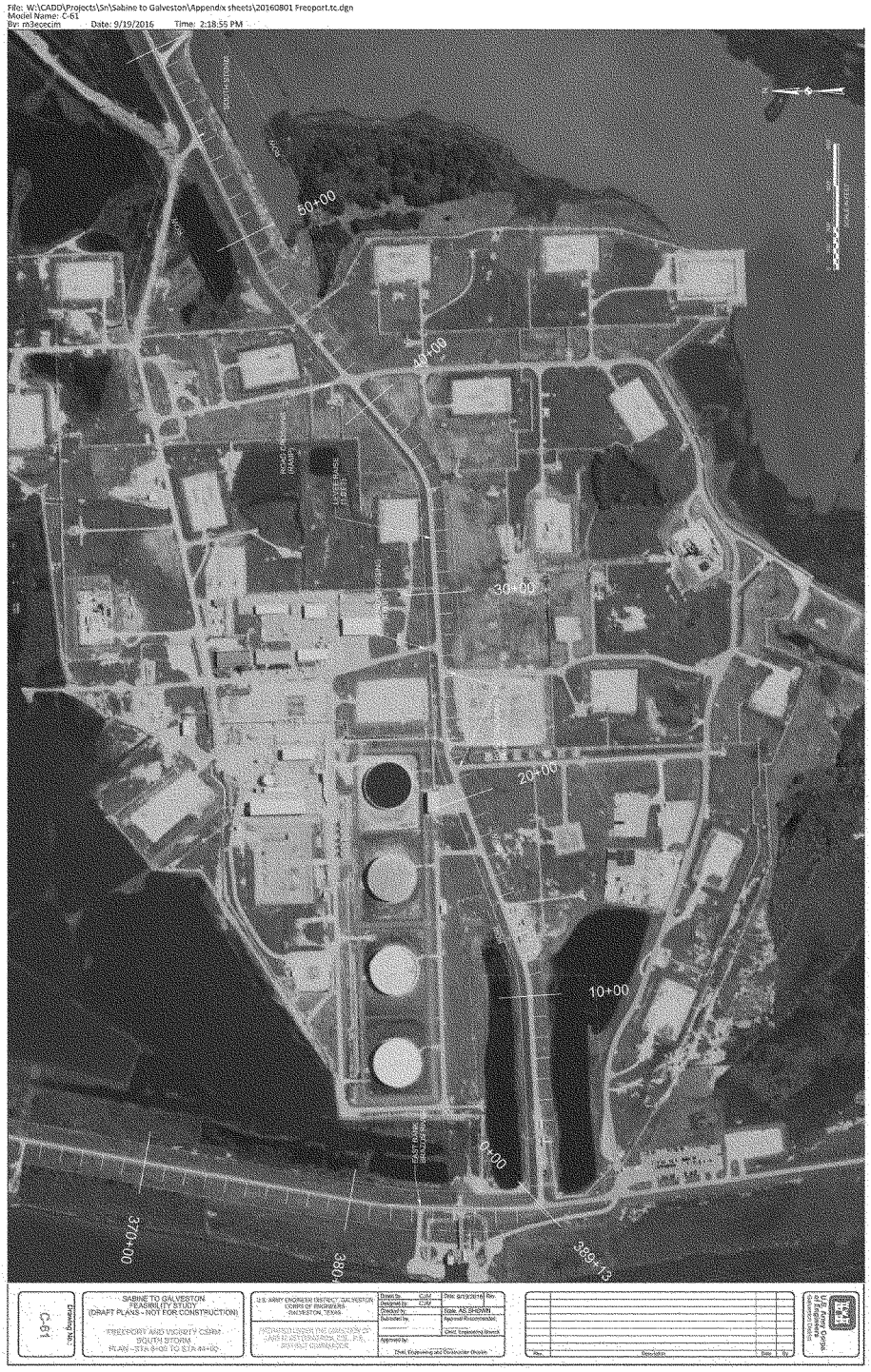
580+00
590+00
600+00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40+00
30+00
20+00
10+00
0+00
370+00
360+00
350+13
C-61
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FREEPORT AND VICINITY CSRM
SOUTH STORM
PLAN - STA 8+00 TO STA 44+00
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date: 9/20/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev. Description Date By
U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\20160801 Freeport.tc.dgn
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Drawing No: C-62

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

FREEPORT AND VICINITY CSRM
EAST BASIN BRAZOS RIVER
FREEPORT PUMP STATION

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE SUPERVISION OF:
CHIEF, ENGINEERING BRANCH
GALVESTON DISTRICT

Drawn by: C-62
Designed by: C-62
Checked by:
Submitted by:

Date: 9/19/2016
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch

Approved by:
Chief, Engineering and Construction Division

No. Description Date By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\C-63 Levee to floodwall tie-in.dgn
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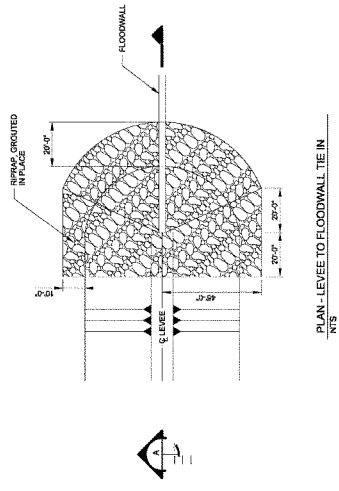
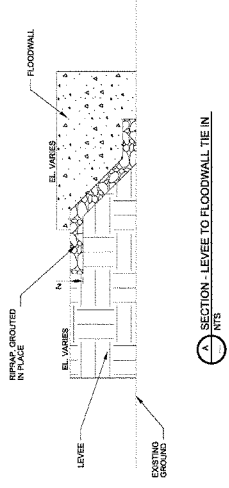
By: mSeegerim Date: 9/21/2016 Time: 9:51:36 AM



PLAN - LEVEE TO FLOODWALL TIE IN
N.T.S.



A SECTION - LEVEE TO FLOODWALL TIE IN
N.T.S.

Drawing No.: C-63

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

LEVEE DETAILS

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.
COLONEL, U.S. ARMY, COMMANDING

Drawn by: C.M
Designed by: C.M
Checked by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division

Date:
Rev:
Scale: AS SHOWN
Approved Recommended:
Chief, Engineering Branch

Rev	Description	Date	By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\C-64 Mitigation plan overview.dgn
Model Name: Default
By: mbecnicm Date: 9/21/2016 Time: 9:51:42 AM
MITIGATION AREA 11
MITIGATION AREA 52
MITIGATION AREA 51
MITIGATION AREA 53
MITIGATION AREA 54
MITIGATION AREA 55
MITIGATION AREA 56
MITIGATION AREA 57
MITIGATION AREA 58
MITIGATION AREA 59
BRIDGE CITY
ORANGE
CHANNEL
LEGEND
LEVEE
FLOODWALL
MITIGATION AREA LIMITS
NAVIGATION CHANNEL CENTERLINE
N
0 2400 4800 9600 14400
SCALE IN FEET
Drawing No.
C-64
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
MITIGATION
LOCATION PLAN
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Chief, Engineering Branch
Chief, Engineering and Construction Division
Date:
Scale: AS SHOWN
Approved Revised Installed
Chief, Engineering Branch
Date
Description
By
No.

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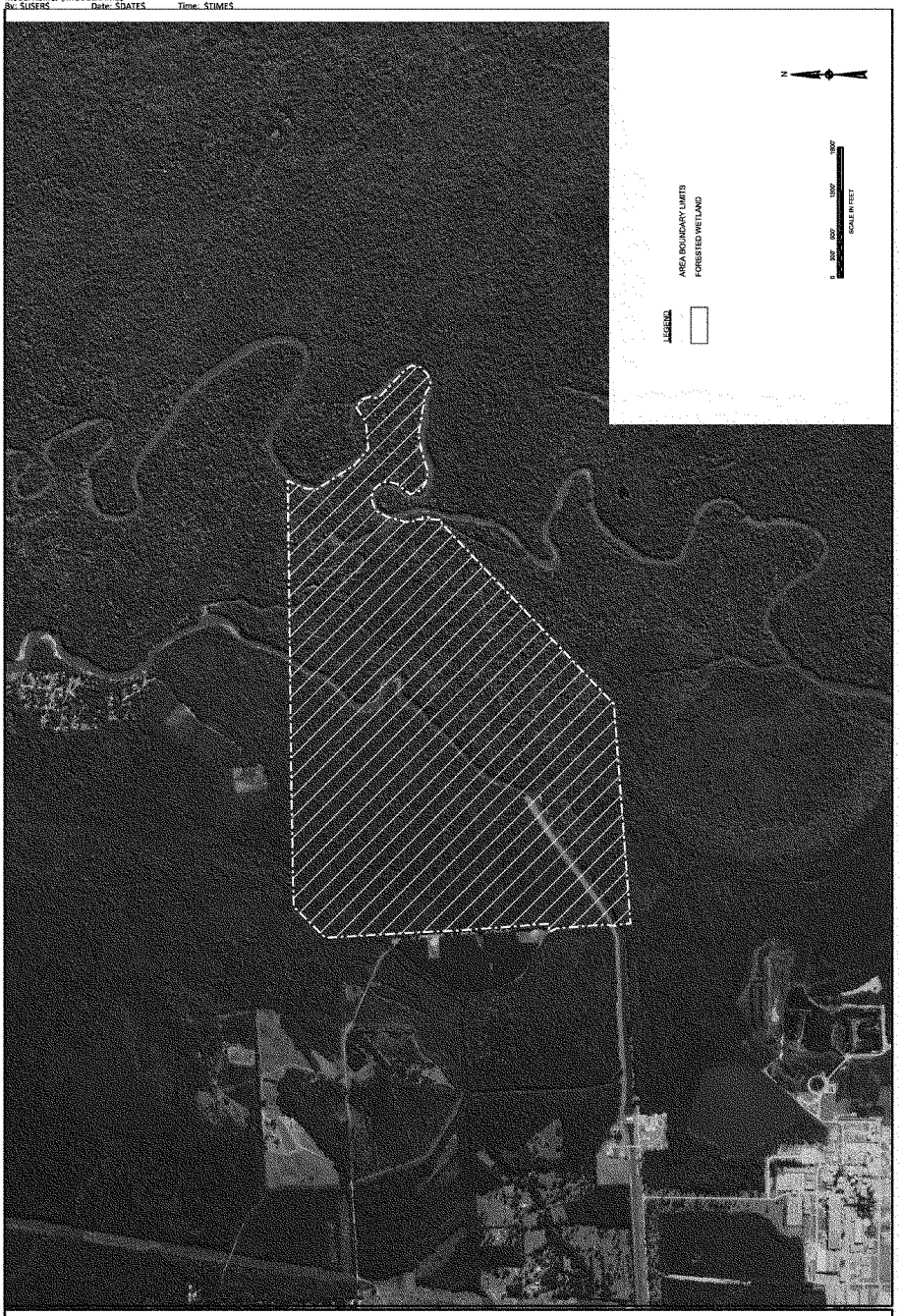
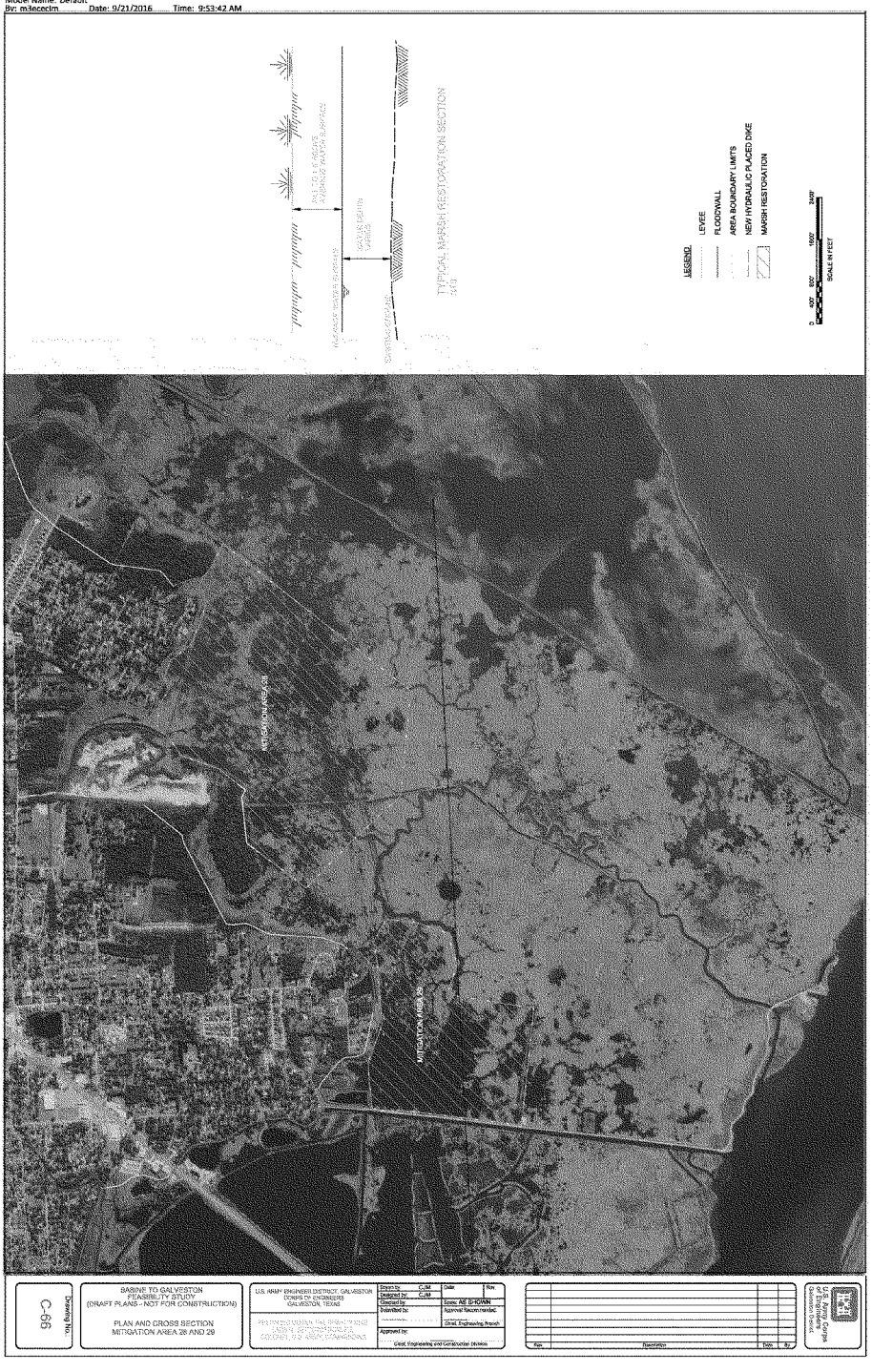


BABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

PLAN
MITIGATION AREA 11

U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

Drawing No.: C-65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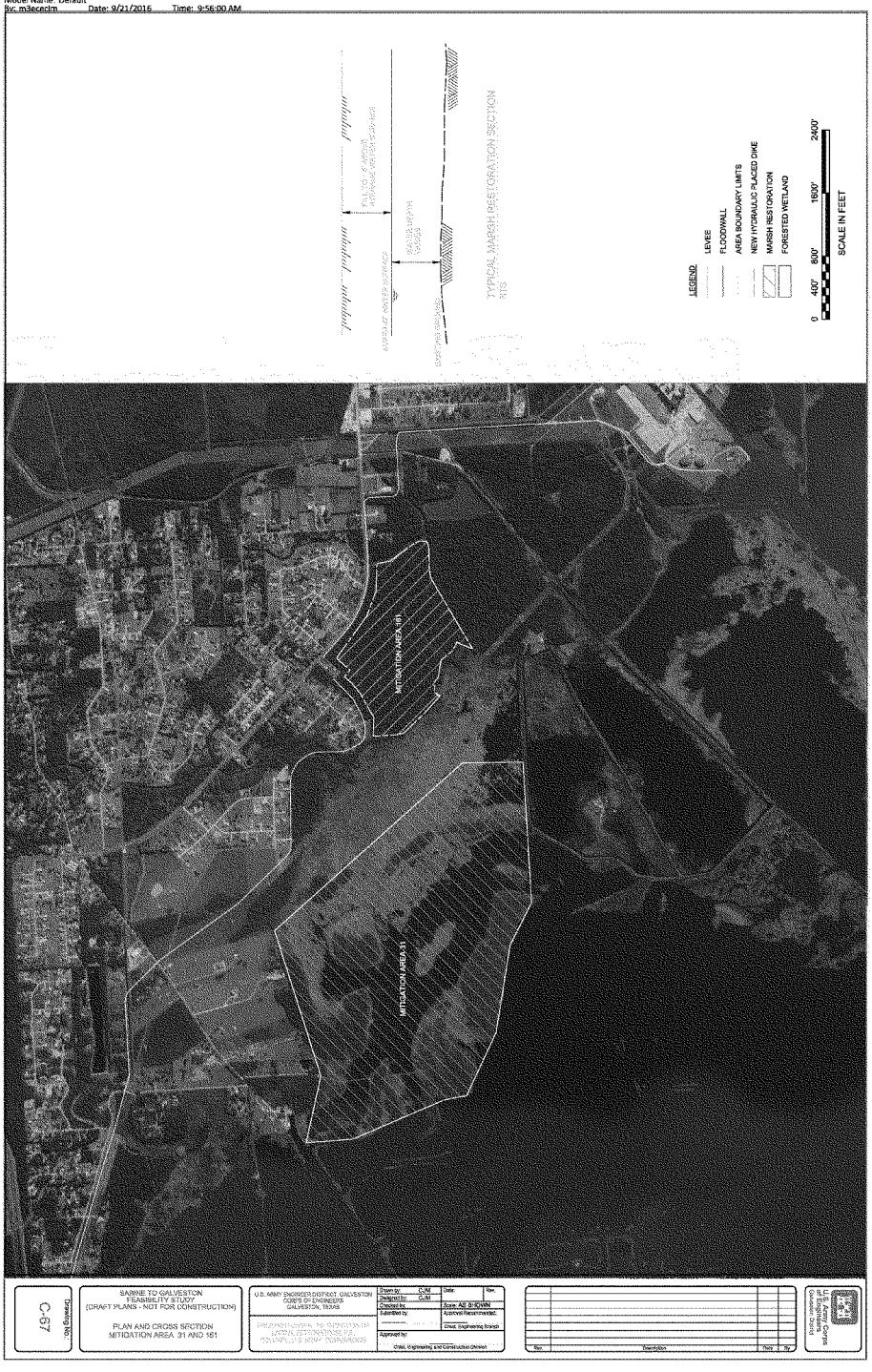
TYPICAL MARSH RESTORATION SECTION
LEGEND
LEVEE
FLOODWALL
AREA BOUNDARY LIMITS
NEW HYDRAULIC PLACED DIKE
MARSH RESTORATION
SCALE IN FEET
MITIGATION AREA 28
MITIGATION AREA 29
BARRIE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
PLAN AND CROSS SECTION
MITIGATION AREA 28 AND 29
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Checked by:
Submitted by:
Approved by:
Date:
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Chief, Engineering and Construction Division
Rev.
Description
Date
By
Drawing No.
C-66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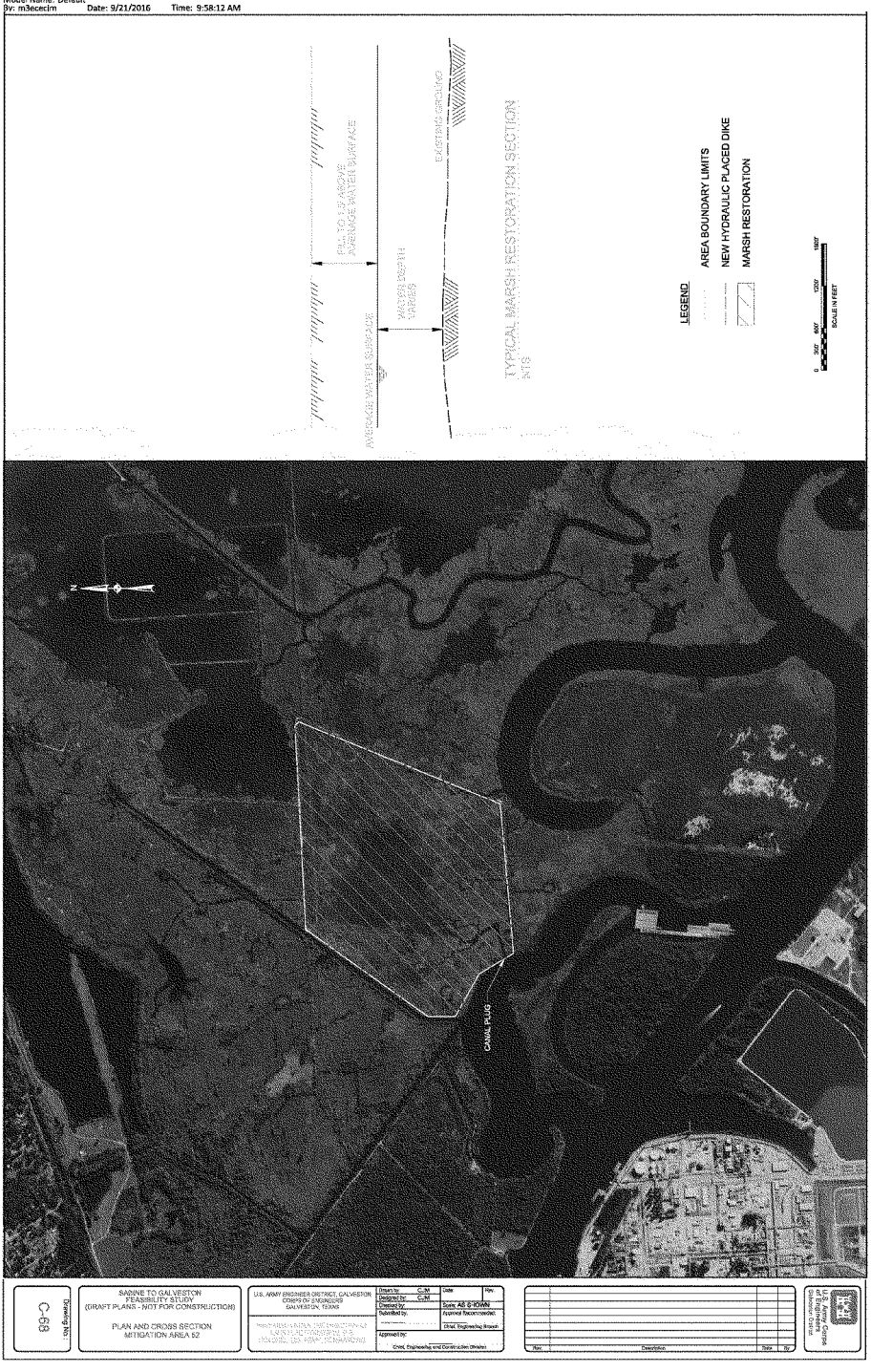
TYPICAL MARSH RESTORATION SECTION
NTS
LEGEND
LEVEE
FLOODWALL
AREA BOUNDARY LIMITS
NEW HYDRAULIC PLACED DIKE
MARSH RESTORATION
FORESTED WETLAND
0 400' 800' 1600' 2400'
SCALE IN FEET
MITIGATION AREA 161
MITIGATION AREA 31
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
PLAN AND CROSS SECTION
MITIGATION AREA 31 AND 161
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Created by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division
Date:
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Rev.
Description
Date
By
C-67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TYPICAL MARSH RESTORATION SECTION
NTS
AVERAGE WATER SURFACE
MARSH WIDTH VARIES
EXISTING GROUND
LEGEND
AREA BOUNDARY LIMITS
NEW HYDRAULIC PLACED DIKE
MARSH RESTORATION
0 250 500 1000 1500
SCALE IN FEET
N
CANAL PLUG
C-68
SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
PLAN AND CROSS SECTION
MITIGATION AREA 52
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
Drawn by: CJM
Designed by: CJM
Date
Checked by:
Scale: AS IS HWM
Submitted by:
Approved Recommended:
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division
Rev.
Description
Date
By
U.S. Army Corps of Engineers
Galveston District

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

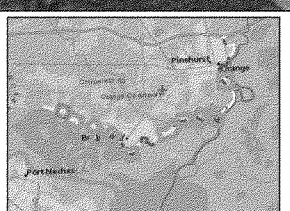


Image: 2015 TNRIS

N

0 200 400 Feet

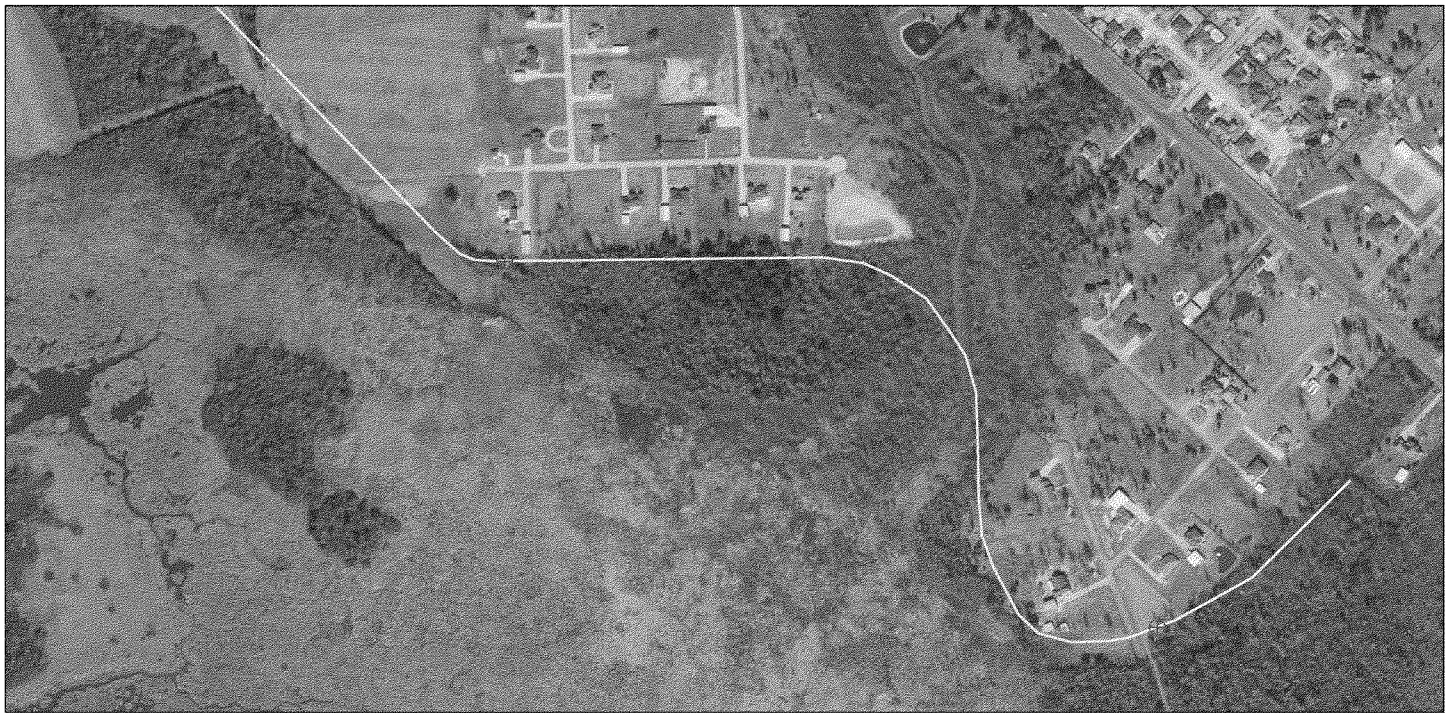
ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-69

1045



US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

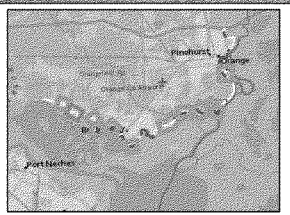


Image: 2015 TNRIS

N

0 350 700 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-70

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

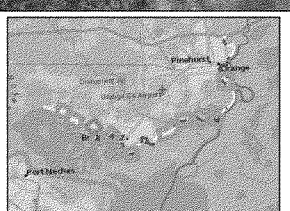


Image: 2015 TNRIS

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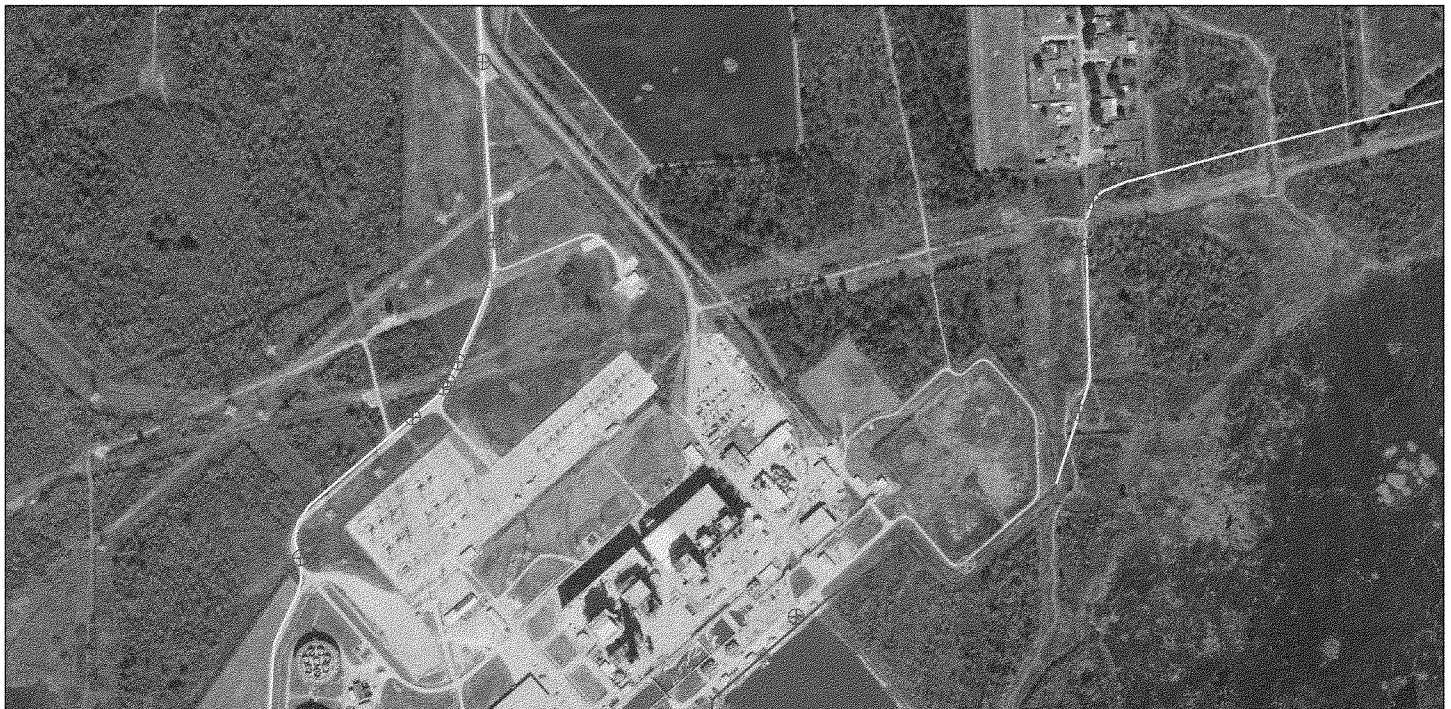
0 200 400 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-71



US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

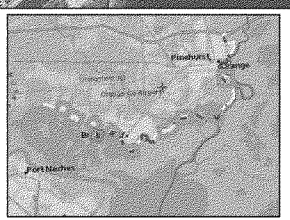


Image: 2015 TNRIS

N

0 400 800 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-72

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

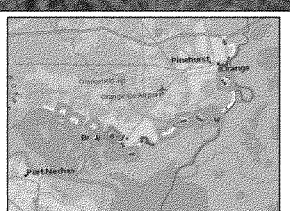


Image: 2015 TNRIS

N

0 100 200 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-73

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

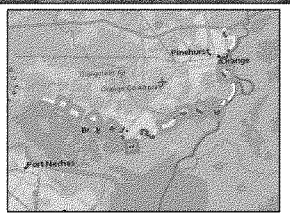


Image: 2015 TNRIS

N

0 100 200 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-74

1050

US Army Corps of Engineers ®
Galveston District

Pipe Diameter
2.38" - 10.75"
12.75" - 22"
24" - 42"

Gate
Floodwall
Levee
Work Areas

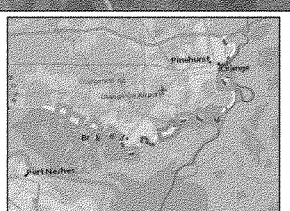


Image: 2015 TNRIS

N

0 500 1,000 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-75

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

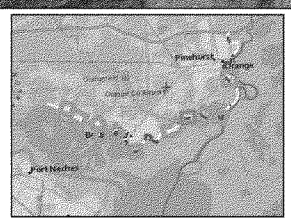


Image: 2015 TNRIS

N

0 300 600 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-76

1052

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

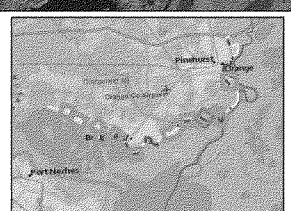


Image: 2015 TNRIS

N

0 500 1,000 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-77

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 2.38" - 10.75"
- 12.75" - 22"
- 24" - 42"

- Gate
- Floodwall
- Levee
- Work Areas

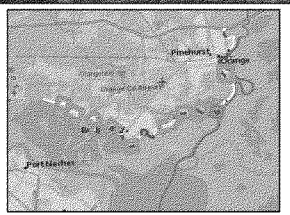


Image: 2015 TNRIS

N

0 175 350 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-78

US Army Corps of Engineers ®
Galveston District

Pipe Diameter
2.38" - 10.75"
12.75" - 22"
24" - 42"

Gate
Floodwall
Levee
Work Areas

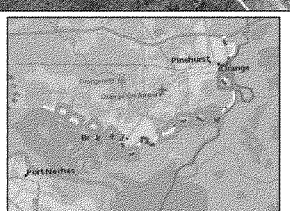


Image: 2015 TNRIS

N

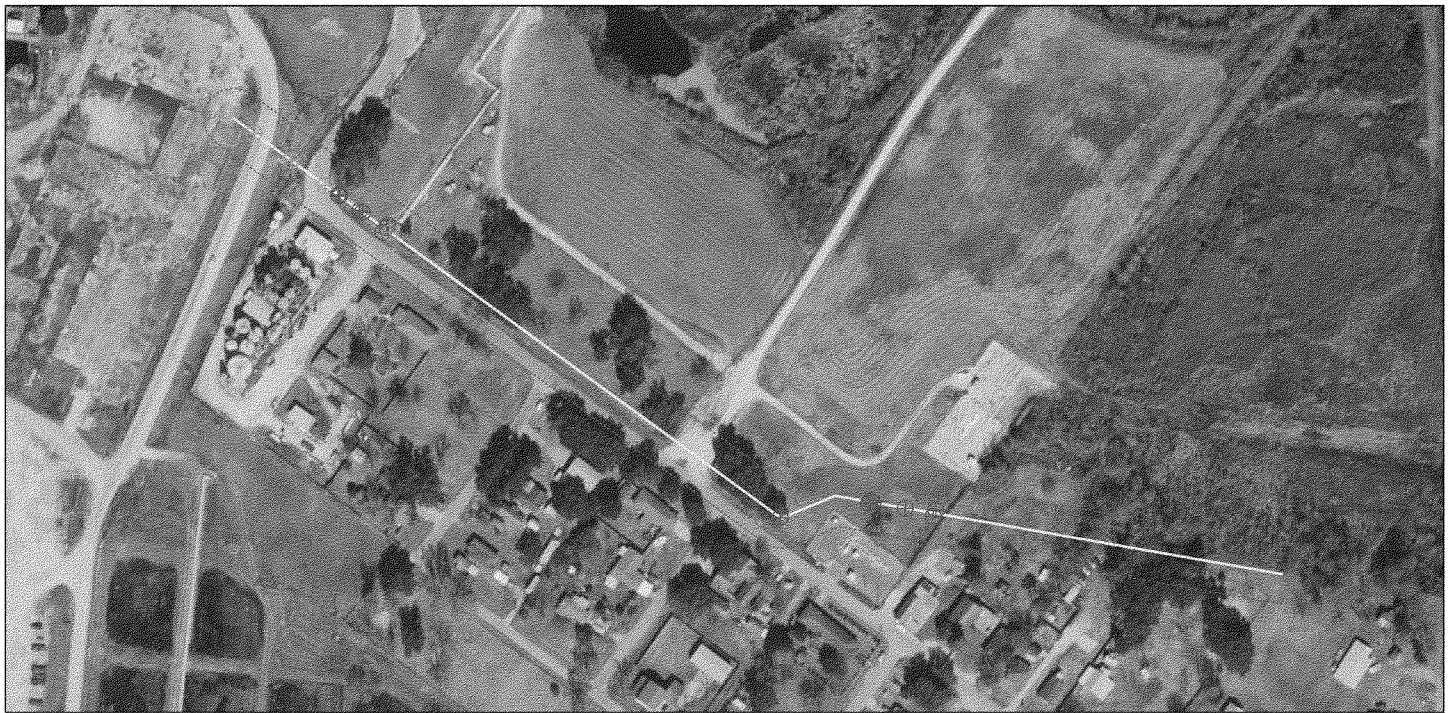
0 425 850 Feet

ORANGE COUNTY CSRM

24 June 2016

Work Area Pipe Crossings

C-79



US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 4" - 10.75"
- 12" - 20"
- 22" - 36"

- Work Area
- Levee
- Floodwall

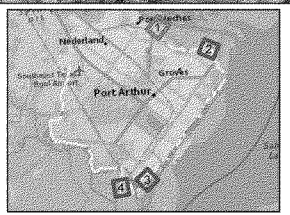


Image: 2015 TNRIS

N

0 150 300 Feet

PORT ARTHUR AND VICINITY CSRM

6 July 2016

Work Area Pipe Crossings

C-80

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 4" - 10.75"
- 12" - 20"
- 22" - 36"

- Work Area
- Levee
- Floodwall

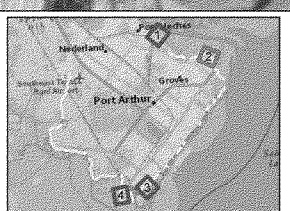


Image: 2015 TNRIS

N

0 50 100 Feet

PORT ARTHUR AND VICINITY CSRM

6 July 2016

Work Area Pipe Crossings

C-81

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 4" - 10.75"
- 12" - 20"
- 22" - 36"

- Work Area
- Levee
- Floodwall

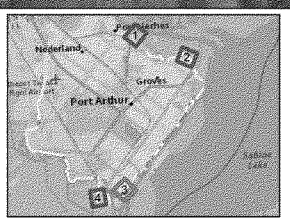


Image: 2015 TNRIS

N

0 50 100 Feet

PORT ARTHUR AND VICINITY CSRM

6 July 2016

Work Area Pipe Crossings

C-82

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 4" - 10.75"
- 12" - 20"
- 22" - 36"

- Work Area
- Levee
- Floodwall

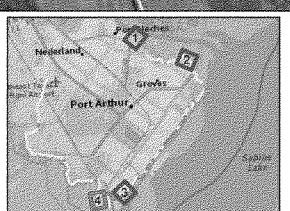


Image: 2015 TNRIS

N

0 125 250 Feet

PORT ARTHUR AND VICINITY CSRM

6 July 2016

Work Area Pipe Crossings

C-83

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 4" - 10.75"
- 12" - 20"
- 24" - 40"

Work Area
Gate
Levee
Floodwall

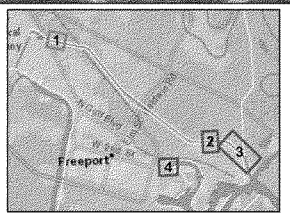


Image: 2015 TNRIS

N

0 250 500 Feet

FREEPORT AND VICINITY CSRM

6 July 2016

Work Area Pipe Crossings

C-84

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 4" - 10.75"
- 12" - 20"
- 24" - 40"

Work Area
Gate
Levee
Floodwall

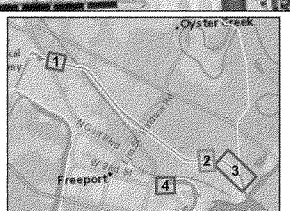


Image: 2015 TNRIS

N

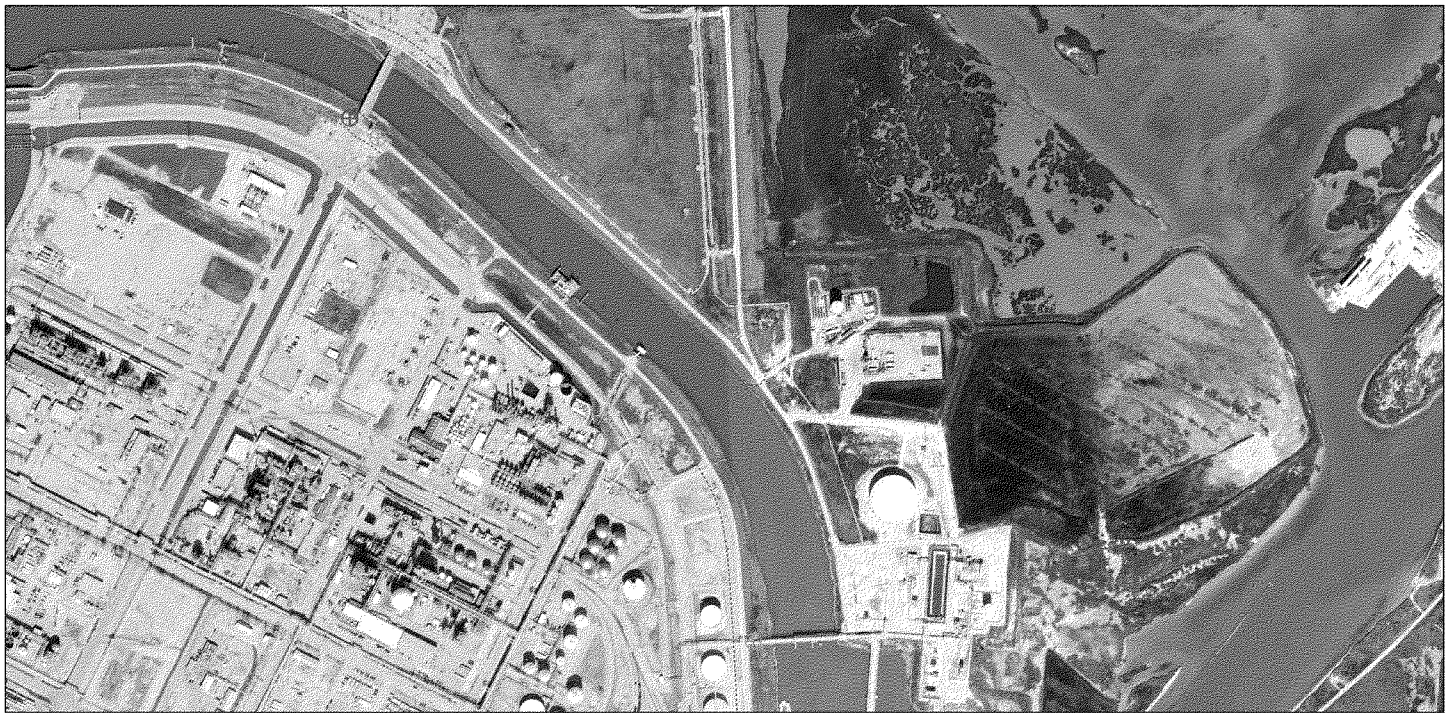
0 175 350 Feet

FREEPORT AND VICINITY CSRM

6 July 2016

Work Area Pipe Crossings

C-85



US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 4" - 10.75"
- 12" - 20"
- 24" - 40"

Work Area
Gate
Levee
Floodwall

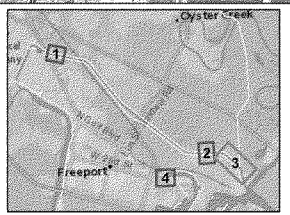


Image: 2015 TNRIS

N

0 500 1,000 Feet

FREEPORT AND VICINITY CSRM

6 July 2016

Work Area Pipe Crossings

C-86

1062

US Army Corps of Engineers ®
Galveston District

Pipe Diameter

- 4" - 10.75"
- 12" - 20"
- 24" - 40"

Work Area
Gate
Levee
Floodwall

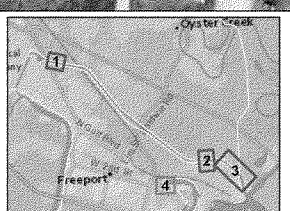


Image: 2015 TNRIS

N

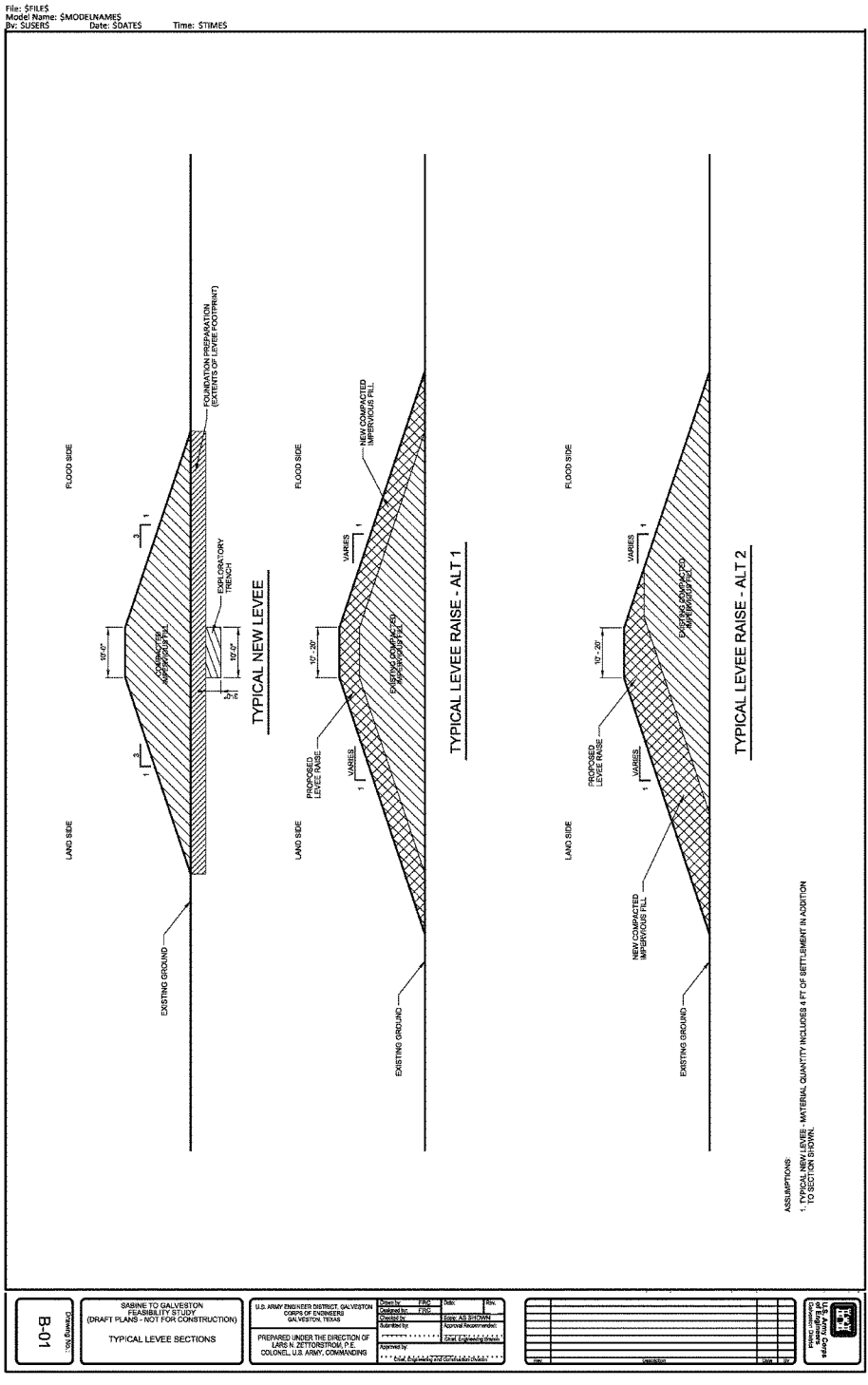
0 125 250 Feet

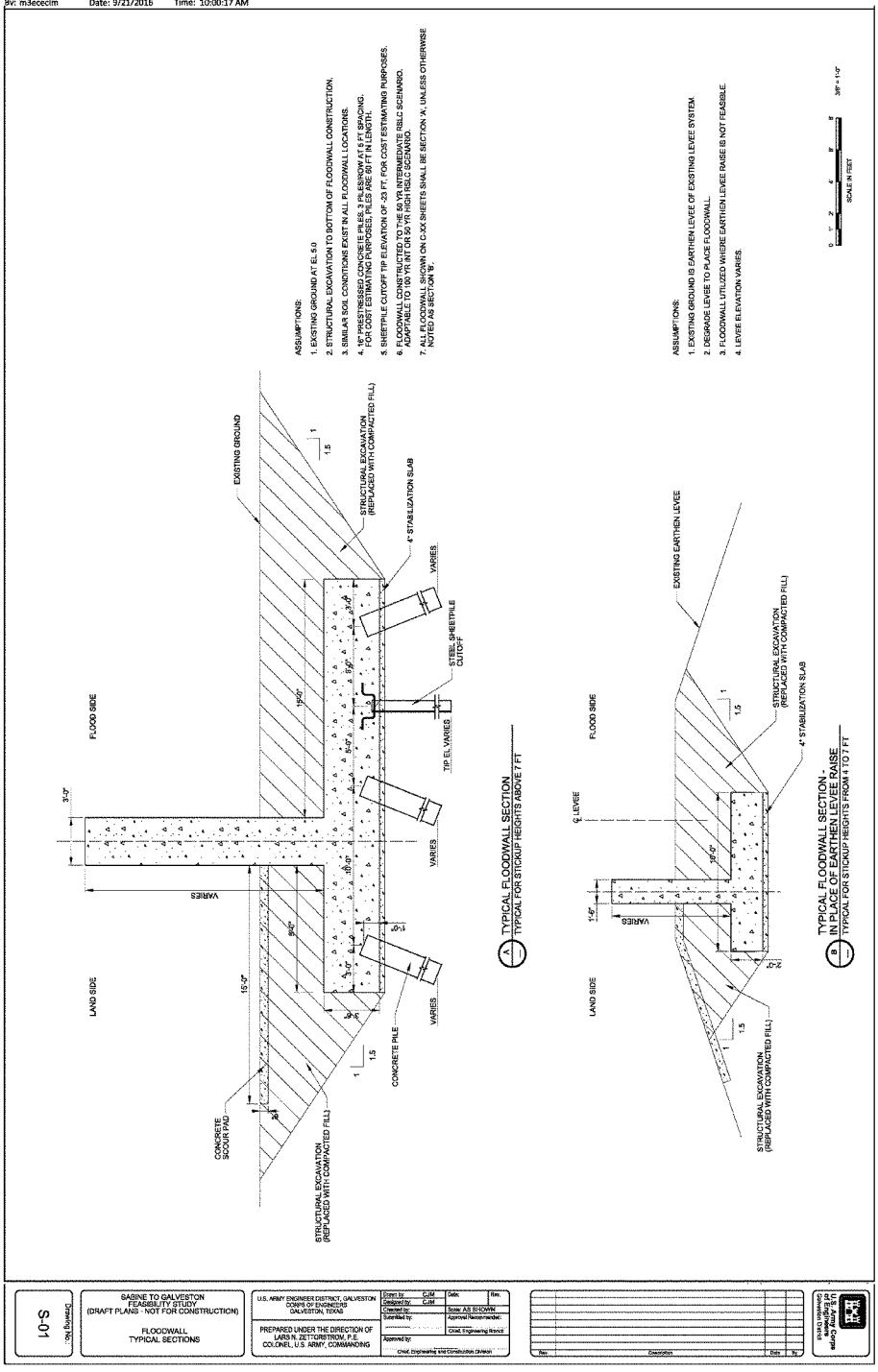
FREEPORT AND VICINITY CSRM

6 July 2016

Work Area Pipe Crossings

C-87


File: $FILE$
Model Name: $MODELNAME$
By: $USER$ Date: $DATE$ Time: $TIME$
FLOOD SIDE
LAND SIDE
EXISTING GROUND
FOUNDATION PREPARATION (EXTENTS OF LEVEE FOOTPRINT)
EXPLORATORY TRENCH
CONTRACTED IMPERVIOUS FILL
10'-0"
10'-0"
2'-0"
TYPICAL NEW LEVEE
PROPOSED LEVEE RAISE
10' - 20'
VARIES
NEW COMPACTED IMPERVIOUS FILL
EXISTING COMPACTED IMPERVIOUS FILL
TYPICAL LEVEE RAISE - ALT 1
TYPICAL LEVEE RAISE - ALT 2
ASSUMPTIONS:
1. TYPICAL INSTALLED LEVEE MATERIAL QUANTITY INCLUDES 4 FT OF SETTLEMENT IN ADDITION TO SECTION SHOWN.
B-01
SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)
TYPICAL LEVEE SECTIONS
U.S. ARMY ENGINEER DISTRICT, GALVESTON CORPS OF ENGINEERS GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF LARS N. ZETTERSTROM, P.E. COLONEL, U.S. ARMY, COMMANDING
Drawn by: FRC
Checked by: FRC
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Division
Approved by:
Chief, Planning and Environmental Division
Date:
Rev.
Description
Date
By


File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\S-01 FLOODWALL typical section.dgn
Model Name: Drawing
Pw: m3ecocim Date: 9/21/2016 Time: 10:00:17 AM
ASSUMPTIONS:
1. EXISTING GROUND AT EL. 5.0
2. STRUCTURAL EXCAVATION TO BOTTOM OF FLOODWALL CONSTRUCTION.
3. SIMILAR SOIL CONDITIONS EXIST IN ALL FLOODWALL LOCATIONS.
4. 16" PRESTRESSED CONCRETE PILES, 3 PILES/ROW AT 6 FT SPACING. FOR COST ESTIMATING PURPOSES, PILES ARE 80 FT IN LENGTH.
5. SHEETPILE CUTOFF TIP ELEVATION OF -23 FT. FOR COST ESTIMATING PURPOSES.
6. FLOODWALL CONSTRUCTED TO THE 80 YR INTERMEDIATE RSLC SCENARIO. ADAPTABLE TO 100 YR INT OR 90 YR HIGH RSLC SCENARIO.
7. ALL FLOODWALL SHOWN ON C-XX SHEETS SHALL BE SECTION 'A', UNLESS OTHERWISE NOTED ON RESPECTIVE SHEET.
FLOOD SIDE
LAND SIDE
EXISTING GROUND
STRUCTURAL EXCAVATION (REPLACED WITH COMPACTED FILL)
4" STABILIZATION SLAB
STEEL SHEETPILE CUTOFF
CONCRETE PILE
CONCRETE SCOUR PAD
VARIES
TIP EL VARIES
A TYPICAL FLOODWALL SECTION
TYPICAL FOR STICKUP HEIGHTS ABOVE 7 FT
ASSUMPTIONS:
1. EXISTING GROUND IS EARTHEN LEVEE OF EXISTING LEVEE SYSTEM.
2. DEGRADE LEVEE TO PLACE FLOODWALL.
3. FLOODWALL UTILIZED WHERE EARTHEN LEVEE RAISE IS NOT FEASIBLE.
4. LEVEE ELEVATION VARIES.
EXISTING EARTHEN LEVEE
℄ LEVEE
B TYPICAL FLOODWALL SECTION - IN PLACE OF EARTHEN LEVEE RAISE
TYPICAL FOR STICKUP HEIGHTS FROM 4 TO 7 FT
SCALE IN FEET
3/8" = 1'-0"
S-01
SABINE TO GALVESTON FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)
FLOODWALL TYPICAL SECTIONS
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS
PREPARED UNDER THE DIRECTION OF
LARS N. ZETTERSTROM, P.E.
COLONEL, U.S. ARMY, COMMANDING
Drawn by: CJM
Designed by: CJM
Created by:
Submitted by:
Approved by:
Chief, Engineering and Construction Division
Date:
Rev:
Scale: AS SHOWN
Approval Recommended:
Chief, Engineering Branch
Rev
Description
Date
By

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\S-02 Adams Bayou - Gate Structure Plan.dgn
Model Name: Default
By: mSececim Date: 9/21/2016 Time: 10:00:20 AM

Drawing No.: S-02

SABINE TO GALVESTON
FEASIBILITY STUDY
(DRAFT PLANS - NOT FOR CONSTRUCTION)

ADAMS BAYOU
GATE STRUCTURE PLAN

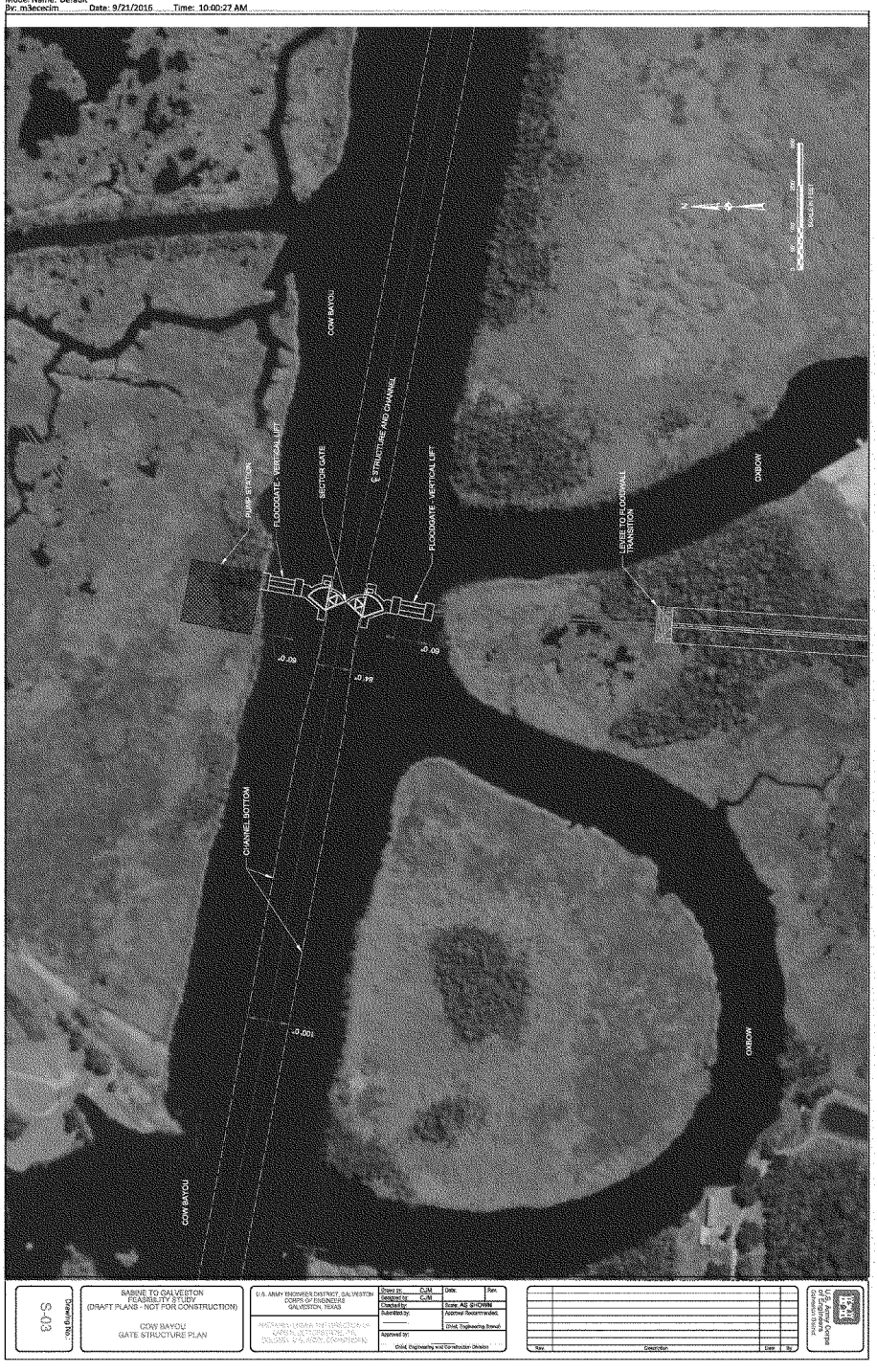
U.S. ARMY ENGINEER DISTRICT, GALVESTON
CORPS OF ENGINEERS
GALVESTON, TEXAS

Drawn by: CJM | Date: | Rev.
Designed by: CJM
Checked by: X | Scale: AS SHOWN
Submitted by: | Approved Recommended
Approved by: | Chief, Engineering Branch
Chief, Engineering and Construction Division

Rev	Description	Date	By

U.S. Army Corps of Engineers
Galveston District

File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\S-03 Cow Bayou - Gate Structure Plan.dgn
Model Name: Default
By: m3eccim Date: 9/21/2015 Time: 10:00:27 AM

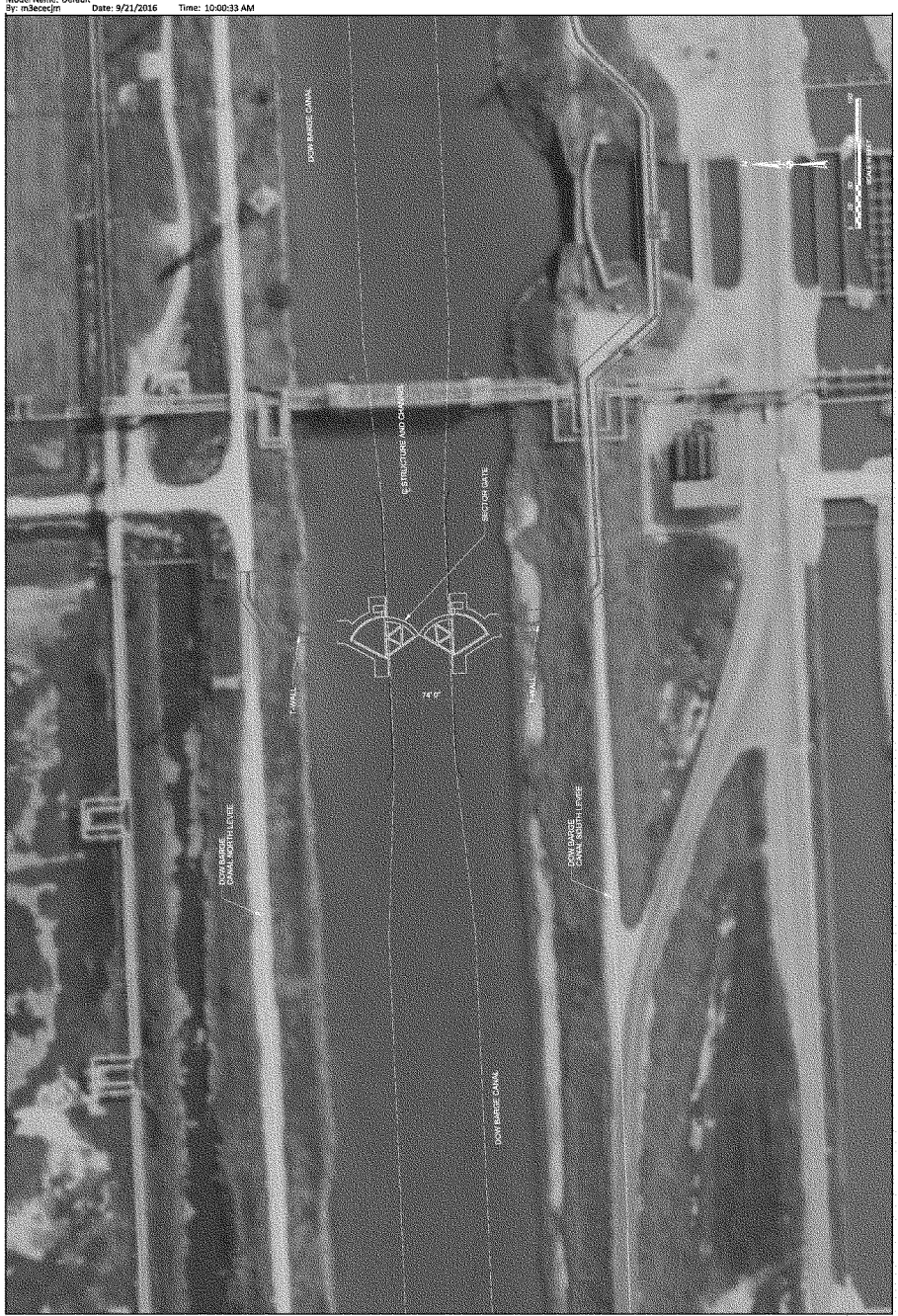


Drawing Number: S-03	SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION) COW BAYOU GATE STRUCTURE PLAN	U.S. ARMY ENGINEER DISTRICT, GALVESTON CORPS OF ENGINEERS GALVESTON, TEXAS	Sheet by: CJM Date: Rev. Designed by: CJM Checked by: Scale: AS SHOWN Submitted by: Approved/ Recommended: Chief, Engineering Branch Approved by: Chief, Engineering and Construction Division

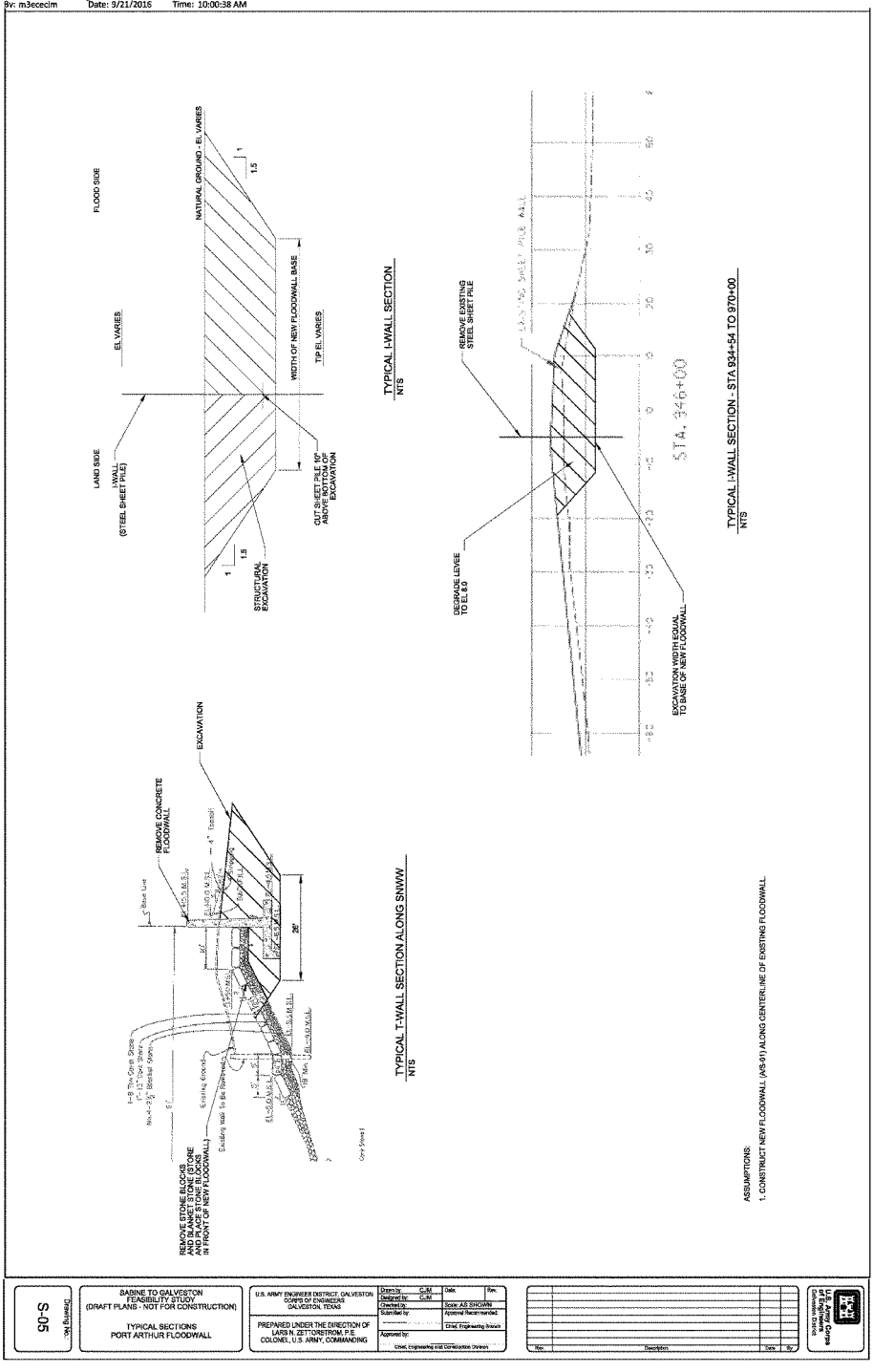
Rev.	Description	Date	By

U.S. Army Corps of Engineers Galveston District

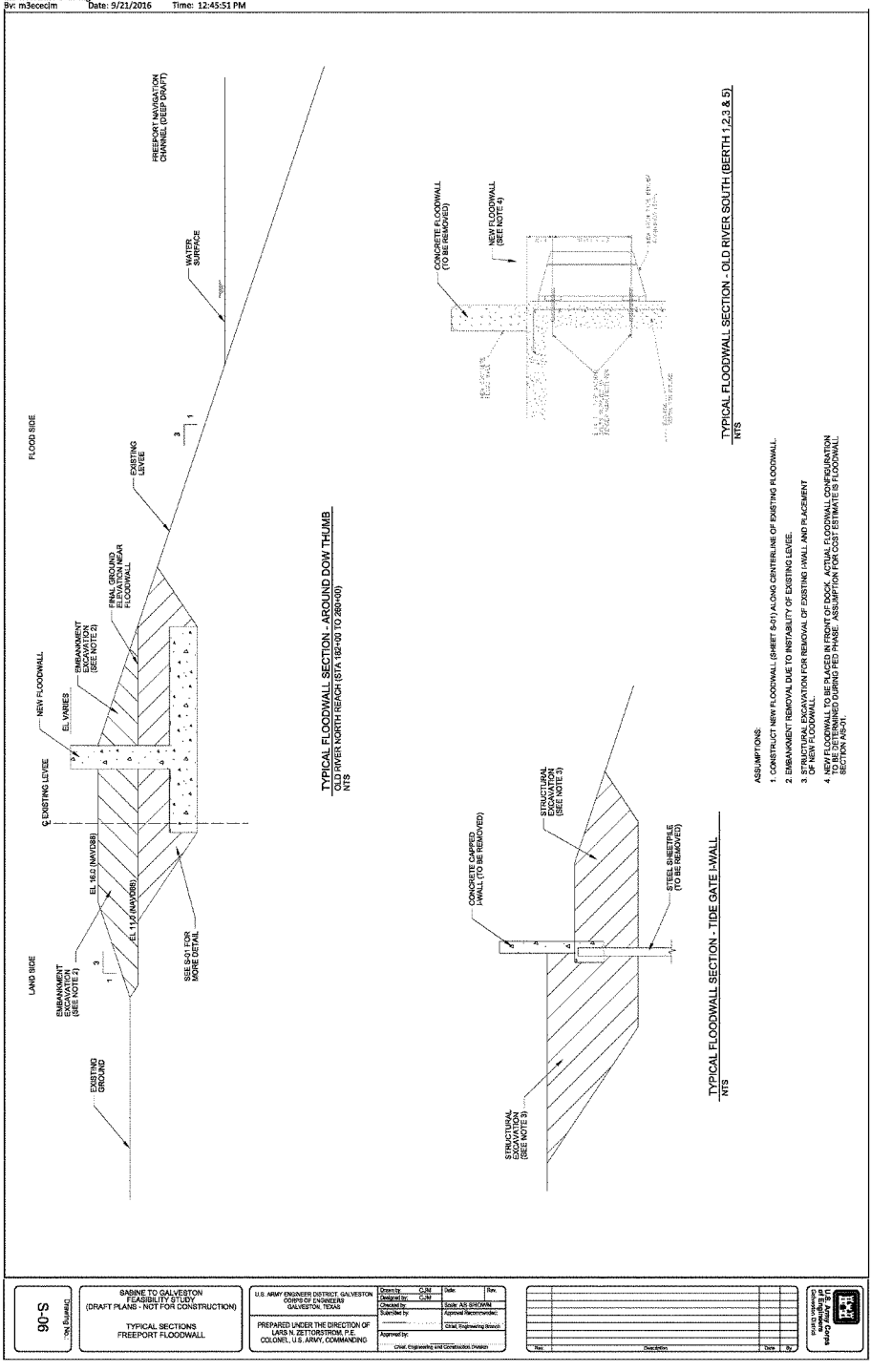
File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\S-04 DOW Barge Canal - Gate Structure Plan.dgn
Model Name: Default
By: m3eceejm Date: 9/21/2016 Time: 10:00:33 AM



File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\S-05 Port Arthur Floodwall - Typical Sections.dgn
Model Name: Drawing
By: m3ecejm Date: 9/21/2016 Time: 10:00:38 AM



File: W:\CADD\Projects\Sn\Sabine to Galveston\Appendix sheets\S-06 Freeport Floodwall - Typical Sections.dgn
Model Name: Drawing
By: m3cecdm Date: 9/21/2016 Time: 12:45:51 PM



S-06

SABINE TO GALVESTON FEASIBILITY STUDY (DRAFT PLANS - NOT FOR CONSTRUCTION)

TYPICAL SECTIONS FREEPORT FLOODWALL

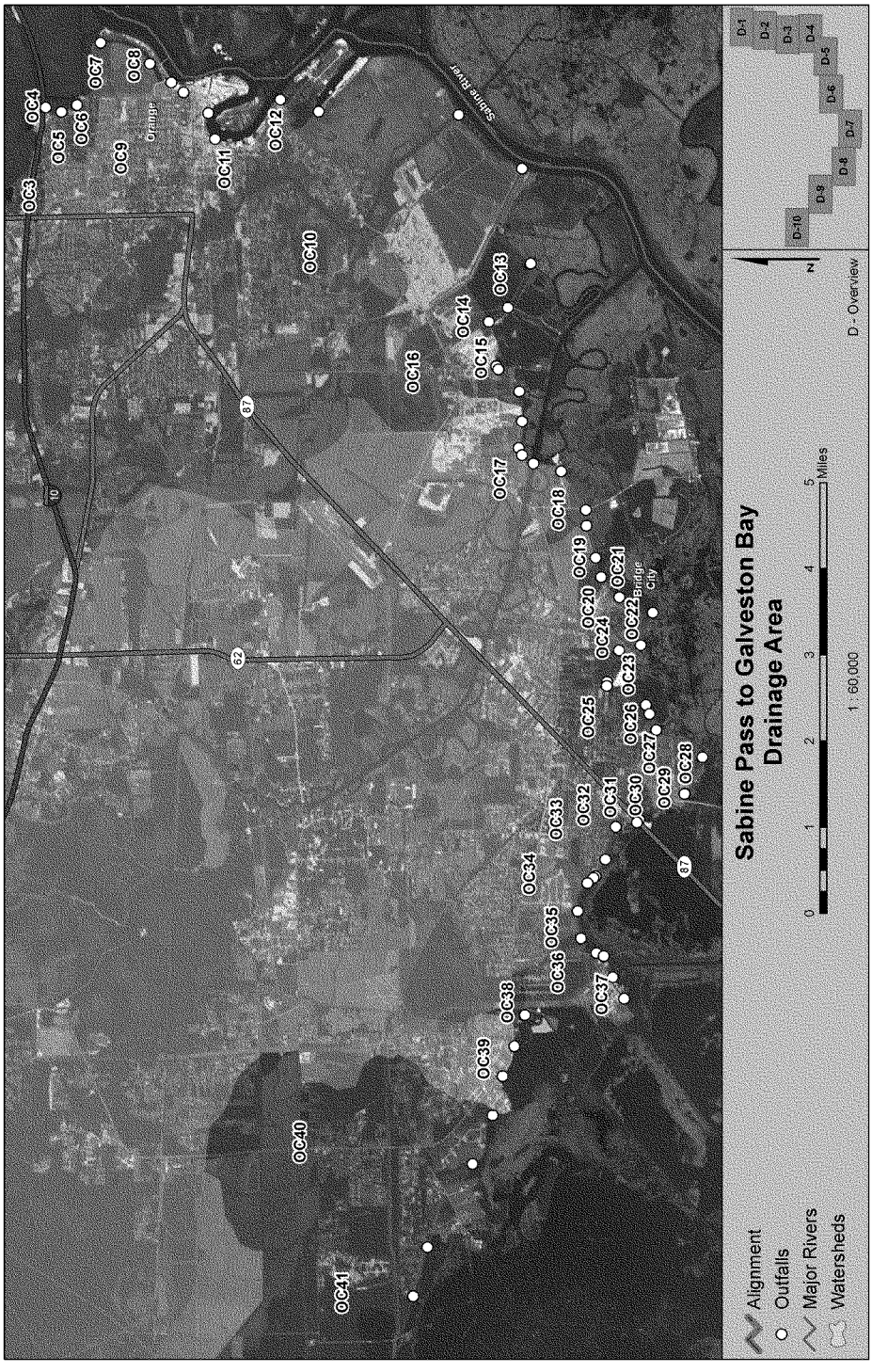
U.S. ARMY ENGINEER DISTRICT, GALVESTON CORPS OF ENGINEERS GALVESTON, TEXAS

PREPARED UNDER THE DIRECTION OF LARS N. ZETTERSTROM, P.E. COLONEL, U.S. ARMY, COMMANDING

Drawn by: CJM Date: Rev.
Designed by: CJM
Checked by: Scale: AS SHOWN
Submitted by: Approved Recommended:
Chief, Engineering Branch
Approved by:
Chief, Engineering and Construction Division

Rev. Description Date By

Plotted on 24 Hour Clock
Plotted by: m3cecdm


Sabine Pass to Galveston Bay
Drainage Area
Alignment
Outfalls
Major Rivers
Watersheds
0 1 2 3 4 5 Miles
1 : 60,000
N
D - Overview
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10
OC1
OC2
OC3
OC4
OC5
OC6
OC7
OC8
OC9
OC10
OC11
OC12
OC13
OC14
OC15
OC16
OC17
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OC19
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OC21
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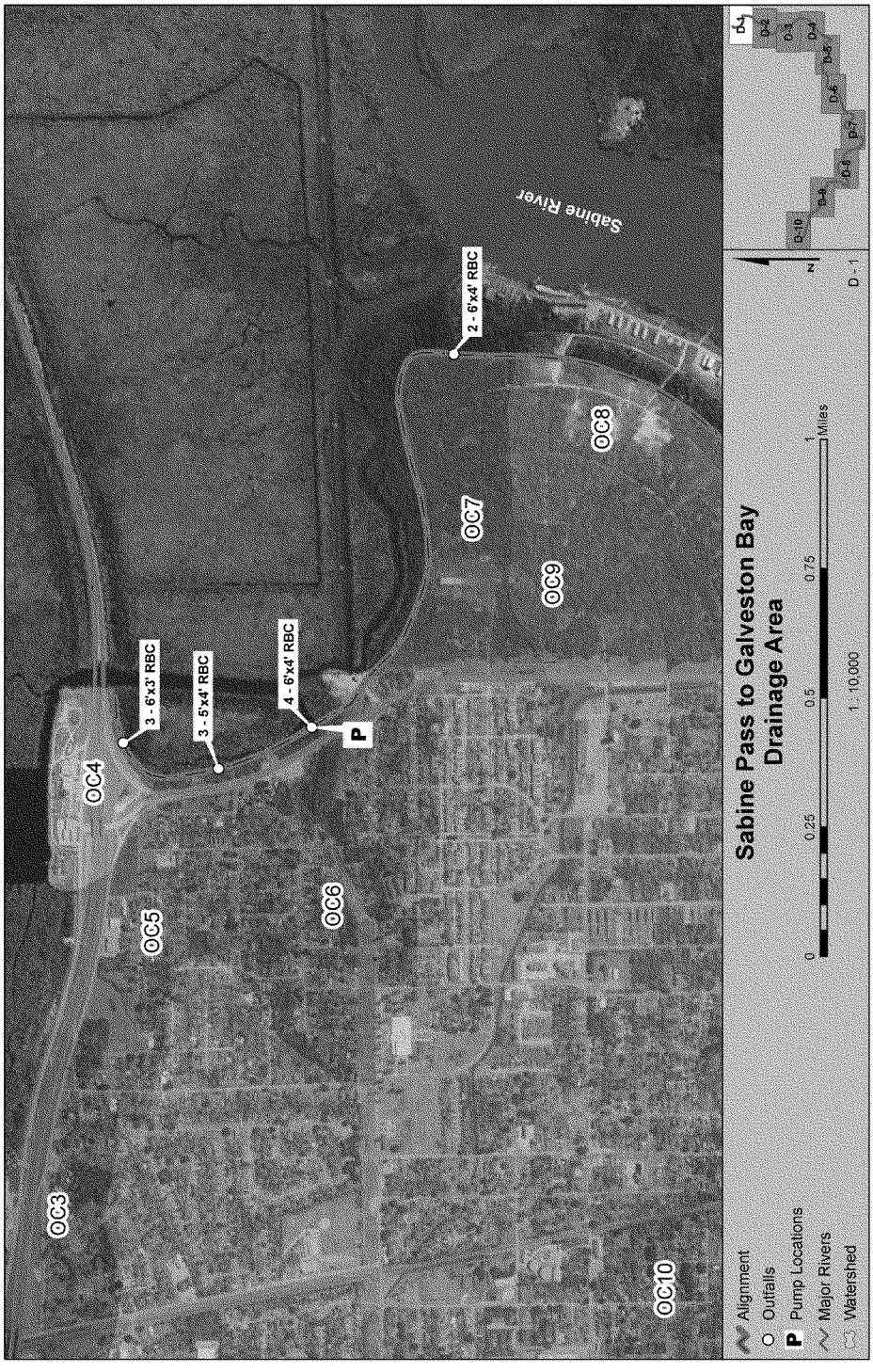
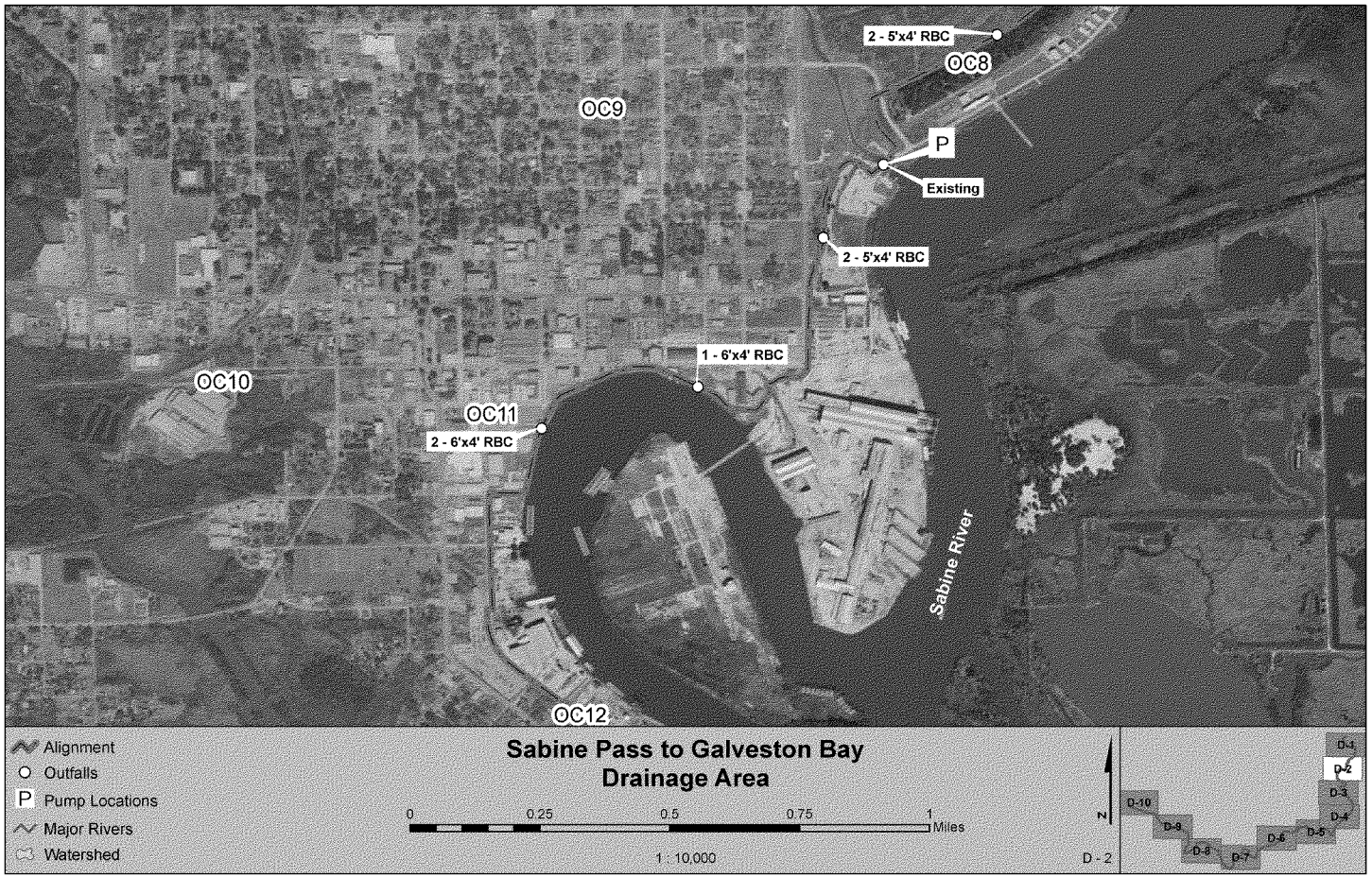
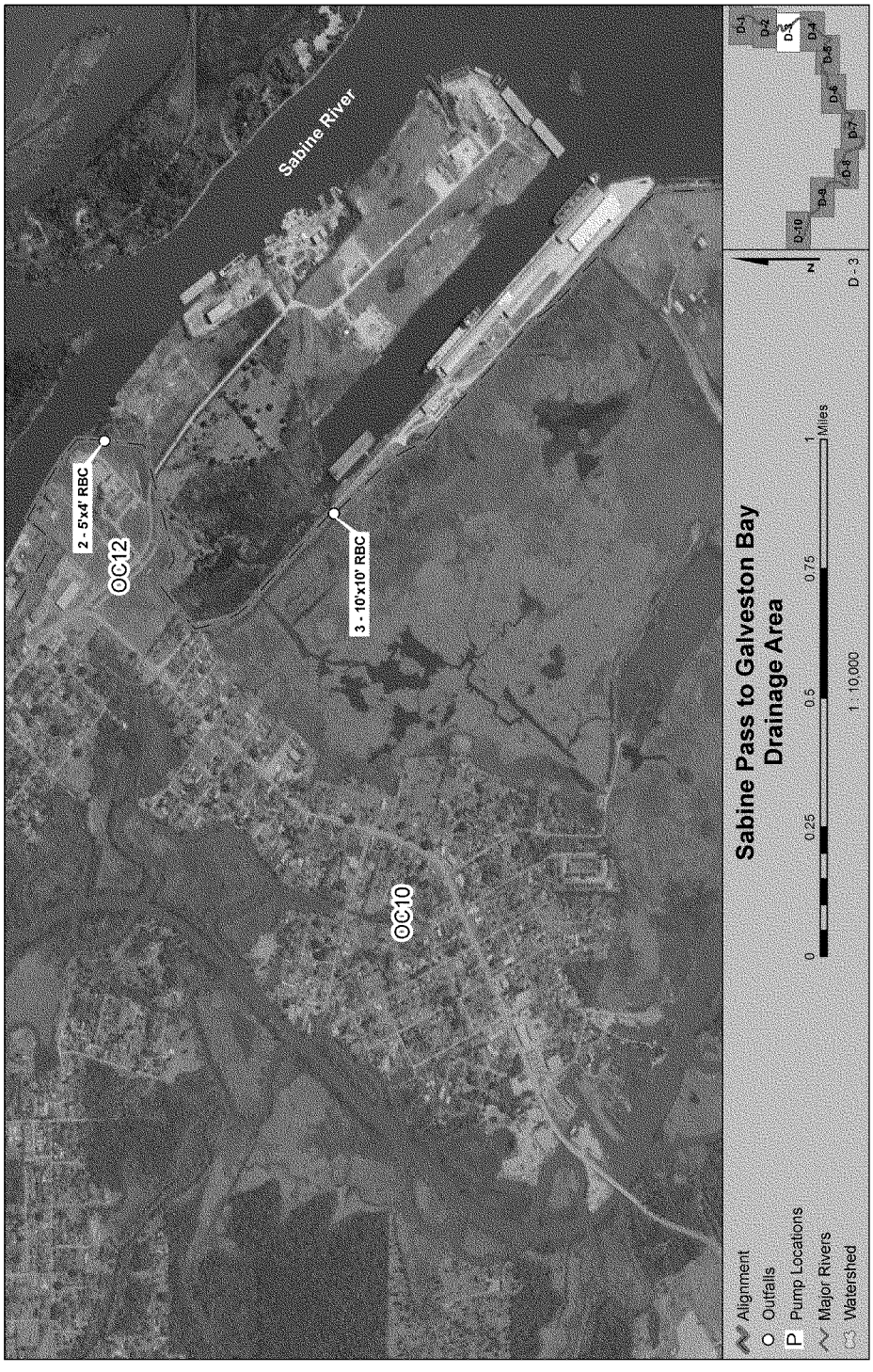
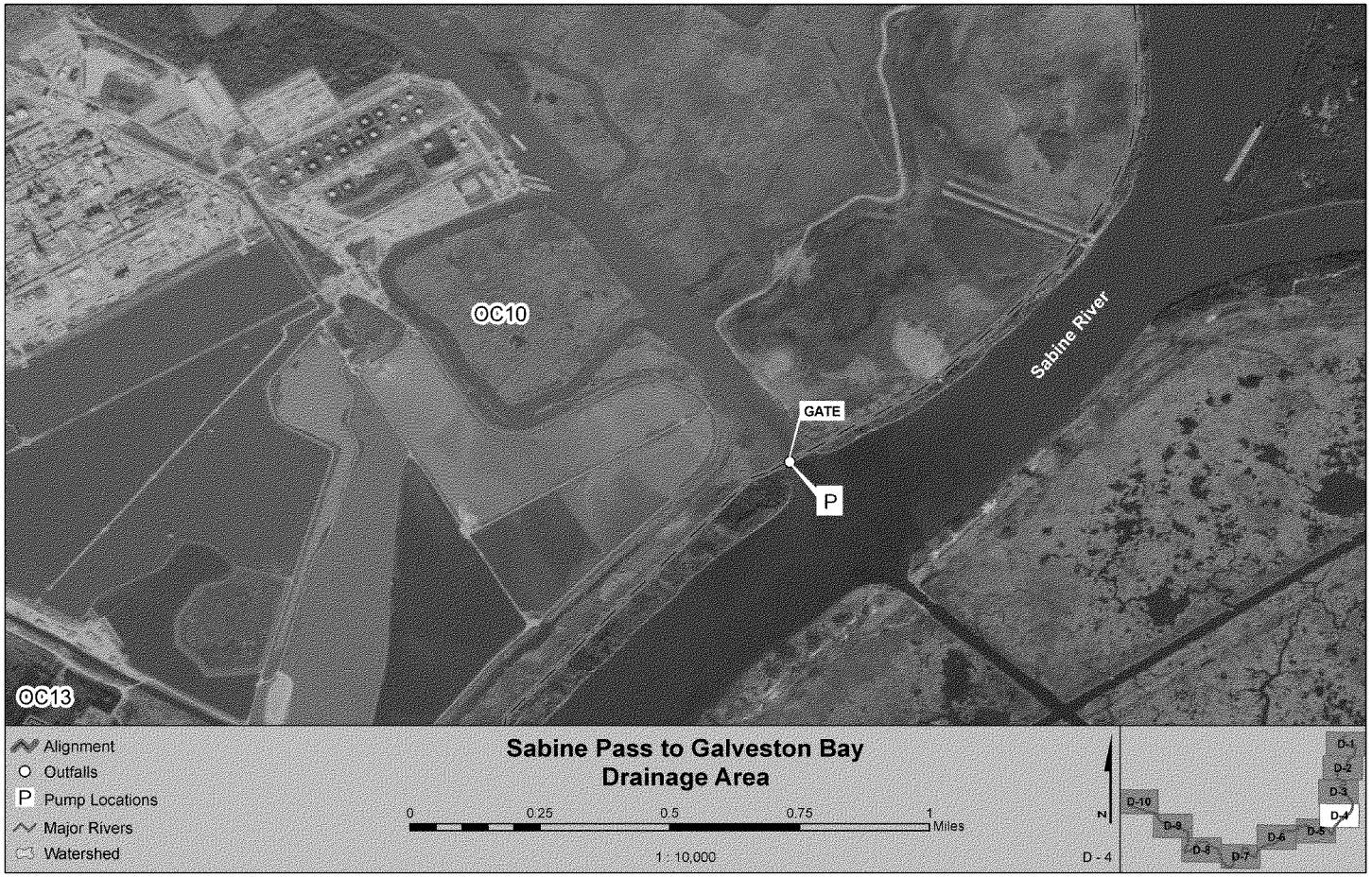
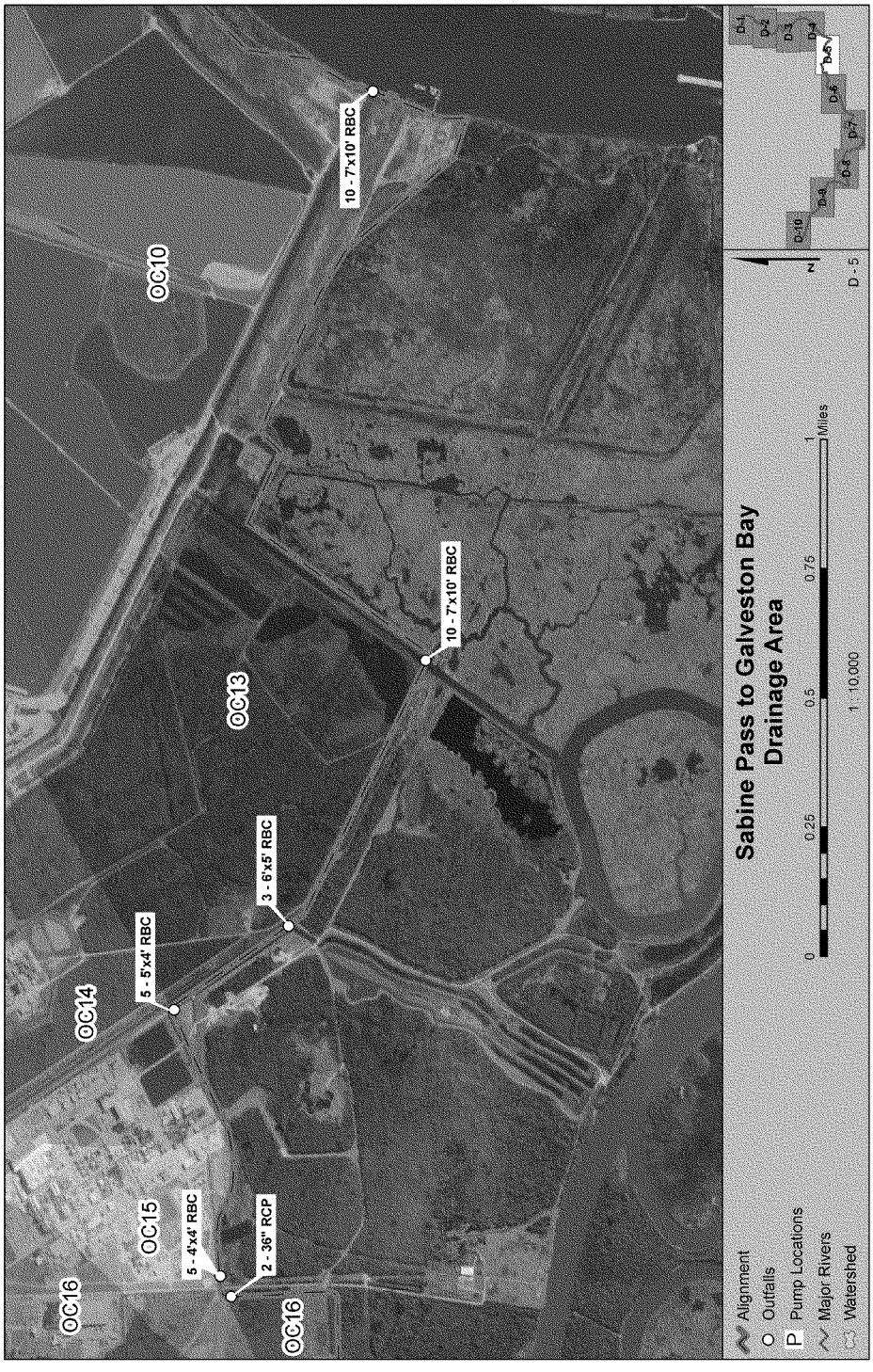
OC23
OC24
OC25
OC26
OC27
OC28
OC29
OC30
OC31
OC32
OC33
OC34
OC35
OC36
OC37
OC38
OC39
OC40
OC41
Orange
Sabine River
Bridge City
10
62
87
87

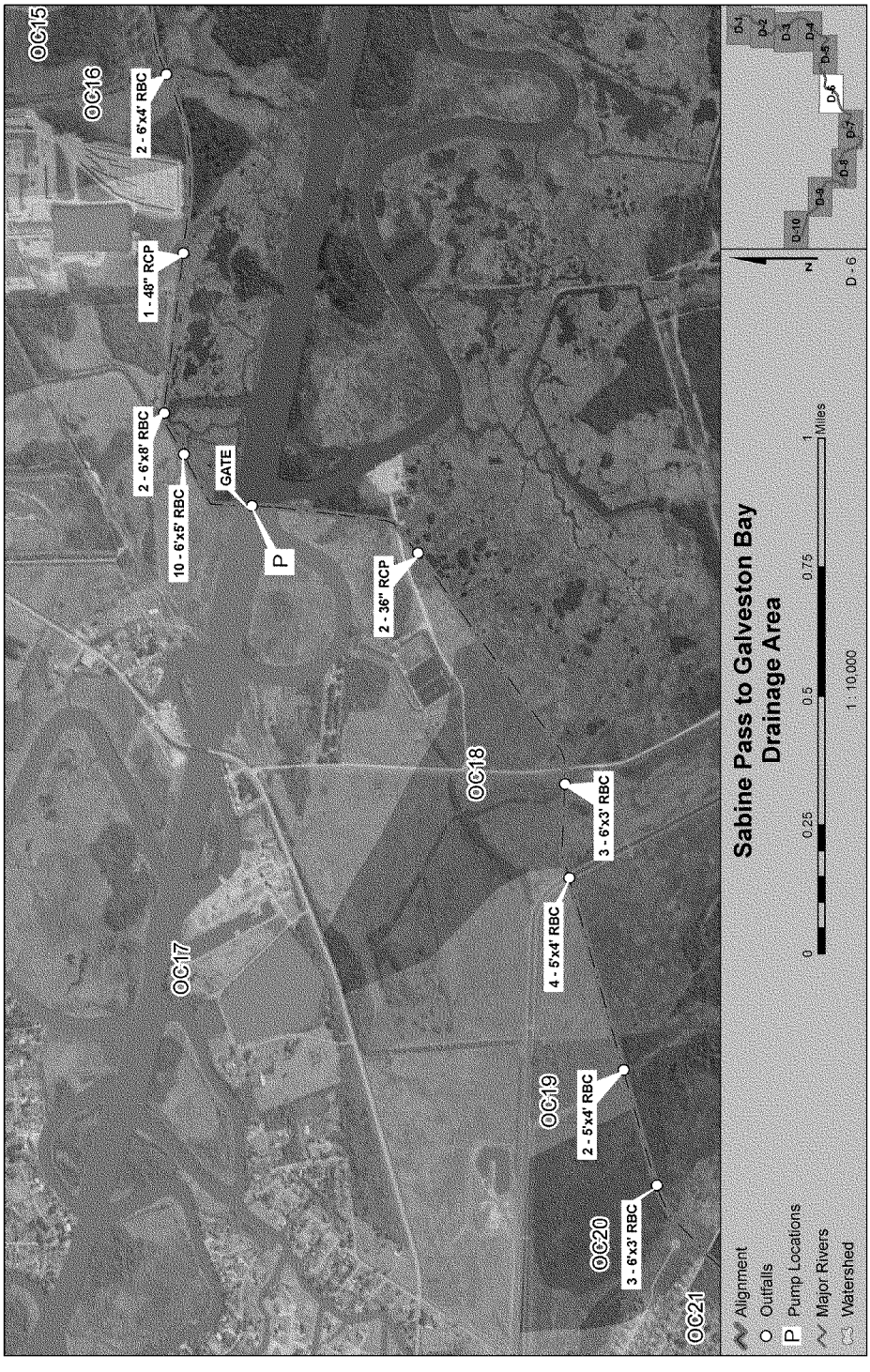

Sabine Pass to Galveston Bay
Drainage Area
1 : 10,000
0
0.25
0.5
0.75
1 Miles
N
D - 1
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
OC3
OC4
OC5
OC6
OC7
OC8
OC9
OC10
3 - 6'x3' RBC
3 - 5'x4' RBC
4 - 6'x4' RBC
2 - 6'x4' RBC
P
Sabine River

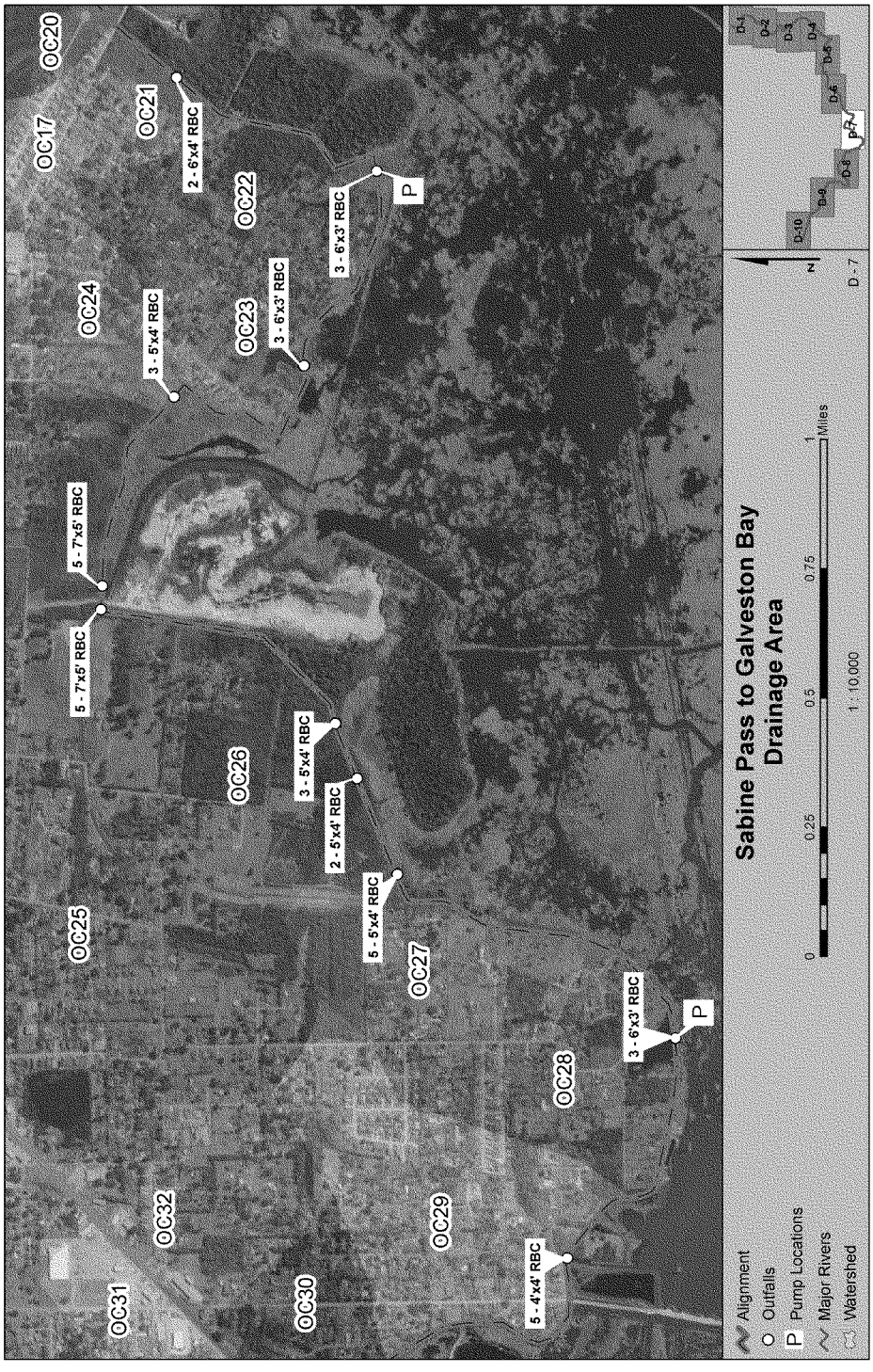

2 - 5'x4' RBC
OC8
OC9
P
Existing
2 - 5'x4' RBC
1 - 6'x4' RBC
OC10
OC11
2 - 6'x4' RBC
Sabine River
OC12
Alignment
Outfalls
P Pump Locations
Major Rivers
Watershed
Sabine Pass to Galveston Bay
Drainage Area
0
0.25
0.5
0.75
1
Miles
1 : 10,000
N
D - 2
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10

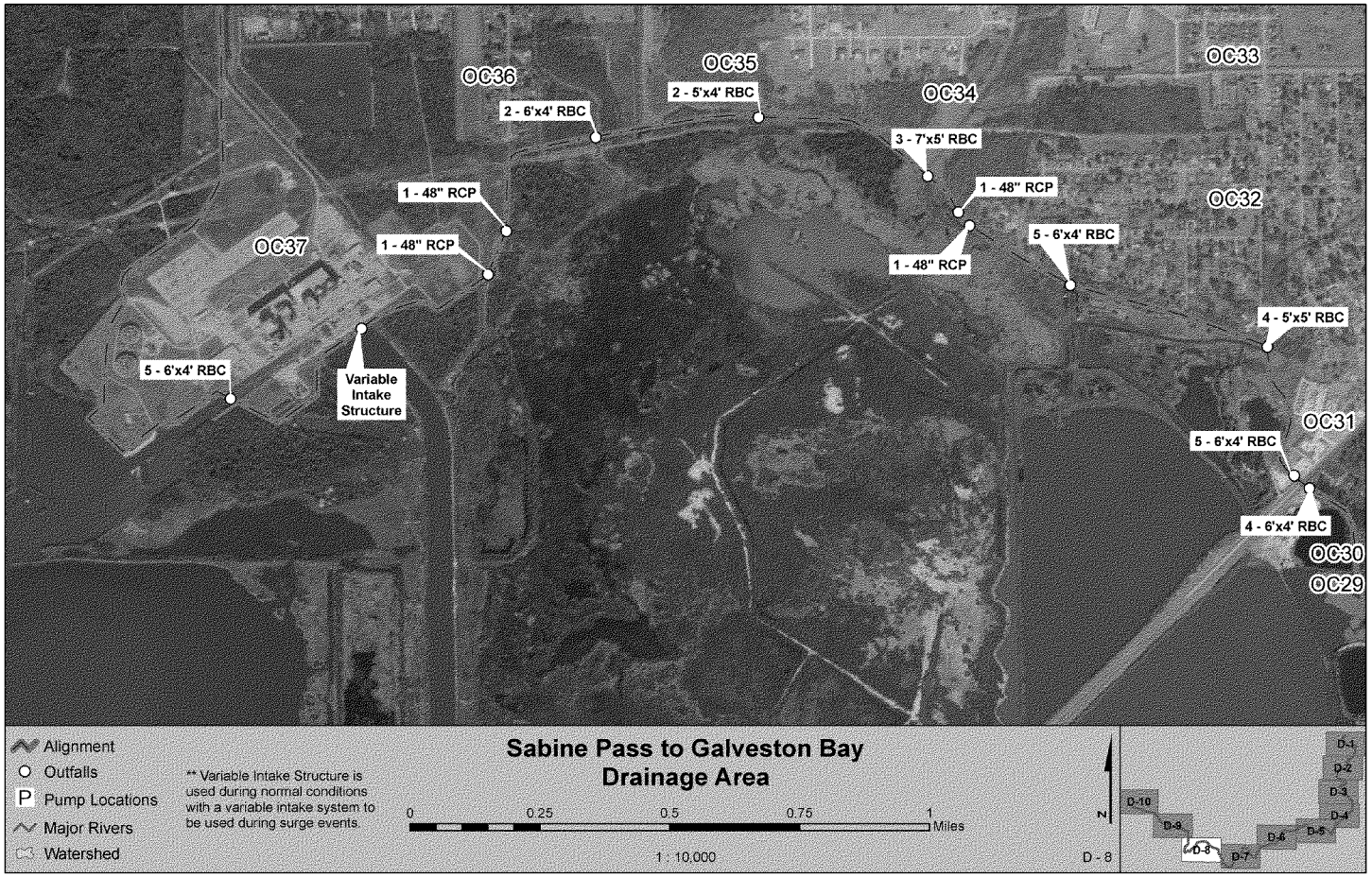

Sabine River
2 - 5'x4' RBC
3 - 10'x10' RBC
OC12
OC10
Sabine Pass to Galveston Bay
Drainage Area
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
0
0.25
0.5
0.75
1
Miles
N
1 : 10,000
D - 3
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10

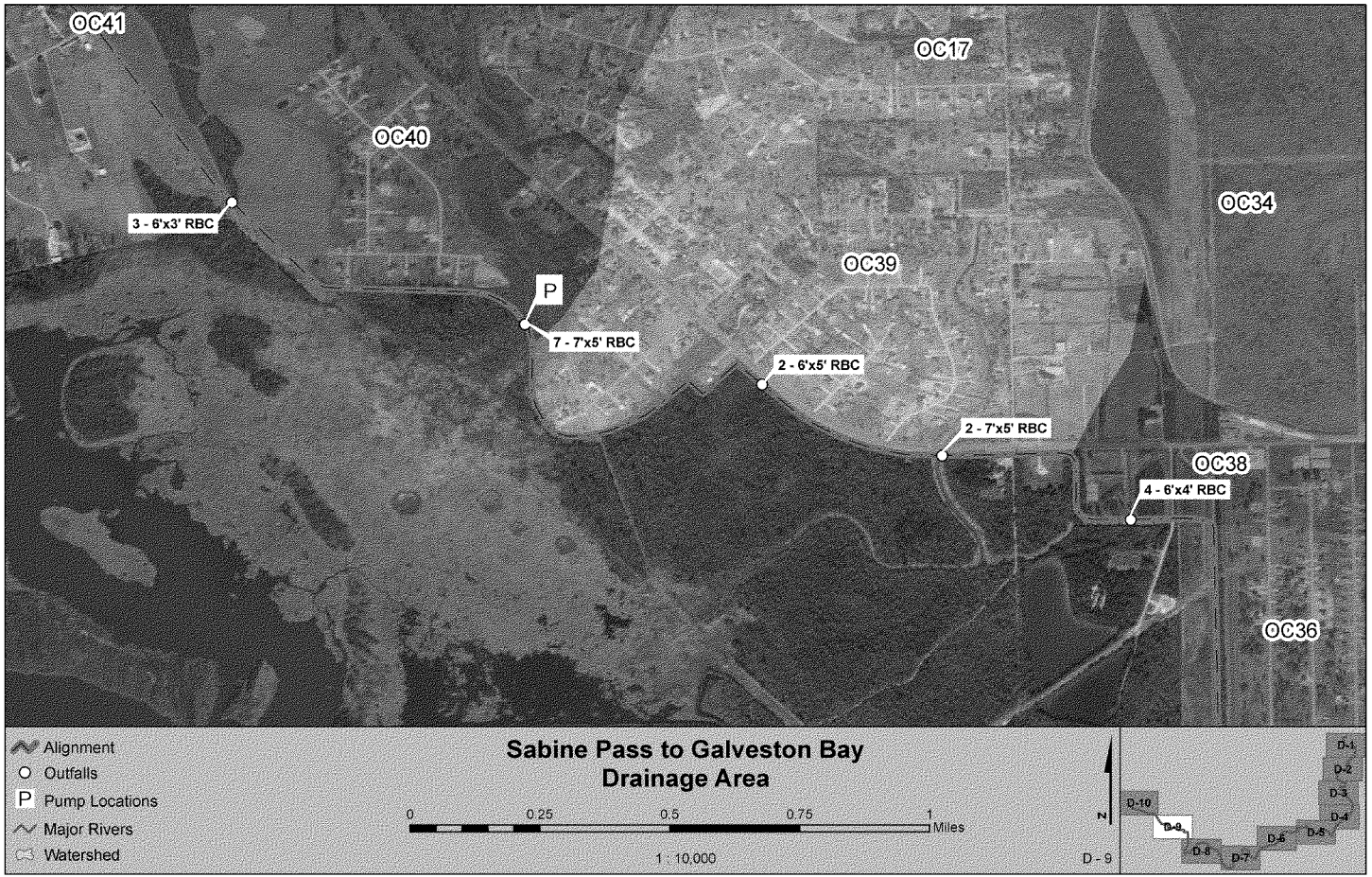

OC10
OC13
Sabine River
GATE
P
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
Sabine Pass to Galveston Bay
Drainage Area
0
0.25
0.5
0.75
1
Miles
1 : 10,000
N
D - 4
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10


OC16
OC15
OC14
OC13
OC10
OC16
5 - 4'x4' RBC
2 - 36" RCP
5 - 5'x4' RBC
3 - 6'x5' RBC
10 - 7'x10' RBC
10 - 7'x10' RBC
Sabine Pass to Galveston Bay
Drainage Area
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
0
0.25
0.5
0.75
1
Miles
1 : 10,000
D - 5
N
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10

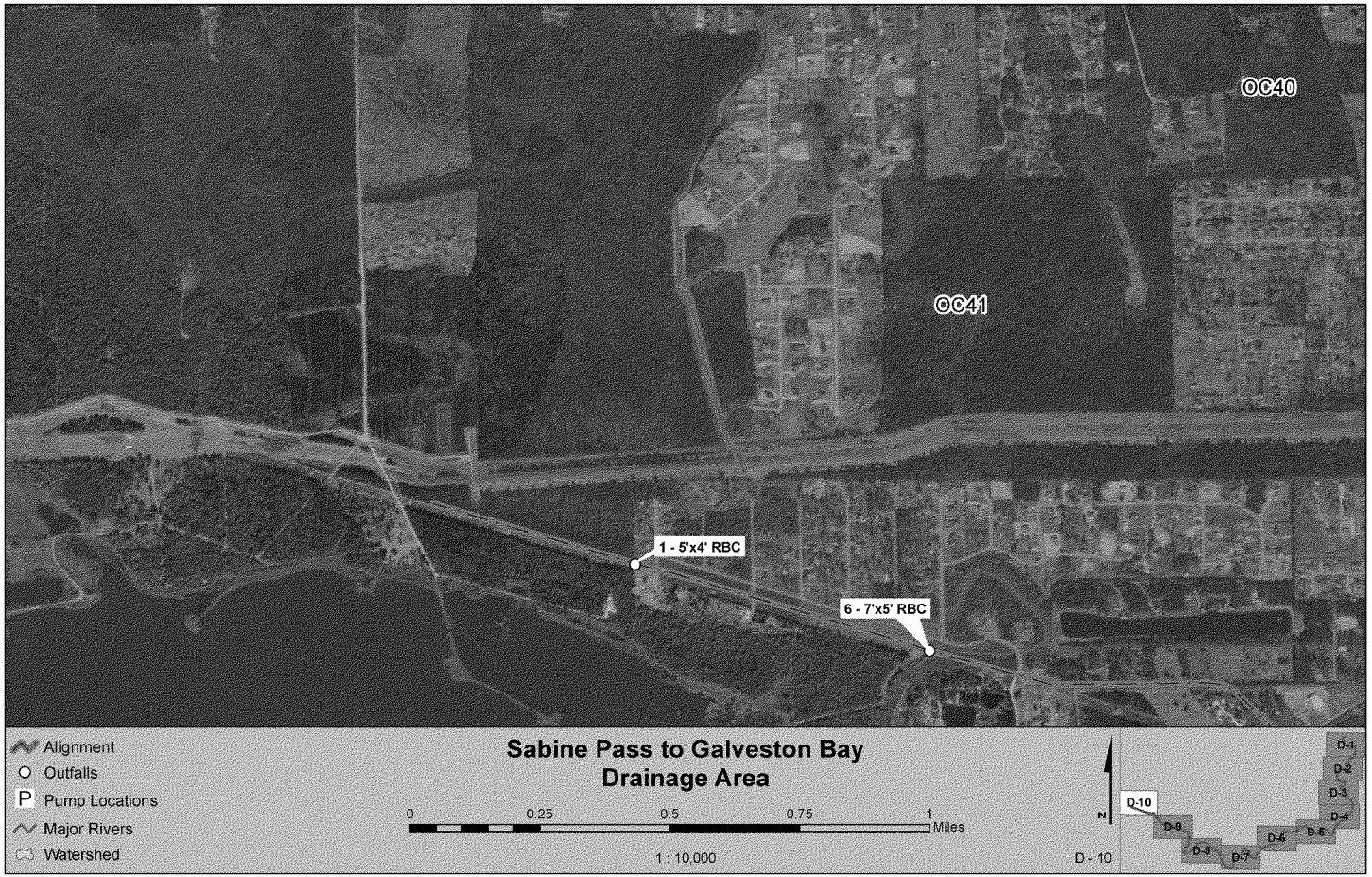

OC15
OC16
OC17
OC18
OC19
OC20
OC21
2 - 6'x4' RBC
1 - 48" RCP
2 - 6'x8' RBC
10 - 6'x5' RBC
GATE
P
2 - 36" RCP
4 - 5'x4' RBC
3 - 6'x3' RBC
2 - 5'x4' RBC
3 - 6'x3' RBC
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
Sabine Pass to Galveston Bay
Drainage Area
0
0.25
0.5
0.75
1
Miles
1 : 10,000
N
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10
D - 6


OC31
OC32
OC30
OC29
OC28
OC27
OC25
OC26
OC24
OC23
OC22
OC21
OC17
OC20
5 - 4'x4' RBC
3 - 6'x3' RBC
P
5 - 5'x4' RBC
2 - 5'x4' RBC
3 - 5'x4' RBC
5 - 7'x5' RBC
5 - 7'x5' RBC
3 - 5'x4' RBC
3 - 6'x3' RBC
3 - 6'x3' RBC
2 - 6'x4' RBC
P
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
Sabine Pass to Galveston Bay
Drainage Area
0
0.25
0.5
0.75
1
Miles
1 : 10,000
N
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10

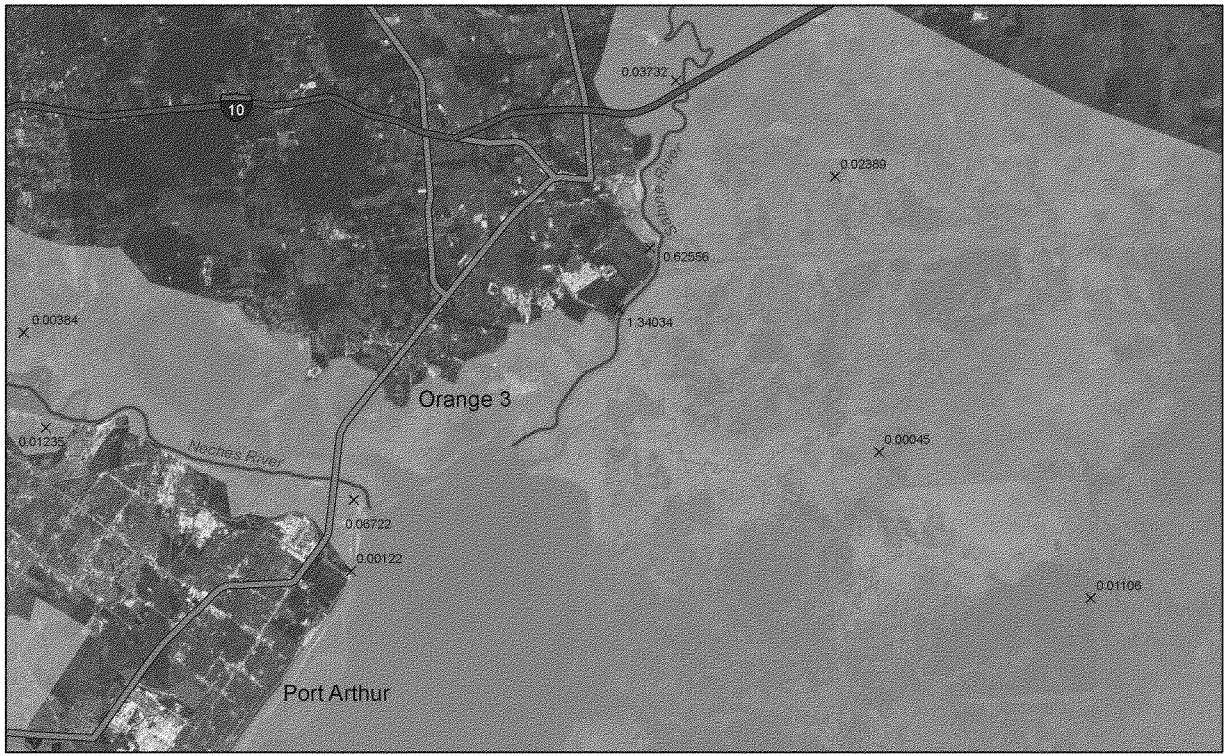

OC36
OC35
OC34
OC33
OC32
OC31
OC30
OC29
OC37
2 - 6'x4' RBC
2 - 5'x4' RBC
3 - 7'x5' RBC
1 - 48" RCP
1 - 48" RCP
1 - 48" RCP
1 - 48" RCP
5 - 6'x4' RBC
4 - 5'x5' RBC
5 - 6'x4' RBC
Variable Intake Structure
5 - 6'x4' RBC
4 - 6'x4' RBC
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
** Variable Intake Structure is used during normal conditions with a variable intake system to be used during surge events.
Sabine Pass to Galveston Bay
Drainage Area
0
0.25
0.5
0.75
1
Miles
1 : 10,000
N
D - 8
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10


OC41
OC17
OC40
OC34
3 - 6'x3' RBC
OC39
P
7 - 7'x5' RBC
2 - 6'x5' RBC
2 - 7'x5' RBC
OC38
4 - 6'x4' RBC
OC36
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
Sabine Pass to Galveston Bay
Drainage Area
0
0.25
0.5
0.75
1
Miles
1 : 10,000
N
D - 9
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10

1080


OC40
OC41
1 - 5'x4' RBC
6 - 7'x5' RBC
Alignment
Outfalls
Pump Locations
Major Rivers
Watershed
Sabine Pass to Galveston Bay
Drainage Area
0
0.25
0.5
0.75
1
Miles
1 : 10,000
N
D - 10
D-1
D-2
D-3
D-4
D-5
D-6
D-7
D-8
D-9
D-10

Adjacent Impacts



Surge Impact Change (WP-WOP)

- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1
- 1 - 1.25
- 1.25 - 1.5

Miles
0 10 20 30 40 50

N W E S

Interstate
Highway
Change
Levee
River

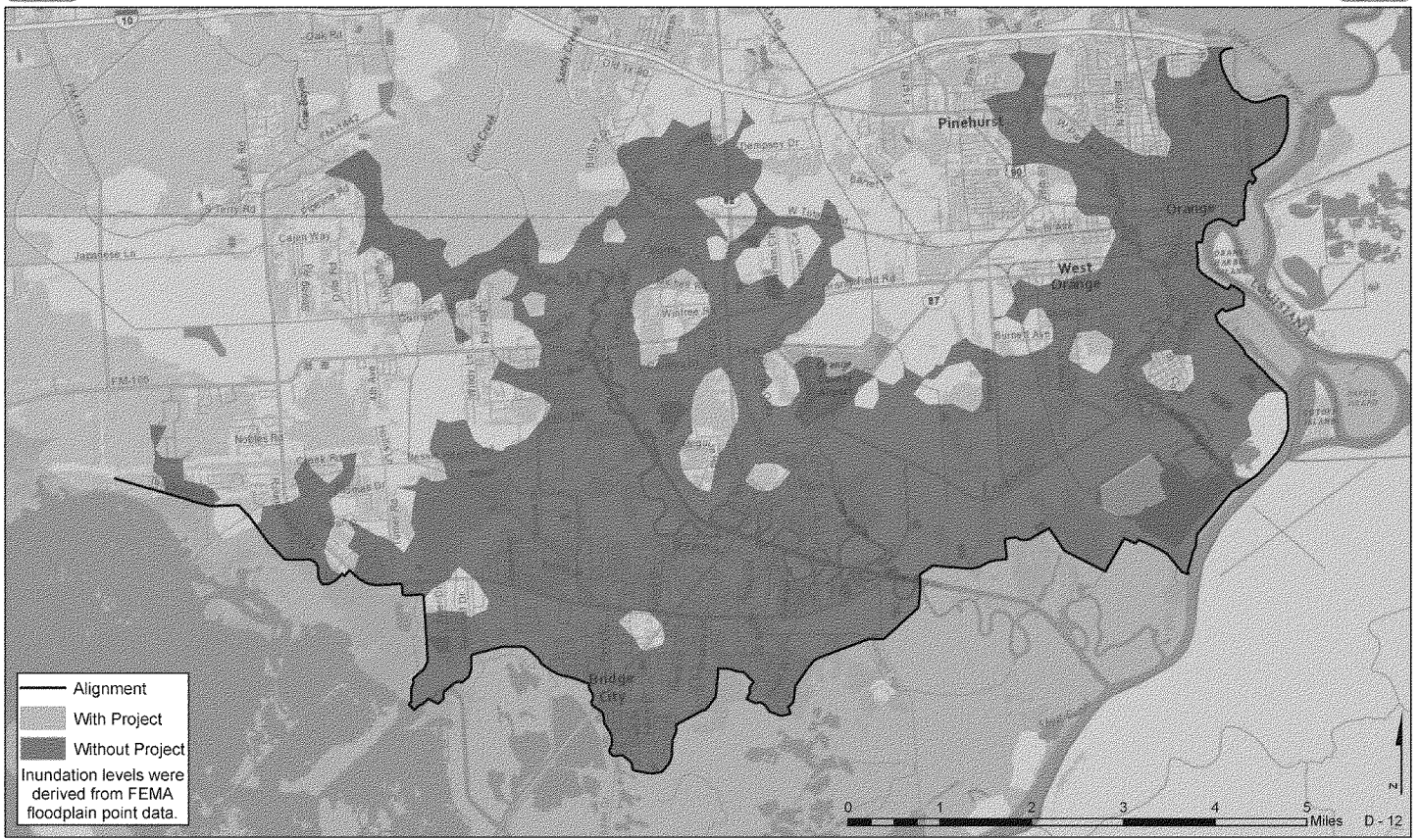
The surge builds at the levee, but other than the levee area there is no significate impact to the surge height. In areas away from the levee line the change remains coinstant within -0.5 and 0.5 ft.

Source: ERDC Surge Modeling

D - 11

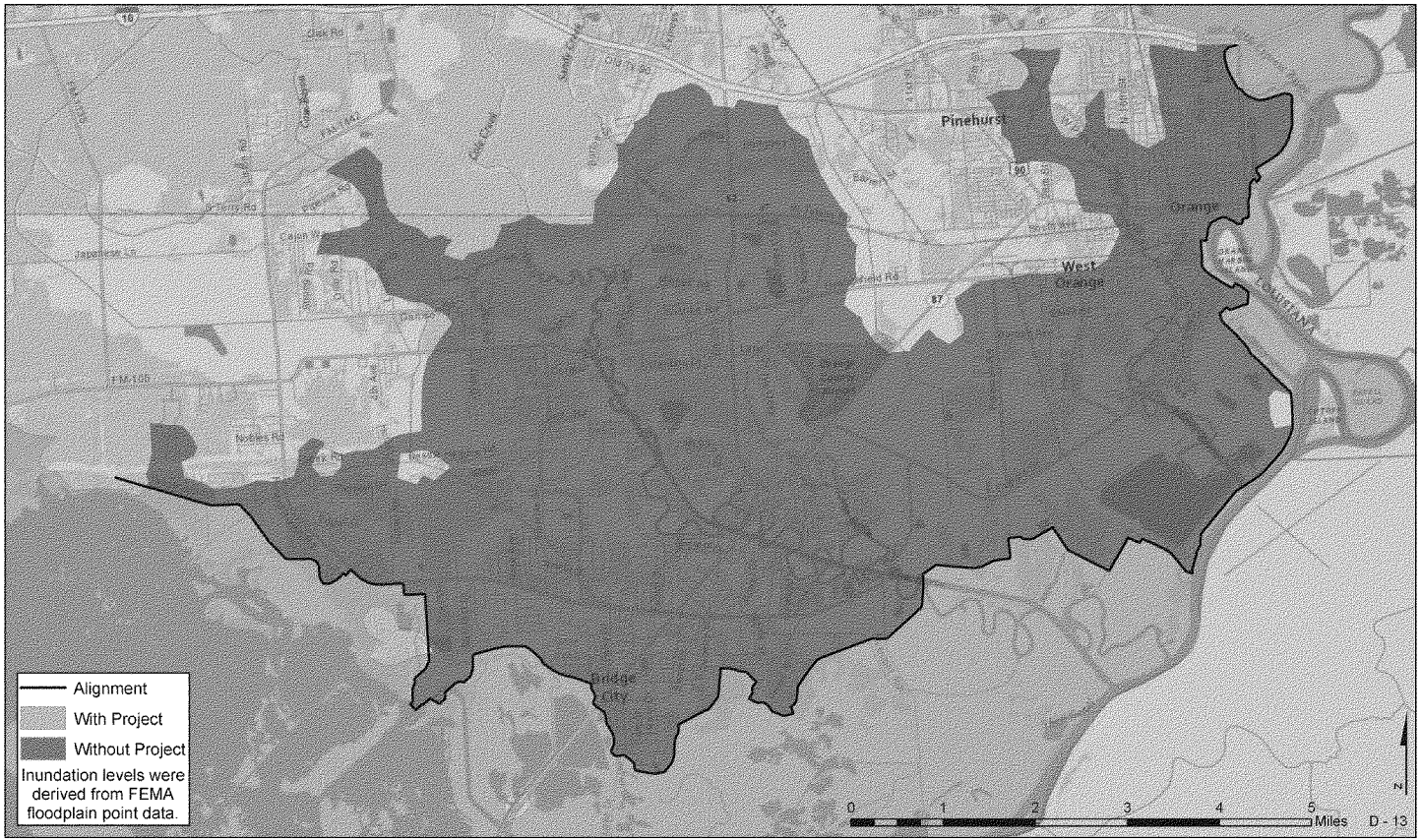
Orange 3 Inundation Change

at the 100 Year Floodplain Level



Orange 3 Inundation Change

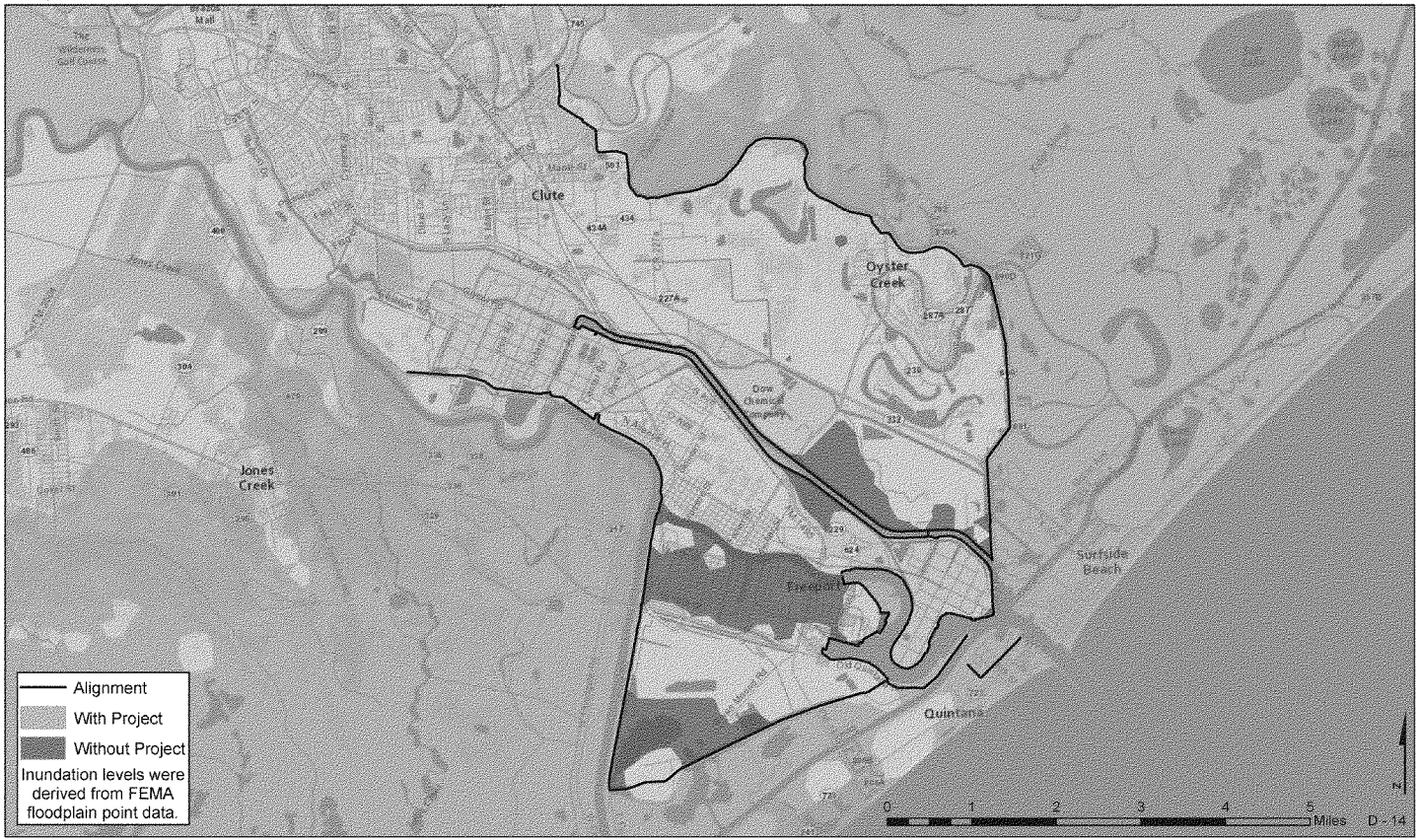
at the 500 Year Floodplain Level



D - 13

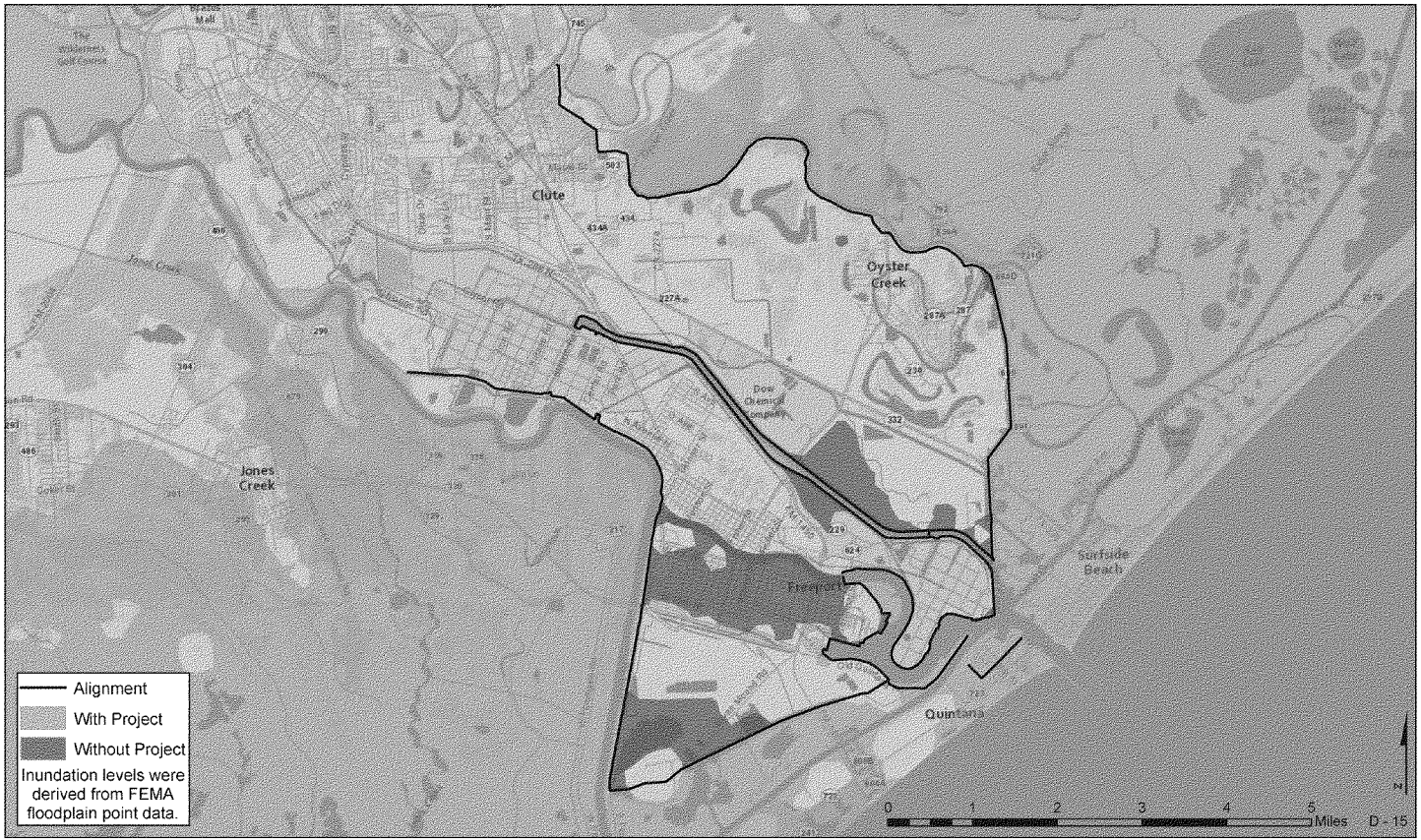
Freeport Inundation Change

at the 100 Year Floodplain Level



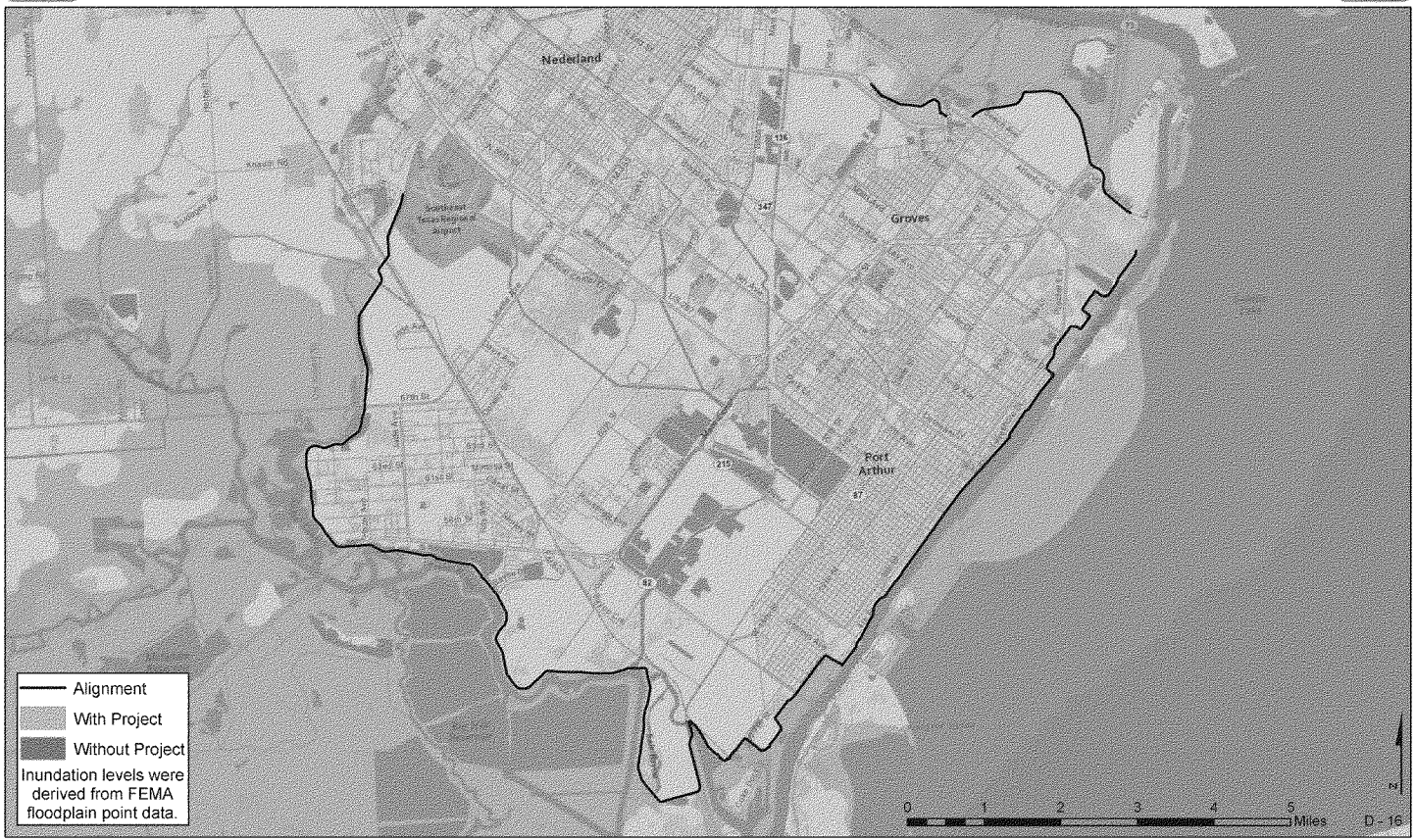
Freeport Inundation Change

at the 500 Year Floodplain Level



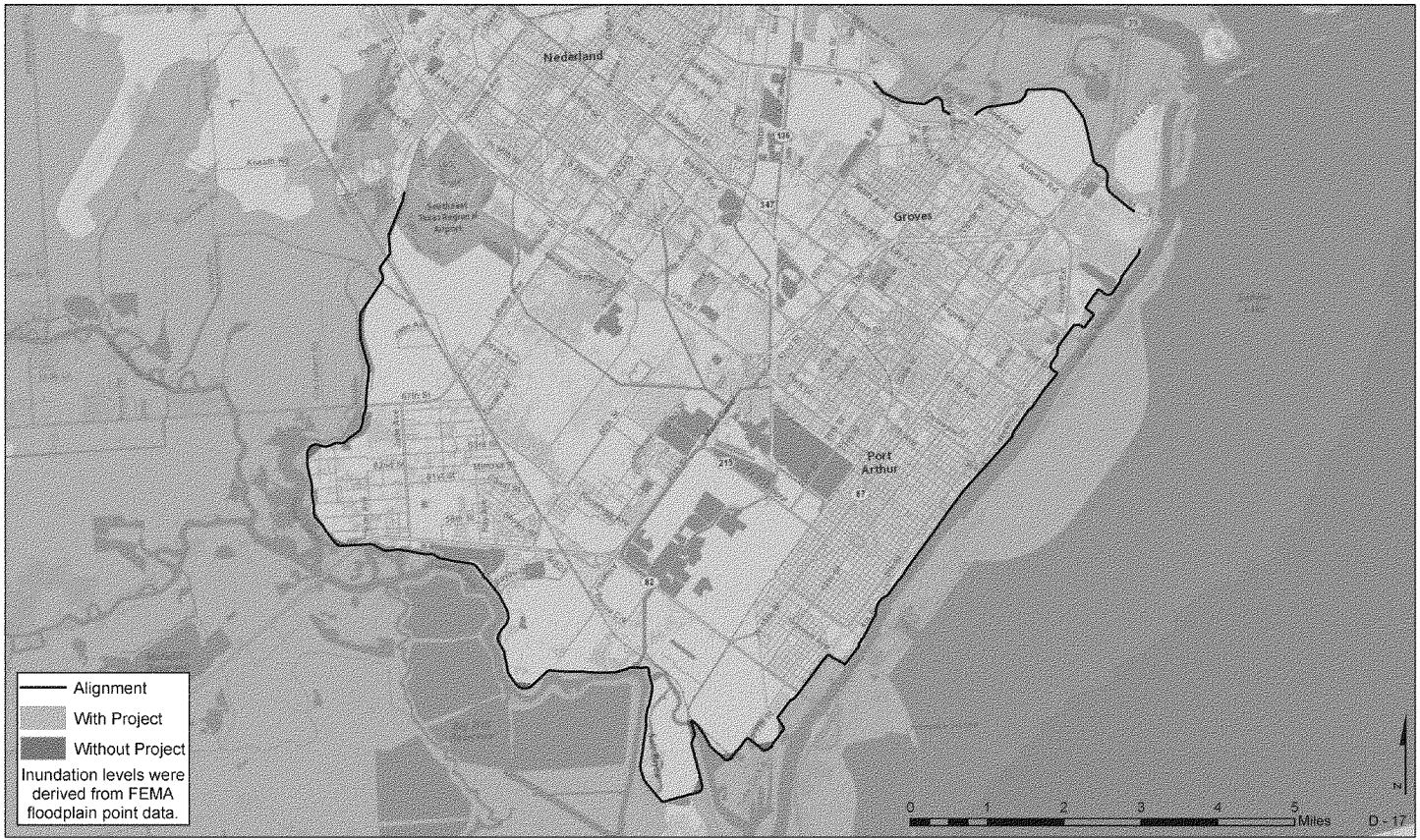
Port Arthur Inundation Change

at the 100 Year Floodplain Level



Port Arthur Inundation Change

at the 500 Year Floodplain Level



FOR CONTINUATION OF HOUSE DOCUMENT 115-174

SABINE PASS TO GALVESTON BAY, TEXAS COASTAL STORM RISK MANAGEMENT AND ECOSYSTEM RESTORATION: FINAL INTEGRATED FEASIBILITY REPORT – ENVIRONMENTAL IMPACT STATEMENT

SEE PART 2