TEXAS COASTAL RESILIENCY MASTER PLAN

TECHNICAL REPORT

MARCH 2023

Commissioner
Dawn Buckingham, M.D.
Texas General Land Office

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Acronyms and Abbreviations

AAHU	Average Annual Habitat Units
ac	Acres
ACE	Accumulated Cyclone Energy
ACS	American Community Survey
ADCIRC	Advanced Circulation Model
AMI	Area Median Income
ANWR	Aransas National Wildlife Refuge
ASCE	American Society of Civil Engineers
BCA	Benefit Cost Analyses
BEG	Bureau of Economic Geology
BLS	Bureau of Labor Statistics
BUDM	Beneficial Use of Dredge Material
CBBEP	Coastal Bend Bays and Estuaries Program
C-CAP	Coastal Change Analysis Program
CDBG	Community Development Block Grant
CDBG-MIT	Community Development Block Grant-Mitigation
CDR	Community Development and Revitalization
CEJST	Climate and Economic Justice Screening Tool
CEPRA	Coastal Erosion Planning and Response Act
CIAP	Coastal Impact Assistance Program
CMP	Coastal Management Program
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSRM	Coastal Storm Risk Management
CY	Cubic Yards
CZB	Coastal Zone Boundary
Database	Project Geospatial Database
DOC	Depth of Closure
E&D	Engineering and Design
EF JRB	Ellington Field Joint Reserve Base
EJ	Environmental Justice
EPA	Environmental Protection Agency
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FMA	Flood Mitigation Assistance
ft	Feet
GBS	General Building Stock
GCCPRD	Gulf Coast Community Protection and Recovery District
GCPD	Gulf Coast Protection District
GDP	Gross Domestic Product
GIS	Geographic Information System
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
GMSL	Global Mean Sea Level
GMSLR	Global Mean Sea Level Rise
GOMESA	Gulf of Mexico Energy Security Act
GPS	Global Positioning System
ha	Hectares
Hazus	Hazards U.S.
HIFLD	Homeland Infrastructure Foundation-Level Data
Hollaway	Hollaway Environmental + Communication Services, Inc.
HOT	Hotel Occupancy Tax
HRI	Harte Research Institute for Gulf of Mexico Studies
HUC	Hydrologic Unit Code
HUD	U.S. Department of Housing and Urban Development
HVRI SoVI®	The University of South Carolina Hazards and Vulnerability Research Institute’s Social Vulnerability Index dataset
ID	Identification
in	Inches

iPaC	U.S. Fish and Wildlife Service's Information for Planning and Consultation Tool
IPCC	Intergovernmental Panel on Climate Change
km/h	Kilometers per Hour
kt	Knot
LiDAR	Light Detection and Ranging
LMI	Low- to Moderate-Income
LULC	Land Use/Land Cover
MLLW	Mean Lower Low Water
m	Meters
m^3	Cubic Meters
mm	Millimeters
mph	Miles per Hour
MSA	Metropolitan Statistical Area
MTS	Maritime Transportation System
NAVD88	North American Vertical Datum of 1988
NAICS	North American Industry Classification System
NAS	Naval Air Station
NbS	Nature-Based Solution
NCEI	National Centers for Environmental Information
NER	National Ecosystem Restoration
NFHL	National Flood Hazard Layer
NFWF	National Fish and Wildlife Foundation
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NOEP	National Ocean Economics Program
NO_x	Nitrogen Oxides
NPP	Net Primary Productivity
NRDA	Natural Resource Damage Assessment
NRI	National Risk Index
NWI	National Wetland Inventory
NWR	National Wildlife Refuge
O&M	Operations and Maintenance
OSSF	On-Site Sewage Facilities
pH	potential of hydrogen
PM_{10}	Particulate Matter with Diameter of 10 Microns or Less
PSP	Public Sector Partnership
RCP	Representative Concentration Pathways
Report	Technical Report to the Texas Coastal Resiliency Master Plan
RESTORE Act	Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act
RMP	Risk Management Plan
RMS	Risk Management Solutions
RMW	Radius of Maximum Wind
RSLR	Relative Sea Level Rise
RV	Recreational Vehicle
SAV	Submerged Aquatic Vegetation
SLAMM	Sea Level Affecting Marshes Model
SLR	Sea Level Rise
SMS	Surface-water Modeling System
SRES	Special Report on Emissions Scenarios
SSO	Sanitary Sewer Overflow
SVI	Social Vulnerability Index
SWAN	Simulating Waves in the Nearshore Model
TAC	Technical Advisory Committee
TBD	To be determined
TCEQ	Texas Commission on Environmental Quality
TCRMP	Texas Coastal Resiliency Master Plan
TEV	Total Economic Value
TNC	The Nature Conservancy
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TSSWCB	Texas State Soil and Water Conservation Board

TTIG	Texas Trustee Implementation Group
TWDB	Texas Water Development Board
TWG	Technical Working Group
TxDOT	Texas Department of Transportation
UD	Unauthorized Discharge
USACE	U.S. Army Corps of Engineers
USD	U.S. Dollars
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UT	The University of Texas at Austin
VLM	Vertical Land Movement
VM	Virtual Machine
VOC	Volatile Organic Compounds
WCTS	Wastewater Collection and Transmission System
WMA	Wildlife Management Areas
WWTP	Wastewater Treatment Plants

1 Introduction

1.1 Purpose and Approach

The Texas General Land Office (GLO) has prepared an update to the 2019 Texas Coastal Resiliency Master Plan (TCRMP) to guide the restoration, enhancement, and protection of the state's natural resources. The updated 2023 TCRMP provides a framework to protect communities, infrastructure, and ecological assets from coastal hazards that include short-term, direct impacts (e.g., flooding, storm surge) and long-term, gradual impacts (e.g., erosion, habitat loss).

The TCRMP is a tool for selecting and implementing projects that produce measurable economic and ecological benefits to advance coastal resiliency, provide for meaningful stakeholder engagement, and work toward an adaptable planning process that accommodates changing coastal conditions as well as the evolving needs and preferences of the citizens of Texas.

The goal of this Technical Report (Report) is to support the content of the TCRMP by demonstrating the application of sound and objective science and engineering drawn from current data and information. This Report presents the methodology employed in TCRMP development, the outcome of coastal analysis tasks (e.g., project identification, project screening, Technical Advisory Committee [TAC] analysis, technical assessments), and the rationale for TCRMP outcomes and proposed Actions.

Development of the 2023 TCRMP started in September 2019 and continued through February 2023. The overall planning process is outlined in the TCRMP itself, as well as **Section 3** of this document. Beyond enhancing the planning framework, tasks for TCRMP development included soliciting updated information from project sponsors, screening 2019 Tier 1 projects for eligibility and progressing them to implementation, as well as the identification of new Tier 1 project candidates. Additionally, the 2023 planning process required direct involvement from the TAC through participation in five rounds of meetings in 2020, 2021, and 2022, and the completion of a vulnerability survey. This effort by the TAC provided the Planning Team with insight from technical experts, agencies, local stakeholders, and other organizations. The planning process also entailed the development of technical analyses and modeling, including data-driven action assessments, enhanced modeling, ecosystem services, and economic benefits. This resiliency plan is a continuation of the GLO's 2017 TCRMP and 2019 TCRMP and builds on the efforts made by the Planning Team at that time.

1.2 Report Content and Structure

This Report consists of 10 sections.

- **Section 1:** Provides an overview of the Report's purpose and goals, its relationship to the TCRMP and its technical approach, and introduces the various partners involved in the development effort of the 2023 TCRMP.
- **Section 2:** Presents an overview of the Texas coastal landscapes and environments.
- **Section 3:** Discusses the role of the TAC in the 2023 planning process.
- **Section 4:** Presents the methodology and planning principles used to guide the 2023 TCRMP technical assessments.
- **Section 5:** Describes the technical assessments undertaken to inform the development of the 2023 TCRMP.
- **Section 6:** Describes the modeling efforts used to inform the development of the 2023 TCRMP.
- **Section 7:** Presents a discussion of the socioeconomic state of the coast, including a characterization of the Texas coastal economy.
- **Section 8:** Introduces the project evaluation methodology used for project prioritization and inclusion.
- **Section 9:** Provides the final prioritized project list for the 2023 TCRMP, including Tier 1, Tier 2, and Tier 3 projects.
- **Section 10:** Presents a list of references used to develop the 2023 TCRMP.

1.3 Plan Partners

Development of all aspects of the TCRMP, including the planning framework and the technical work, was a collaborative effort among multiple partners that collectively represented a diverse array of disciplines. Presented below is an introduction to the various partners and their respective roles and responsibilities.

GLO

The GLO is authorized under state legislation to restore, enhance, and protect the state's coastal natural resources. To that end, the GLO led preparation of the TCRMP and, in so doing, provided a framework for projects that protect communities, infrastructure and ecological assets from coastal vulnerabilities, such as coastal flooding, storm surge, erosion, and habitat loss. The GLO managed its Planning Team (**Figure 1-1**), listed and described below, that was responsible for overseeing the direction and approach of TCRMP development activities, as well as those associated with this Technical Report.

Figure 1-1. The GLO's Planning Team

AECOM

AECOM was selected to provide planning and engineering support for technical elements of the TCRMP development process. AECOM's responsibilities included participating in planning activities, liaising with the GLO and other partners (e.g., TAC, Technical Working Group (TWG)), and leading various technical tasks. The latter included literature review of existing models and data, project identification and review, planning-level engineering, analysis of benefits and socio-economic impacts, project technical assessments, analysis of resiliency strategies, data driven actions, coastal modeling, database development, report production, and TCRMP preparation assistance.

AECOM's team included one Texas-based firm, Hollaway Environmental + Communication Services, Inc. (Hollaway) to assist with public outreach and environmental planning.

Harte Research Institute

The Harte Research Institute (HRI) for Gulf of Mexico Studies at Texas A&M University-Corpus Christi provided technical expertise on physical and ecological systems along the Texas coast. This entailed acquiring or developing datasets and reference materials to contribute to technical analyses and support TCRMP development. In addition, HRI performed a high-level vulnerability assessment for coastal changes due to relative sea level rise (RSLR), land loss, and storm surge impacts. HRI performed landcover change and storm scenario modeling for each of the planning regions and developed geohazard maps for strategic coastal communities.

Hollaway

Hollaway led outreach efforts that entailed coordinating with the TAC, local officials, and government entities. Hollaway also developed informational materials for the various end users of the TCRMP and produced the TCRMP and other materials for the Texas State Legislature, the TAC, and public consumption.

1.4 Stakeholder Engagement

The 2023 TCRMP planning process included several primary stakeholder engagement elements. Each of these elements was documented and supported through standalone efforts, but this section of the Report will serve as an overview of the entire process to show efficiencies and proper synchronization that was accomplished amongst the multiple elements. These major stakeholder engagement elements are:

- TAC
- Public Engagement
- Community Outreach
- Targeted Conceptual Project Stakeholder Engagement
- Ecosystem Services TWG
- San Antonio Bay Working Group
- Texas Legislature Outreach

Each of these elements are described below to identify who, when, and how these various engagement efforts occurred.

Technical Advisory Committee

The planning process involved engagement with a TAC, composed of coastal practitioners and technical experts in the four regions identified in the TCRMP. The TAC members are GLO-identified statewide and regional decision makers, technical experts, coastal practitioners, and coastal residents/users with insights into coastwide vulnerabilities, opportunities, and unmet needs. The TAC includes researchers in many fields of coastal science; local, state, and federal natural resource agency personnel; members of public, private, and nongovernmental organizations; and engineering and planning experts. The TAC provided input and feedback to the GLO and its partners on matters such as coastal vulnerabilities, identification and evaluation of candidate programs and projects, and draft TCRMP sections.

The TAC includes researchers, engineers, local and state officials, natural resource agency personnel, and members of public, private, and non-governmental organizations (**Figure 1-2**). The TAC has been the traditional stakeholder group engaged under TCRMP efforts, so the 2023 TCRMP continued to build off previous TAC engagement by engaging them in multiple sets of TAC meeting rounds throughout 2020, 2021, and 2022, the details of which can be found in **Section 3**.

Figure 1-2. TAC Entities

Public Engagement

The Planning Team initially planned to hold five (5) regional evening public meetings in late May or early June 2020 to invite the public to learn about the TCRMP and how it relates to their daily lives living on or near the Texas coast. This meeting was to follow afternoon TAC meetings described further in Section 3.1 of this document, with the goal primarily being to inform and increase public awareness to the GLO's efforts to improve Texas coastal resilience. However, the onset of the novel Coronavirus Disease 2019 (COVID-19) pandemic in early 2020 caused these meetings to be delayed to a later point in time until they could be held in person and not via a virtual platform.

Community Outreach Meetings

Historically, local government involvement has been lower than desired throughout the TCRMP planning process. To increase representation of this stakeholder group and emphasize the importance of their input in driving the project identification and TCRMP refinement process, AECOM and the GLO held two virtual community outreach meetings in April 2021 for community representatives along the Texas coast. These meetings provided an overview of the TCRMP planning process, emphasized the importance of local stakeholder involvement, described how the TCRMP can support projects and actions of the coastal communities, and provided success stories of TCRMP projects implemented through the planning process. The meetings included a presentation describing the goals of the TCRMP, a general timeline of the planning process, the framework that the TCRMP Planning Team operates under, the vulnerabilities facing the Texas coast, and modeling efforts used to identify areas along the coast that are most vulnerable, both economically and ecologically. A copy of the PowerPoint presented at these meetings is included in **Appendix A**.

Targeted Conceptual Project Stakeholder Engagement

The 2019 TCRMP Tier 1 list included numerous conceptual projects that, in most cases, did not garner the support needed for implementation post-publication. As is too often the case, conceptual projects struggle to acquire grant funds, which makes it challenging to progress projects toward design and implementation without a committed local sponsor or committed funds. In an effort to move all Tier 1 projects towards successful implementation, 31 of these projects were identified, local stakeholder groups engaged, and stakeholder action groups assembled from members of the TAC so that project implementation could be progressed and eventually handed-off to the proper lead stakeholder or project proponent. A full discussion of this effort is included in **Section 1.6** of this report.

Ecosystem Services Technical Working Group

The Ecosystem Services TWG is a stakeholder group that is mostly independent from other TCRMP stakeholder groups. However, some members overlap between the groups, so the TWG is considered part of the broader stakeholder engagement efforts. The TWG process is covered in more detail in the Ecosystem Services and Hazard Mitigation section of this document (see **Section 5.5**). The TWG is a critical part of the AECOM task of developing tools and information for leveraging ecosystem services as part of national and state level hazard mitigation efforts. As part of the effort, AECOM engaged a small TWG to support technical content development and provide validation of concepts developed under that task. The TWG consists of AECOM, GLO, and HRI team members, but also includes external members from select non-governmental organizations and federal agencies. Because members include stakeholders outside of the primary project team, an engagement strategy was important to the effort's success.

External stakeholders represented in the TWG include:

- The Nature Conservancy (TNC)
- National Wildlife Federation
- Texas Coastal Exchange
- U.S. Army Corps of Engineers (USACE)
- Federal Emergency Management Agency (FEMA)
- The Water Institute of the Gulf

- Greater Caribbean Energy & Environment Foundation

For more information about the methodology to further hazard mitigation for nature-based projects, developed in coordination with the TWG, see **Section 5.5**.

San Antonio Bay Working Group

This working group was formed as a result of the GLO's continued efforts to implement R2-17: San Antonio Bay Hydrologic Regional Watershed Plan, a conceptual project identified as a Tier 1 priority in the 2019 TCRMP. The San Antonio Bay Working Group began meeting in March of 2020, aiming to create a regional watershed plan to investigate the viability of alternative options for improved freshwater inflow, water quality, and stormwater management in the San Antonio Bay region. Through a series of quarterly meetings facilitated by the GLO and AECOM, the group detailed six primary goals for the continuation of the project. These include: (1) freshwater inflow management, (2) restoration of the Guadalupe Delta Estuary, (3) addressing gaps in monitoring data, (4) identifying habitat protection and restoration opportunities, (5) creation of a data collection hub for data collaboration within the group, and (6) engagement with upstream community members. The project life cycle will involve continual data gathering, technical analysis, and consultations with stakeholders to identify efforts that can be made to meet the group's goals. The last meeting held by the GLO and AECOM in February 2022 focused on the data hub that, if implemented, would allow the stakeholders to link publicly available data through a shared site. It was also decided during this meeting that any ongoing efforts stemming from the working group would be led by the organizations within the group, which include representatives from:

- Freese & Nichols,
- Guadalupe Blanco River Authority,
- Port of West Calhoun,
- San Antonio Bay Partnership,
- San Antonio River Authority,
- Texas Commission on Environmental Quality (TCEQ),
- Texas State Soil and Water Conservation Board (TSSWCB),
- Texas Parks and Wildlife Department (TPWD), and
- Texas Water Development Board (TWDB).

Texas Legislature Outreach

As a part of the outreach strategy working toward the 2023 TCRMP, the Planning Team was charged with publishing a legislative update that could be presented during the 2021 Texas Legislative Session. The document focused on reporting to all Texas legislators the progress the GLO made between the publication of the 2019 TCRMP and the legislative session, and how recent funding acquired by the GLO was put towards a multitude of resiliency projects on the Texas coast. Additionally, the update served to inform coastal legislators of the work being conducted in their own districts, and to introduce the session to the new initiatives that would take place under the 2023 TCRMP. A full discussion of the legislative update is included in **Section 1.5**.

1.5 2021 Legislative Update

Excerpts from the 2021 TCRMP Legislative Update are included in subsequent subsections. The complete legislative update document is included as **Appendix B**.

1.5.1 Funding Update

The 2019 TCRMP, completed in March 2019, identified 123 Tier 1 coastal resiliency projects recommended to protect the coast from current and future coastal hazards, and alleviate vulnerabilities. The total cost of the projects recommended in the 2019 TCRMP was estimated to be $5.4 billion. As of December 2020, of the 123 recommended projects, 77 projects were underway, and 23 of these were fully funded. To assist representatives from the Texas State Legislature with understanding the coastal resilience funding needs in their respective districts, **Table 1-1** and **Table 1-2**, below, were provided to show the total cost of Tier 1 projects in each district, along with the percent of projects funded.

Funding for coastal resiliency projects in Texas has been increasing in recent years (see **Figure 1-3**), spurred in part by the increase in hurricanes and tropical storm activity in the Gulf of Mexico. This recent increase in funding sources has provided an opportunity for the GLO to leverage the work of the TCRMP to prioritize coastal projects using federal and local funding more effectively.

- GLO Coastal Programs – There are several federal and state grant funding programs that the GLO administers supporting coastal projects in Texas. These include the Coastal Erosion Planning and Response Act (CEPRA), the Gulf of Mexico Energy Security Act (GOMESA), which pays out royalties from oil and gas exploration in the Gulf of Mexico, and the Coastal Management Program (CMP), funded by the National Oceanic and Atmospheric Administration (NOAA), among others.
- Hotel Occupancy Tax (HOT) – The HOT House Bill No. 6 was passed during the 2019 Texas Legislative Session and included dedicating 2% of HOT revenues in coastal counties to the GLO's CEPRA program to boost the state's capabilities to address coastal erosion and ensure money spent on the Texas coast stays on the Texas coast.
- Integration with Community Development Block Grant-Mitigation (CDBG-MIT) – The GLO is administering nearly $4.3 billion in CDBG-MIT grants through its Community Development and Revitalization (CDR) Division. Of these funds, the Coastal Resiliency Program is set to receive $100 million for coastal resiliency projects. CDR is identifying eligible Tier 1 projects (**Figure 1-4**) from the TCRMP and is working alongside stakeholders to progress these projects.
- Coastal Texas Study – Led by the USACE, this is a multi-year study to examine ways to reduce risk faced by coastal communities and industries to coastal storms. The GLO is partnering with the Army Corps as the non-federal sponsor of this study, sharing 50% of study costs with the federal government.
- RESTORE Act - Funds collected from civil and criminal penalties from the Deepwater Horizon oil spill are administered through three funding streams: National Fish and Wildlife Foundation's (NFWF) Gulf Environmental Benefit Fund, Natural Resource Damage Assessment (NRDA), and RESTORE. The 2019 TCRMP has been referenced as a representation of regional priorities for the allocation of funding under the RESTORE Act.

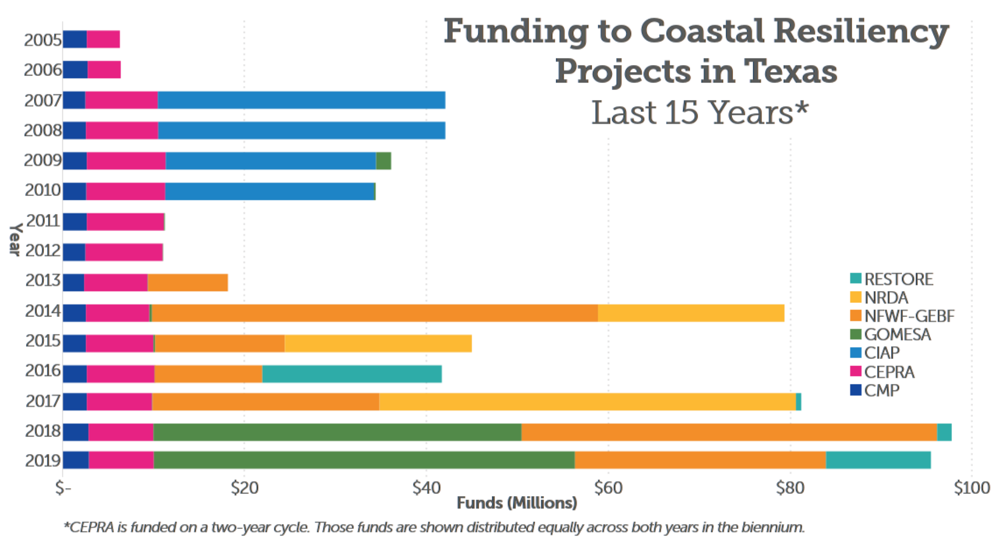


Figure 1-3. Funding to Coastal Resiliency Projects in Texas

Legislative District Overview

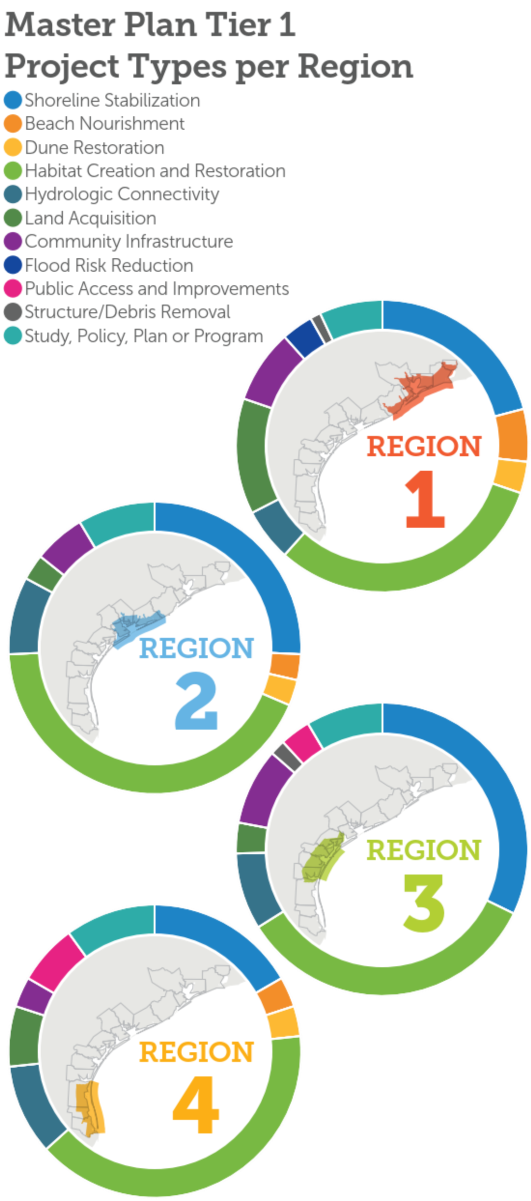


Figure 1-4. Tier 1 Project Types per Region

Table 1-1. House District Summary

Region	House District	Number of Projects*	Cost of Projects	Percent Funded
1	21	14	$2.8 B	5%
	22	3	$883 M	0%
	23	19	$513 M	26%
	24	4	$71.5m	26%
1, 2	25	22	$1.1 B	3%
2, 3	30	18	$89.1 M	56%
3, 4	31	3	$29.2 M	17%
3	32	8	$24.1 M	44%
	34	4	$10.9 M	69%
4	37	11	$139 M	15%
3	43	8	$17.6 M	65%
1	128	1	$10 M	0%
	129	2	$45.3 M	78%
1 - 4	Statewide	15	$26.4 M	35%

Table 1-2. Senate District Summary

Region	Senate District	Number of Projects*	Cost of Projects	Percent Funded
1	3	5	$2.4 B	0%
	4	24	$1.5 B	5%
	6	1	$10 M	0%
	11	18	$380 M	22%
1, 2	17	4	$767 M	0%
2, 3	18	34	$209 M	24%
3	20	7	$17.8 M	42%
	21	5	$12.8 M	68%
3, 4	27	16	$148 M	16%
1 - 4	Statewide	15	$26.4 M	35%

Ongoing Projects

The GLO's Coastal Division has been working with project stakeholders to move projects from the 2019 TCRMP into action. Of the 123 Tier 1 projects identified in the TCRMP, 77 are currently ongoing and 21 have progressed since the 2019 TCRMP (**Figure 1-5**). In addition to the Tier 1 TCRMP projects, several major coastal infrastructure projects are proposed for Texas in the coming years.

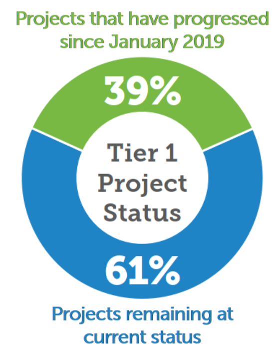


Figure 1-5. Project Progression

Leveraging Funds

By paying part of the cost of Texas coastal resiliency projects, the State has been able to leverage other federal funds that are not administered by the GLO's Coastal Program, as well as local match funds from partnering communities. While there is still considerable funding needed to complete all the Tier 1 projects (**Figure 1-6**), the TCRMP's locally driven process has seen considerable success in bringing additional funding for projects to better protect the Texas coastal area (**Figure 1-7**).

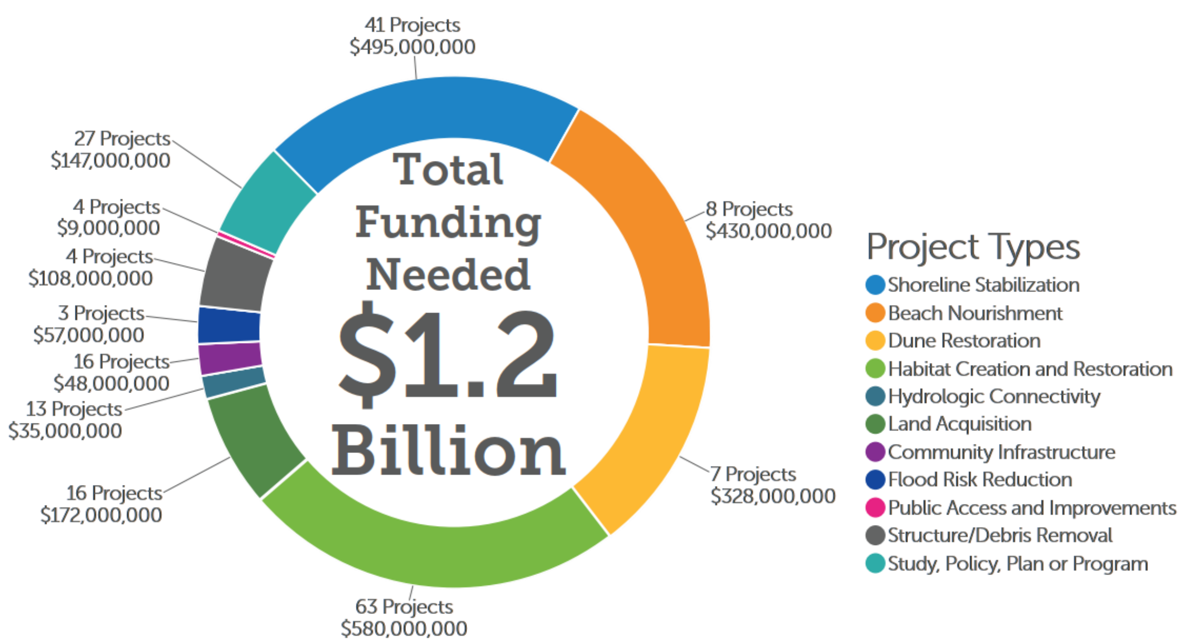


Figure 1-6. TCRMP Funding Needed as of December 2020

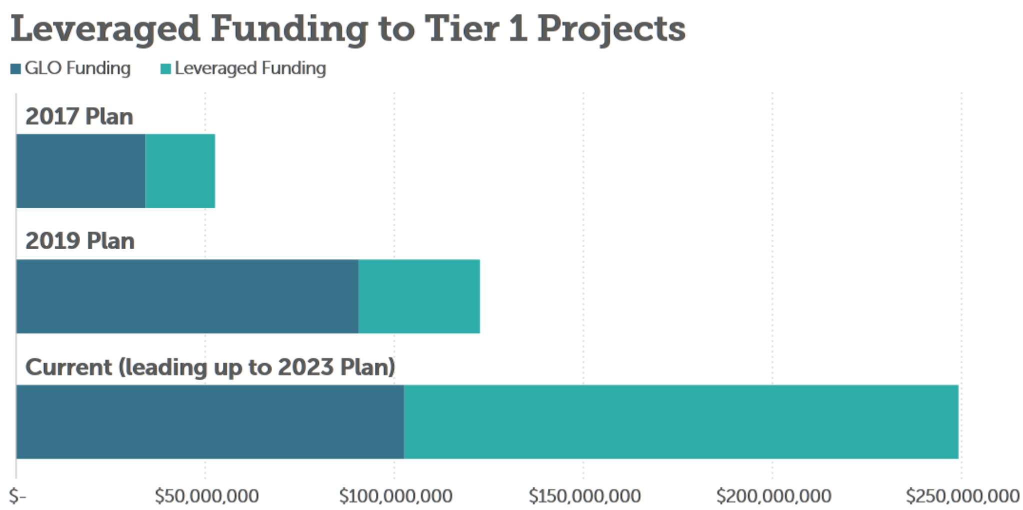


Figure 1-7. Leveraged Funding to Tier 1 Projects (as of December 2020)

1.5.2 Improvements for the 2023 TCRMP

Although this information is covered throughout the Report, a short summary of the information that was presented to the Texas Legislature regarding the 2023 TCRMP is included below. This was an important section of the legislative update because it outlined the importance of continuing to fund the GLO's coastal resiliency efforts.

New Data & Modeling

Looking toward the 2023 TCRMP, the GLO is working to improve the coastal modeling suite by refining input data and producing new map products to share with communities.

- **Improved Model Inputs:** Updates to and development of geospatial data will add to our current knowledge of the state of the Texas coast, including its topography, geo-environments, infrastructure, human use, and socio-economic settings. This will further enhance our understanding of how to increase resiliency through the TCRMP.
- **Additional Storm and Sea Level Rise (SLR) Scenarios:** GLO is expanding the capabilities of future change modeling using ensembles of synthetic storms and additional SLR scenarios developed by NOAA to better gauge the human and natural vulnerability of the coastal zone.
- **Geohazards Mapping:** New maps will present geospatial data showing current condition, past changes, and predicted future changes in the coupled natural-human system of the Texas coastal plain. The results will show how communities are embedded in the coastal landscape to better understand which communities and environments are most vulnerable to changes along the Texas coast. These maps will help identify which areas are most in need of resiliency enhancements.

Enhancements to the Planning Process

- **Sediment Volume Calculations:** The GLO is investigating the long-term sediment needs along the Texas Gulf shoreline based on historic erosion trends and future projected RSLR. This will help the GLO in scheduling renourishment activities and in regional sediment management planning efforts.
- **Resilient Project Design Guides:** The GLO is developing a set of Design Guides for stakeholders, project managers, and city planners along the Texas coast. The guides will help end users understand how to design more resilient projects in the coastal landscape.

- **Ecosystem Services:** The GLO created an Ecosystem Services TWG to use the latest academic data as it is developed to calculate the benefits of ecosystem services from coastal resiliency projects to capture cost-benefits more accurately.

1.6 Targeted Conceptual Project Stakeholder Engagement

One of AECOM's planning tasks for the 2023 TCRMP effort included helping the GLO implement more Tier 1 projects identified in the 2019 TCRMP. One of the most effective ideas to accomplish this was to promote promising (conceptual) projects that were not progressing for a variety of reasons, but which were believed to be primarily due to a lack of a local sponsor or sponsors investing in the project. The AECOM team worked to engage local sponsors, stakeholder, or project owners to help inform them and give them tools to support these projects through the next stages of development. To accomplish this, the AECOM team developed a list of 31 conceptual Tier 1 projects from the 2019 TCRMP that were flagged as needing additional assistance based on internal reviews. Status updates for each of these conceptual projects are included in **Table 1-3** through **Table 1-7**.

Table 1-3. Coastwide Conceptual Projects Status Updates

2019 TCRMP Project Identification (ID)	Project Name	Description
R0-3	Coastwide Texas Seagrass Restoration ($2M)	Project efforts focused on the collection of supporting information and did not need additional support from the Conceptual Project Process.
R0-6	Evacuation Route Study for Coastal Resilience ($250k)	This project did not need additional help from the Conceptual Project Process; additional coordination opportunities between the Texas Department of Transportation (TxDOT) and the GLO were identified.
R0-11	Subsidence Study and Monitoring ($500K)	This program received funding and momentum without help from the Conceptual Project Process.
R0-12	Longshore Transport Modeling ($1M)	This is a GLO sponsored program that is being implemented through the CEPRA program. No further action was taken.
R0-14	Development of Optimal Coastwide Bathymetric and Topographic Models ($250k)	This project received funding and momentum without help from the Conceptual Project Process.
R0-15	National Wetland Inventory (NWI) Updates ($50k)	This project is now ongoing.

Table 1-4. Region 1 Conceptual Projects Status Updates

2019 TCRMP Project ID	Project Name	Description
R1-3	Old River Cove Restoration ($15.2M)	Stakeholder submitted application for a Texas Trustee Implementation Group (TTIG) grant.
R1-5	Sabine Neches Waterway Dredge Placement Island Habitat Restoration ($3.7M)	This project received funding and momentum without help from the Conceptual Project Process.
R1-8	Double Bayou Habitat Preservation ($5M)	Project received support under the Conceptual Project Process.
R1-9	Chambers County Wetland Restoration ($25M)	This project received funding and momentum without help from the Conceptual Project Process.

2019 TCRMP Project ID	Project Name	Description
R1-13	O'Quinn IH-45 Causeway Intertidal Marsh Restoration ($4.3M)	This project received funding and momentum without help from the Conceptual Project Process.
R1-18	East Bay Living Shorelines and Wetland Restoration ($8.9M)	This project received funding and momentum without help from the Conceptual Project Process.
R1-33	Galveston Bay Rookery Island Restoration ($37.5M)	This project received funding and momentum without help from the Conceptual Project Process.
R1-45	Galveston Bay Oyster Reef Planning and Restoration	This project received funding and momentum without help from the Conceptual Project Process.
R1-46	Texas City Levee Erosion Control and Marsh and Oyster Reef Restoration ($2.8M)	This project received funding and momentum without help from the Conceptual Project Process.

Table 1-5. Region 2 Conceptual Projects Status Updates

2019 TCRMP Project ID	Project Name	Description
R2-3	Welder Flats Wildlife Management Area (WMA) ($1.6M)	This project received funding and momentum without help from the Conceptual Project Process.
R2-5	Redfish Lake Living Shoreline ($4.7M)	This project received funding and momentum without help from the Conceptual Project Process.
R2-12	Coon Island Restoration ($5.5M)	This project received funding and momentum without help from the Conceptual Project Process.
R2-17	San Antonio Bay Hydrologic Regional Watershed Plan ($250k)	Project received support under the Conceptual Project Process.
R2-19	Brazos River and San Bernard River Restoration Strategy and Management Plan	Stakeholders submitted a CMP application for funding their sediment flow study for the Brazos River and San Bernard River.

Table 1-6. Region 3 Conceptual Projects Status Updates

2019 TCRMP Project ID	Project Name	Description
R3-4	Portland Living Shoreline ($3M)	This project received funding and momentum without help from the Conceptual Project Process.
R3-6	Lamar Beach Road Protection ($3.5M)	This project received funding and momentum without help from the Conceptual Project Process.
R3-8	Newcomb's Point Shoreline Stabilization ($2.7M)	The stakeholders have moved forward with TTIG and Community Development Block Grant (CDBG) applications for funding.
R3-10	Long Reef and Deadman Island Shoreline Stabilization and Habitat Protection ($3.4M)	Stakeholders have applied for CMP funding for the restoration and stabilization of these islands.
R3-12	Tern Island and Triangle Tree Island Rookery Habitat Protection ($3.6M)	This project received funding and momentum without help from the Conceptual Project Process.

2019 TCRMP Project ID	Project Name	Description
R3-17	Guadalupe Delta Estuary Restoration ($3.9M)	Project received support under the Conceptual Project Process.
R3-22	Restore Barrier Island Bayside Wetlands on Mustang Island ($8.4M)	Stakeholders have submitted two TTIG applications.

Table 1-7. Region 4 Conceptual Projects Status Updates

2019 TCRMP Project ID	Project Name	Description
R4-6	Restore Laguna Madre Rookery Islands ($12.1M)	This project is ongoing.
R4-7	Mansfield Rookery Island Shoreline Protection ($3.8M)	This project received funding and momentum without help from the Conceptual Project Process.
R4-8	Bahia Grande Living Shoreline ($5.4M)	Project received support under the Conceptual Project Process.
R4-13	Laguna Madre RSLR Monitoring and Adaptive Management ($500k)	This project received funding and momentum without help from the Conceptual Project Process.

2 Coastal Environments

This overview is drawn from the 2017 TCRMP and 2019 TCRMP, and describes features of the coastal landscape, highlighting the dynamic interactions that take place between the Gulf of Mexico and Texas bays and barrier islands. These features form the foundation for coastal ecosystems that provide a range of protective measures and supply various economic benefits to coastal communities, the state, and the nation. All of this underscores the importance of safeguarding what Texas's citizens value.

2.1 The Coastal Landscape

The Texas coast stretches 350 miles from South Padre Island to the Louisiana border, extending through a diverse array of bays and estuaries, barrier islands and peninsulas.

2.1.1 Bays and Estuaries

The Texas coastal region is characterized by eight major bay systems: Sabine Lake, Galveston Bay, Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay, Upper Laguna Madre, and Lower Laguna Madre (**Figure 2-1**). The bay systems are bodies of water that are partially enclosed by land and are separated from the Gulf of Mexico by barrier islands and peninsulas, except for openings (passes and inlets) that allow for water to flow from the Gulf of Mexico into bays.

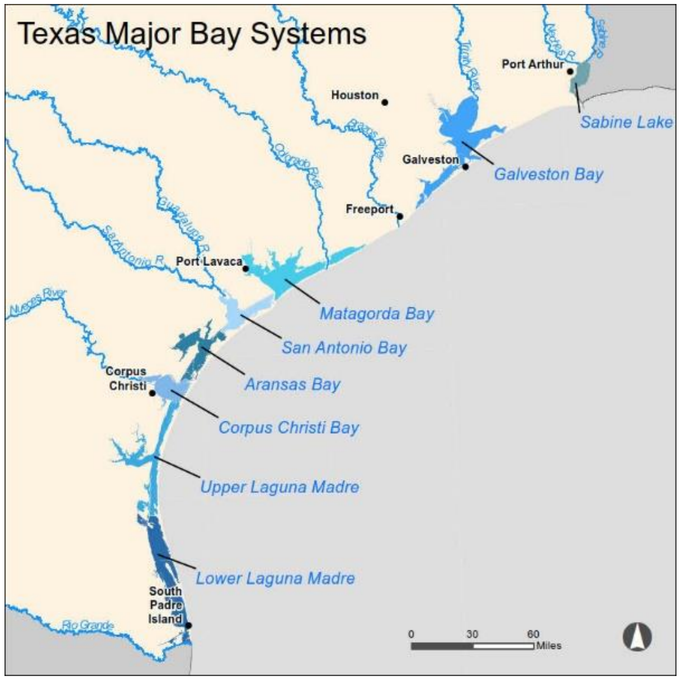


Figure 2-1. Texas Major Bay Systems

In Texas, many bays are also estuaries, or bodies of water where freshwater from rivers and streams empties and mixes with saltwater from the Gulf of Mexico. The major estuaries in Texas are named for the primary rivers emptying into them. The Trinity-San Jacinto Estuary (Galveston Bay) is the largest estuary in Texas. Estuaries form a transition zone between river environments and marine environments, and this mixture of freshwater and saltwater is known as brackish water. In estuaries, freshwater does not flow directly into the open Gulf, but is blocked by bordering mainland, peninsulas, barrier islands or fringing wetlands. Estuaries are affected by both marine (tides, waves, and saltwater) and riverine (inflows of freshwater and sediments) influences. These fresh and saltwater influxes provide high levels of nutrients in the water column and sediments, which supports diverse wetland habitats for fish and wildlife that have adapted to brackish water.

The land area where sediment is deposited at the mouth of a river when it empties into a bay or the Gulf of Mexico is called a delta. A delta grows as sediment from the river accumulates, causing the river to break off into smaller channels, creating wetland habitat. Upstream disruptions to the river can impact delta formation.

These bay systems and the environments they support are influenced by regional weather patterns. About twice as much rain falls in the Sabine Lake region than along the Texas-Mexico border. Texas bays and estuaries follow a similar gradient in terms of salinity, which affects the types of coastal environments along the coast. In the Upper Coast, estuaries have lower salinity levels from increased precipitation that allow smooth cordgrass, known as *Spartina alterniflora,* to thrive in the wetlands. Towards the south, wetlands transition from more freshwater to higher salinity environments and become sparser due to the arid climate. In the southernmost part of the Texas coast, in the high salinity environment of the Laguna Madre, sparsely vegetated tidal flats are more common.

Fisheries

Bays and estuaries also provide diverse Texas Gulf coast habitat (see **Sections 2.2.1** through **2.2.4** for more detailed habitat information) that supports a variety of important commercial and recreational fisheries. Commercially important species include oysters, shrimp, crabs, menhaden, red snapper, king mackerel, and finfish. Recreationally important species include spotted sea trout, red drum, groupers, snappers, and other coastal pelagic species. Many of these species utilize bay systems during various stages of their life cycle, taking advantage of the protected estuarine habitats such as wetlands and seagrasses as nursery habitats to raise their young. Approximately 95 percent of the Gulf's recreationally and commercially important fish (e.g., red drum and spotted seatrout), shellfish (e.g., crab and shrimp) and other marine species rely on estuaries during some part of their life cycle. Juvenile fish, crab and shrimp depend upon estuaries that have adequate freshwater inflows to balance salinity. This critical nursery habitat for most Gulf commercial and recreational finfish and shellfish species provides food and shelter as the species mature, before migrating out into the open waters of the Gulf. Oysters, found only in estuaries, comprise the basis for a thriving commercial harvesting industry and are dependent upon the estuary's brackish waters. Fisheries are a vital natural resource to the Texas economy, particularly in the coastal region, as they provide jobs, food, and recreational opportunities.

2.1.2 Barrier Islands and Peninsulas

Along most of the Texas coast, there is a near-continuous chain of peninsulas and barrier islands that divides the bays and estuaries from the Gulf of Mexico. Barrier islands are long, relatively narrow offshore deposits of sand and sediment that run parallel to the mainland along the coast, whereas peninsulas also run parallel to the mainland, but are still connected to the mainland. Shallow bays or lagoons divide barrier islands and peninsulas from the mainland. Barrier islands and peninsulas are predominately characterized by a Gulf-facing beach and dune system that gradually slopes down to the interior bayside shoreline, supporting various habitats such as wetlands and tidal flats. The Texas Gulf shoreline has two peninsulas and six barrier islands (**Figure 2-2**), including Padre Island, the longest undeveloped barrier island in the world.

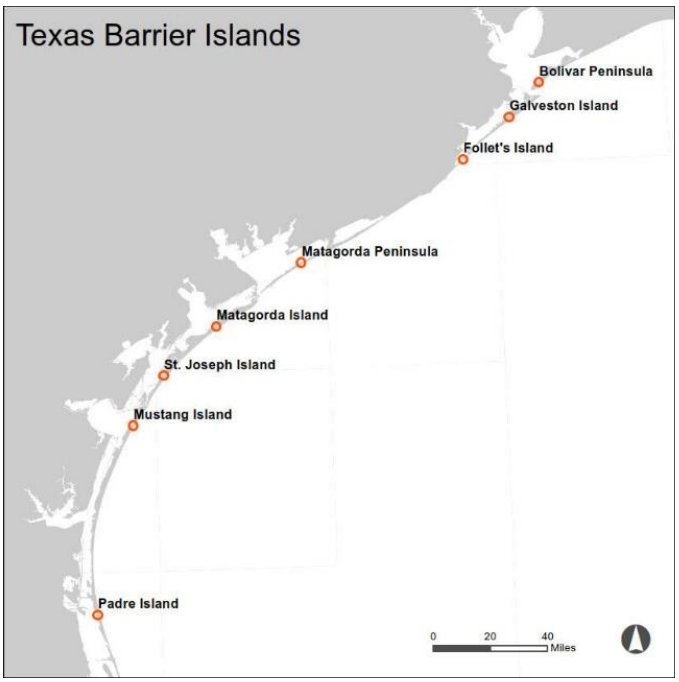


Figure 2-2. Barrier Islands and Peninsulas

By nature, barrier islands are not static landforms; they are dynamic systems, constantly shifting and migrating as sand is moved by waves, tides, currents and changing sea levels. The barrier islands and peninsulas are segmented by numerous natural and man-made passes, or inlets, that allow vessel access between the bays and Gulf, and water circulation of sediment and nutrients vital for bay ecosystem health. Tides and currents carry sediment from the bays – delivered by rivers and streams – into the Gulf where they can be deposited onto Gulf-facing beaches, and from the Gulf to bayside beaches. This provides natural beach nourishment and shoreline protection from erosive wave action. Water movement through an inlet can also deposit sand at both ends of the inlet's mouth, forming tidal deltas. Storm surge enters bays through these inlets and washes over barrier islands, and at weak points, causes breaching and forms new channels from erosion. As storm surge washes over the island, it carries sand from the beach and dunes, depositing it into the bay. This process, called "rolling over," is the method by which a barrier island migrates landward. After a storm, built up water in the bay causes shoreline flooding as it slowly funnels back into the Gulf through inlets.

2.2 Coastal Environments and Ecosystem Services

The coastal landscape provides the foundation for a range of coastal environments, including beaches and dunes, wetlands, coastal uplands, oyster reefs and rookery islands. The primary natural coastal environments found along the Texas Gulf coast are shown in **Figure 2-3**. The economic benefits offered by the natural environments along the coast are diverse and include both traditional and non-traditional factors. Traditional economic factors include the dollars generated for the state through profitable activities such as fishing, ecotourism, and recreation. Non-traditional economic factors, known as ecosystem services, are the benefits provided by the environment that support, sustain and enrich human life. For example, some ecosystem services provided by a wetland include habitat, water purification, erosion control and flood and storm protection. The Multi-hazard Mitigation Council estimates that every dollar spent on natural hazard mitigation saves an average of $4 in future benefits.

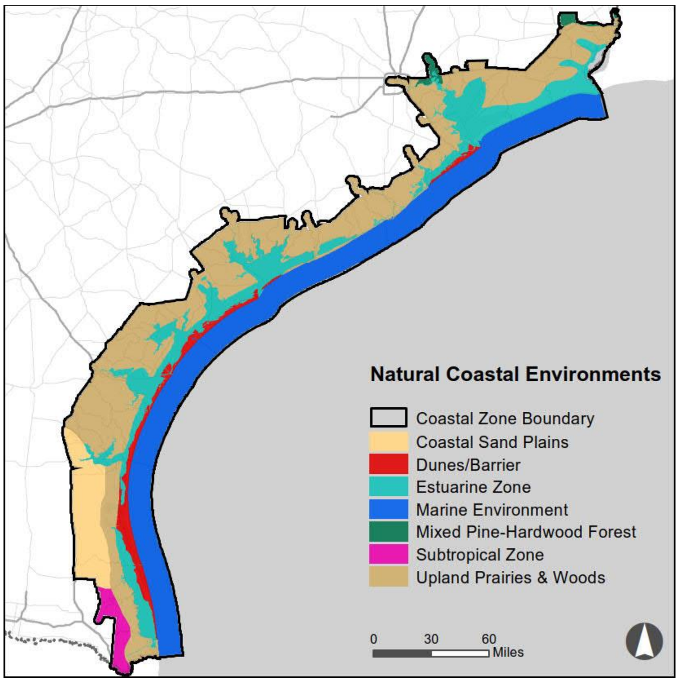


Figure 2-3. Natural Environments Along the Texas Coast

Texas's estuaries may vary in size, ecological characteristics and the amount of precipitation and freshwater inflows received, yet cumulatively they support unique and productive habitat for numerous fish and wildlife species due the high levels of nutrients provided by the brackish waters. The abundant fish and wildlife populations supported by the sheltered waters of estuaries are important to the coastal ecosystem and state economy. Approximately 95 percent of the Gulf's recreationally and commercially important fish (e.g., red drum and spotted seatrout), shellfish (e.g., crab and shrimp) and other marine species rely on estuaries during some part of their life cycle. Juvenile fish, crab and shrimp depend upon estuaries that have adequate freshwater inflows to balance salinity. This critical nursery habitat for most Gulf commercial and recreational finfish and shellfish species provides food and shelter as the species mature, before migrating out into the open waters of the Gulf. Oysters, found only in estuaries, comprise the basis for a thriving commercial harvesting industry and are dependent upon the estuary's brackish waters. Estuaries provide habitat for birds, fish, amphibians, insects, and other wildlife to live, forage, nest and reproduce. Because they are so biologically productive, resident, and migratory birds, by the tens of thousands, rest, and feed in estuarine marshes.

Estuaries provide many ecosystem services, such as water filtration and nutrient regulation and cycling, and contribute to storm surge protection and shoreline stabilization by trapping sediments and rebuilding fringing wetlands. Rivers carry nutrients from upland watershed areas into estuaries, contributing to their high productivity, in addition to sediment and pollutants, which can decrease their productivity. Habitats associated with estuaries, such as freshwater and saltwater wetlands, mud and sand flats, oyster reefs, river deltas and seagrass beds act like enormous filters, helping to remove sediments and pollutants to improve water quality. Improved estuarine water quality also contributes to healthy ocean waters and marine life as the water exchanges from the bay to Gulf. Estuaries and their surrounding wetlands stabilize bay shorelines against erosion and act as natural buffers to protect coastal areas, inland habitats, communities, and infrastructure from flooding and storm surge.

Coastal communities and economies are built around estuaries because they provide commercial and recreational opportunities and support natural resource-based jobs and businesses. Estuaries provide recreational areas to boat, swim, fish, and bird and wildlife watching. The protected waters of estuaries are also important areas for ports and harbors and benefit waterborne transportation and commerce. The economic prosperity of many coastal communities is linked to the health of their respective estuary and the many services and resources provided.

2.2.1 Beaches and Dunes

The Gulf-facing beaches and dunes along Texas barrier islands are highly dynamic systems that provide a first line of defense against the destructive impacts of hurricanes and tropical storms on inland development and sensitive coastal environments. Texas beaches and dunes also provide valuable tourism and recreation opportunities to Texas residents and visitors and are a strong driver of economic activity throughout the coastal zone. Beaches and dunes provide many economic and social benefits, including flood protection, erosion control, water catchment and purification, habitat and foraging for wildlife, tourism and recreation, and aesthetic views.

Gulf beaches and their dune systems provide natural protection for upland areas and landward structures during storms. Beaches also supply foraging and nesting habitat for wildlife, including threatened and endangered species, such as piping plovers and sea turtles. In addition, migratory birds use sand dunes and barrier islands as landing or resting areas after flying thousands of miles over the Gulf of Mexico.

Along the barrier island Gulf shoreline, the interface of sand and sea produces sloping sand dunes and beaches of varying widths. The beach and dune systems are integral to the dynamic beach environment and is constantly in flux due to sand exchange from wind, tides, currents, erosion, and storm impacts. Longshore currents in the Gulf of Mexico play an important role in the configuration of Texas's Gulf-facing beaches and dunes. Along the Upper Coast, one longshore current runs from north to south, while another longshore current runs from south to north, carrying sediment with them. These two currents meet at a convergence zone along the central Texas coast on Padre Island, near the Upper Laguna Madre. At this convergence zone, the beach is wide, and the dune ridge is high and continuous, whereas the beaches in the northern and southern portions of the state are narrower, with less continuous dune ridges. Sand is continually moved along the beach shoreline by longshore currents, and from the beach into the dunes by the wind (see **Figure 2-4**). During typical wave conditions, sand is transported by waves to and from offshore sand bars and the surf zone to the beach, contributing to the formation of the beaches.

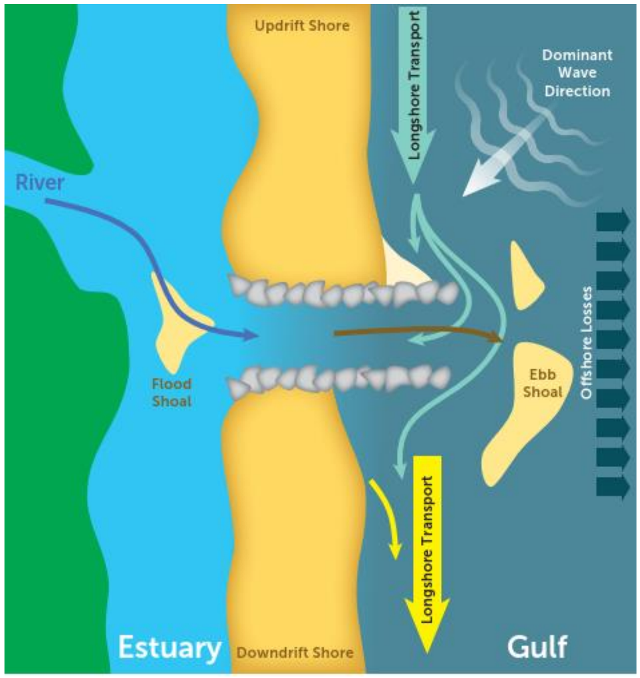


Figure 2-4. The Natural Movement of Sand Along the Gulf Shoreline

Dunes develop when wind blows sand inland where it is trapped by dune vegetation, thereby gradually building up the size of the dune. Wind and rain from seasonal storms can remove sand from the dunes and deposit it back onto the beach. During more severe storms, large amounts of beach and dune sand can be moved out into nearshore water. Storm surges and wind associated with tropical storms and hurricanes, however, can completely wash over barrier islands or completely breach the dune, known as a blowout, flattening dunes and depositing the sand behind the dunes and in the bays. In these cases, depending on sediment supply and other factors, recovery can take years to decades, leaving inland infrastructure and habitats more vulnerable to subsequent storms.

Sand dunes provide a resilient natural barrier to the destructive forces of wind and waves and are therefore the least costly defense against storm-surge flooding and beach erosion. Sand dunes help prevent loss of life and property by absorbing the impact of storm surge and high waves and by stopping or delaying intrusion of water inland. Dune areas are essential to the protection of infrastructure and roads from nuisance flooding, erosion, storm surge, and high wind and waves.

Vegetated dunes are more effective at trapping wind-blown sand to replenish eroded beaches after storms. The health of dune grasses, shrubs and other stabilizing plant life is critical to the balance of this system. Loss of dune vegetation makes the dunes and inland areas more susceptible to wind and water erosion, especially during storms, decreasing the ability of sand dunes to properly protect habitats and ecosystems behind the volatile beach environment. In many areas, beaches have greatly decreased in width over the past several decades, resulting in extremely narrow, and in some cases, a complete loss of the beach and dune system.

Characterizing these benefits through the concept of ecosystem services, Texas beaches and dunes can be seen as providing multiple types of ecosystem services that include: (1) the aforementioned supporting services for wildlife habitats, (2) regulating services through storm protection and erosion control, and (3) cultural services including tourism and recreation opportunities to residents and visitors which are strong drivers of economic activity throughout the Texas coastal zone. In addition to these economic and social benefits, beaches and dunes provide other benefits including water catchment and purification, habitat and foraging for wildlife species, and aesthetic views.

Sea Turtles

Several species of endangered sea turtles, including the loggerhead sea turtle, green sea turtle, hawksbill sea turtle, Kemp's Ridley sea turtle, and the leatherback sea turtle, are known to utilize the Texas Gulf coast. In particular, many individuals prefer the remote and expansive beaches along the Padre Island National Seashore. Although turtles are typically only seen on shore during nesting activities, they can also be found within the bay areas, feeding on seagrasses and algae, and in offshore areas, feeding on jellyfish. Sea turtle populations have been in decline over the last century, due to historic overharvesting of the species, incidental capture in fishing gear, and loss of nesting habitats coupled with the relatively slow maturation of the species. However, in 2022, a Kemp's Ridley nest – one of the most endangered of the sea turtles – was found on Babe's Beach in Galveston, a renourished beach that has historically not been a preferred nesting site for turtles. Although unintentional, this success highlights the importance of maintaining and restoring coastal habitats to support vulnerable species.

2.2.2 Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) includes rooted aquatic plants, such as seagrass, and a variety of macroalgae species. These habitats can be found in both freshwater and saltwater, but can be particularly important in estuarine environments, as SAV is a preferred habitat for some species of fish, small invertebrates, and other aquatic organisms in various stages of life. The canopy created by SAV provides fish, both commercial and recreational species, with protection from predators and hosts a variety of small invertebrates and other prey that serve as their food source. Burrowing organisms, such as clams and worms, live in the sediment among the roots, while fish and crabs hide among the shoots and leaves, and ducks graze from above. An estimated 40,000 fish and 50 million small invertebrates can be found in a single acre of SAV.

SAV is a crucial part of the Texas coastal ecosystem. Presently, this habitat is primarily located along the mid-to-lower Texas coast, where the water is warmer, more saline, and contains less suspended sediment; however, the historical distribution of seagrass included areas around Galveston Bay. Much of the seagrass that once flourished along the upper Texas coast has been lost through both natural and anthropogenic causes and very few remnant populations remain. SAV is a valuable habitat along the Texas coast, due to its ability to inhibit the wave action that erodes shorelines. The dense plant canopy of stems and leaves can work to reduce water currents, allowing more sediment to settle in the system which is then trapped by the extensive root system. Additionally, seagrasses are an important food source for many species of migratory waterfowl that utilize the Texas Coastal Bend as part of the American Central flyaway.

The benefits and ecosystem services that SAV habitats provide include: (1) provisioning services as an important cultural and economic resource for coastal populations, and contribute to human welfare by providing fishing and bait collection grounds, substrate for seaweed cultivation, medicinal resources, and food, (2) regulating services from carbon sequestration and shoreline stabilization capabilities with extensive root systems to reduce water currents and help trap sediment, (3) supporting services through sustaining biodiversity in coastal ecosystems, hosting countless species of fish, waterfowl, and sea turtles, and aiding in coastal nutrient cycling processes, and (4) cultural services with the extensive recreational activities that SAV systems can provide (e.g., snorkeling, SCUBA diving, fishing, and non-motorized boating).

Due to their high productivity, SAV and other aquatic plants have the capacity to capture and store carbon dioxide (CO_2) in the rich aquatic soils in which they reside. This "blue carbon" (carbon sequestration occurring primarily underwater) is considered by scientists to be a key factor in providing a solution to the increasing CO_2 levels in the atmosphere. With growing interest in harnessing the power of the natural biological environment to capture excess carbon, protecting aquatic vegetation is a high priority.

2.2.3 Wetlands

Wetlands are naturally occurring or restored lands, including marsh and tidal flats, that are transitional between terrestrial and aquatic systems and, therefore, are periodically saturated or flooded with shallow water. Wetlands are characterized by herbaceous (non-woody) plants that can withstand temporary inundation and are adapted to wet soil conditions.

In the TCRMP, coastal wetlands are typically classified as either estuarine (intertidal) wetlands, including mangroves, or freshwater wetlands.

Estuarine Wetlands

Estuarine wetlands are found along the bay shorelines within an estuary and directly inland of beaches, dunes, and barrier islands. These estuarine ecosystems support unique plant and animal communities that have adapted to brackish water, requiring tidal and freshwater exchange. Salt marshes are the most prevalent types of estuarine wetlands and are characterized by salt-tolerant plants such as smooth cordgrass, glasswort, and saltgrass. Of wetland ecosystems, salt marsh has one of the highest rates of primary productivity due to the influx of nutrients from surface and tidal waters.

Estuarine wetlands provide spawning grounds, nurseries, shelter and food for finfish, shellfish, birds, and other wildlife. The abundance and health of adult stocks of commercially harvested shrimp, blue crabs, oysters, and other species are directly related to the quality and quantity of estuarine wetlands. This is especially true in the Gulf, where 97 percent (by weight) of the fish and shellfish caught by fishermen are dependent on wetlands at some point in their life cycle. Migratory birds use estuarine wetlands as foraging and hunting areas. A frequent pressure to this ecosystem is reduced freshwater inflows, which can result in an increase in salinity, sometimes beyond what estuarine species can tolerate.

Freshwater Wetlands

Freshwater wetlands are areas that receive periodic or permanent influxes of freshwater to support plant life, and often are inundated or completely covered with freshwater. These wetlands derive most of their water from surface waters, including floodwater and runoff, but also receive some groundwater. In the coastal zone, freshwater wetlands typically exist where rivers and streams merge with other bodies of water, including the initial outflows of rivers to estuaries and lagoons. They can also be found in the coastal upland areas along stream banks, lakeside meadows or low-lying areas that receive adequate overland flow of rainwater or stream overflow. These freshwater wetlands support many species that depend upon consistent access to water that is neither too deep nor too brackish. This ecosystem provides a variety of habitat for birds, reptiles, amphibians, mammals, and insects.

Coastal estuarine and freshwater wetlands are among the most biologically productive ecosystems and therefore, provide an important suite of ecosystem services and economic and social benefits. Coastal wetlands provide habitat for plants, fish and wildlife, clean water, convey and store floodwaters, trap sediment, reduce water pollution, help nutrient cycling and soil retention, and can protect shorelines from storms by diffusing wave energy. Many bird species, including rare and endangered species, depend on coastal wetlands for foraging, roosting and nesting areas that are also critical to both migratory and wintering waterfowl.

Mangroves

Black mangroves (*Avicennia germinans*) are a species of woody shrubs that are typically found in tropical or subtropical climates. These shrubs are a unique habitat, as they are able to tolerate a wide range of environmental conditions, including saltwater, freshwater, brackish water, and periods of inundation. In some areas, the black mangrove shrub is used to stabilize shorelines, due to its complex root structure (i.e., pneumatophores) that slows down water flows and supports increased sediment deposition. The pneumatophores also aid in water filtration by removing nitrates, phosphates, and other pollutants. In addition, a diversity of animals can be found using mangrove swamps for protection, feeding, and breeding activities, including a variety of fish, shrimp, and birds. In areas with a warmer climate, black mangroves can grow up to 50 feet (ft) tall. However, in Texas, frequent winter freezes prevent the shrubs from growing beyond 3 ft.

Along the Texas coast, black mangroves are usually found in the south, along the Laguna Madre and in salty, sandy, or clay tidal flats of coastal marshes. In recent years, the warmer climate and milder winters along the Texas coast have allowed the black mangrove species to thrive, quickly becoming a dominant wetland plant displacing salt marsh species in coastal Texas environments. Although the two environments provide similar benefits to coastal species, researchers along the coast speculate that this shift may alter wetland dynamics in the future, whether good or bad.

Ecosystem services provided by coastal wetlands and mangroves in coastal Texas include: (1) regulating services via storm protection, sediment retention, water filtration, nutrient control and cycling, and carbon sequestration, (2) supporting services by enhancing biodiversity and providing habitat (protection, foraging grounds, and nesting and roosting habitat) for a wide variety of coastal species, and (3) cultural services via recreational activities such as kayaking, wildlife viewing, ecotourism, and recreational fishing.

2.2.4 Coastal Uplands

Coastal uplands are areas adjacent to coastal wetlands and can encompass various ecosystems, including swamps, bottomland hardwood forests, coastal prairies, live oak woodlands, and thorny brush. Coastal uplands can be used for agriculture and grazing and provide a dry land base for developing communities and cities. Coastal uplands are also important because they provide a buffer for wetland migration as sea levels rise. Common coastal uplands in Texas include coastal prairies and bottomland hardwood forests.

Coastal Prairies

Coastal prairies are large, open expanses of coastal uplands with continuous grassy vegetation that are located immediately inland of coastal marshes extending along the Gulf of Mexico shoreline. The dominance of grasses in these uplands can be attributed to the heavy clay soil that makes it difficult for woody plant species to establish. Specific areas with coastal prairies include several barrier islands, and the resacas, or disconnected channels, of the Laguna Madre. The natural history of Texas indicates that most of the land surrounding the bays and estuaries of the Texas coast were once a coastal prairie ecosystem and consisted of relatively flat ground with a very subtle, gradual rise in elevation. Once covering over 6.5 million acres (ac) (2.63 million hectares [ha]) of Texas land, coastal prairies now only occupy 65,000 ac (26,300 ha), or less than 1 percent of the original acreage.

Coastal prairie vegetation consists mostly of grasses overlain by a diverse variety of wildflowers and other plants. Areas nearer to the coast typically have shorter grasses and plant life that are accustomed to occasional coastal breezes and storms, whereas areas farther from the coast and slightly higher in elevation have taller grasses and shrubs. The unique flat grasslands and thorny scrublands of the coastal prairie and adjacent marsh areas provide habitat for waterfowl and other wildlife, including endangered species such as the ocelot, the Attwater Prairie Chicken, Eastern Black Rail, and the Jaguarundi. Grasslands used for grazing, with some oak savannah and mesquite vegetation, provide ample habitat for the various species that utilize this ecosystem.

Ecosystem services associated with coastal prairies along the Texas Gulf Coast include: (1) provisioning services such as grazing land for ranching and hunting, (2) regulating services including flood regulation, carbon sequestration, erosion control, and nutrient cycling, (3) supporting services through the creation of habitat and maintenance of biodiversity for waterfowl and other wildlife, including endangered species such as the ocelot, the Attwater prairie chicken, eastern black rail, and the jaguarundi, and (4) cultural services through aesthetics and recreational uses.

Coastal Bottomland Forests

In East Texas and near Galveston Bay, there are large, forested areas adjacent to streambanks and floodplains called bottomland hardwood forests. The primary source of water for these hardwood forests is from riverbank flooding, however, their soil is not as wet as swamps. Common tree species found in these forested areas include bald cypress, water tupelo, oaks, hickory, elm, green ash, red maple, and black willow. These forested areas are home to endangered mammals and birds, as well as rare plants and other species.

Ecosystem services associated with bottomland hardwood forests include: (1) provisioning services such as timber harvest, (2) regulating services include flood storage, groundwater supply and recharge, nutrient cycling, and carbon sequestration, (3) supporting services through habitat creation for plant and wildlife species, and (4) cultural services which provide recreational opportunities such as wildlife viewing as remnant bottomland forests are vital refuges and stopovers for migratory birds along the Central and Mississippi Flyways.

2.2.5 Oyster Reefs

Oyster reefs are submerged colonies of oysters found in nearshore rocky areas, bays, and estuaries, especially near river mouths where waters are brackish and shallow. Oyster reefs in Texas are built primarily by the eastern oyster (*Crassostrea virginica*) through reproduction and settlement of oyster larvae onto existing reef structures, creating large mounds of oysters and oyster shells. Oysters settle on hard substrates, like concrete barriers and rocks, but prefer to colonize on other oyster shells, as they cannot thrive on sandy or soft, muddy bay bottoms. As successive generations of oysters settle and grow, large reef structures can amass, comprised of many individual oysters. It is estimated that oyster reefs have 50 times the surface area of an equally sized flat bottom.

Oyster reefs increase biodiversity and provide valuable habitat for more than 300 marine aquatic species to forage and spawn, creating ideal locations for commercial and recreational fishing. In addition, oysters can filter water by removing pollutants and sediment, providing a vital service to some of the most impaired coastal waters. A single adult oyster can filter roughly six gallons of water every hour.

Ecosystem services provided by oyster reefs include: (1) provisioning services from oyster harvest, (2) regulating services such as sediment stabilization, shoreline protection and erosion control, and water filtration and circulation within estuaries, (3) supporting services include the creation of habitat and enhancement of biodiversity in nearshore ecosystems for juvenile fish and crustaceans, while providing associated species refuge from predation, and (4) cultural services such as recreational opportunities through the support of biodiversity within the fishery.

2.2.6 Rookery Islands

Rookery islands are typically quite small – only a few acres or less in size – and while some naturally exist, most were formed from the placement of dredged material during the creation or maintenance of nearby navigation channels, such as the Gulf Intracoastal Waterway (GIWW), or smaller channels and basins supporting ports and marinas. These islands that dot the back side of the barrier islands and the adjacent bays protect bay shorelines and navigation channels from erosion.

Rookery islands are isolated from the mainland and are too small to sustain predator populations, thereby providing optimal foraging, roosting, breeding, nesting and rearing habitats for migratory birds and a wide variety of colonial waterbirds and coastal shorebirds, including herons, terns, pelicans, egrets, and cormorants. Colonial waterbirds rely on open water, mud flats, estuarine wetlands, and seagrass for foraging. Rookery islands provide areas for birdwatching, ecotourism, and recreational fishing. Nesting pairs on rookery islands can range from a few pairs to thousands depending on island size. Preservation of rookery islands becomes increasingly important as changes in the bays, such as RSLR and sediment management practices, are resulting in the loss and degradation of islands. Several studies conducted in the Galveston Bay estuary found a link between declining waterbird populations and decline in wetland area, including wetlands found on rookery islands – underscoring the need for island preservation.

Ecosystem services provided by rookery islands are widely understudied, and vary by location and scale, but may include: (1) regulating services such as erosion control (though the extent of protection provided varies by location and scale), (2) supporting services through the creation of habitat and enhancement of biodiversity for mostly resident and migratory birds and waterfowl, and (3) cultural services from ecotourism and recreational activities such as wildlife viewing and bird watching and kayaking.

Migratory Birds

The Texas coast serves as an important stopover for many migratory birds traveling south during the winter season in search of warmer climates, abundant food sources, and additional nesting space. Texas lies in the direct path of two of the four major migratory pathways in North America, the Central and Mississippi Flyways, and birds utilizing the Atlantic and Pacific Flyways typically cross over the state as they reach the Gulf of Mexico. In total, 333 of the 338 migratory species in North America have been recorded in Texas. Not only does the state provide a haven for these species during their journey, but also offers recreational birding opportunities to those that visit the coast. In particular, the Texas coast boasts large swaths of critical habitat for both the endangered whooping crane and piping plover species. Protecting these habitats is essential to a thriving migratory bird community and the associated socioeconomic opportunities.

2.3 Tropical Cyclone Activity

A Tropical Cyclone is a rapidly rotating storm system with a low-pressure center, strong winds, a closed, low-level atmospheric circulation, and a spiral arrangement of thunderstorms (which produce heavy rain). Depending on its location and strength, a tropical cyclone can be referred to by different names. In Texas, they are typically known as tropical depressions, tropical storms, and hurricanes.

This section covers the 2019 through 2023 Hurricane seasons in Texas and describes the impacts that Tropical Storms and Hurricanes had on the Texas coast. This information allowed the 2023 TCRMP team to make decisions on project prioritization and served as justification for project funding requests.

2.3.1 2019 Atlantic Hurricane Season

The 2019 Atlantic Hurricane Season began on June 1, and with it came twenty tropical depressions. Of the twenty, eighteen became named tropical or subtropical storms, meaning that 2019 tied with the 1969 season as the fourth most active on record. Six of the tropical/subtropical storms intensified into hurricanes, with three of those developing into major hurricanes (Dorian, Humberto, and Lorenzo), none of which were in Texas. The 2019 season also became the fourth consecutive Atlantic hurricane season with above average activity. It is thought that a stronger west-African monsoon, warmer ocean temperatures, and a low wind shear are factors that may have contributed to such an active season. The 2019 accumulated cyclone energy (ACE) index value, a metric developed by NOAA to indicate the intensity and duration of all tropical storm systems during a hurricane season, was approximately 144 units. On the ACE index scale, a season is considered above normal when the value is above 103 units. In comparison, the ACE index value for the year 2005 was calculated at 270 units, the strongest year on record. On November 30, the 2019 Atlantic Hurricane Season came to an end, having resulted in 230+ deaths and a total of $7.6 billion in damage according to the National Hurricane Center's 2019 Tropical Cyclone Report.

In the Gulf of Mexico, five systems developed, tying with 1957 and 2003 for the highest number of tropical cyclones in the region in a single season. September was the most active month of the 2019 season, featuring seven named storms, including Tropical Storm Imelda, which caused heavy damage to the Texas Gulf coast and is described in detail, below.

Tropical Storm Imelda

In September of 2019, Tropical Strom Imelda began its slow crawl over Southeast Texas, bringing with it a continuous influx of tropical moisture. This moisture supported the formation of rainbands that moved across the same areas of Southeast Texas between September 17 and 19, which caused copious amounts of rainfall over the region. Several counties spanning parts of the Greater Houston metropolitan area and Beaumont, Texas, recorded over 30 inches (in) (76.2 centimeters (cm)) of rain. A station 2 miles south of Fannett, Texas, recorded a maximum rainfall total of 44.29 in (112.5 cm), which made Imelda the seventh-wettest tropical cyclone in U.S. history, fifth wettest in the contiguous U.S., and fourth wettest in Texas history. Due to the high rainfall rates, flood depths in some locations exceeded those recorded in Hurricane Harvey. Where rainfall was heaviest, the total rainfall represented a 1-in-1000-year event. Additionally, destructive flooding occurred along Interstate 10 between Winnie and Orange, Texas, marooning vehicles for 2.5 days. In total, over a thousand vehicles were caught in these floods. Many homes and businesses were also flooded, resulting in a need for numerous high-water rescues. Approximately 8,200 homes were flooded in Harris, Jefferson, Liberty, and Montgomery counties in Texas. The National Centers for Environmental Information (NCEI) estimated Imelda inflicted $5 billion in damage.

Jefferson County, Texas was the most heavily impacted by Imelda, where an estimated 5,100 homes were flooded in the county, suffering $14 million in damage. Encroaching floodwaters prompted the evacuation of Riceland Medical Center in Chambers County, Texas. Stream flooding persisted for days in Hardin County, Texas, where 10-40 in (25.4-101.6 cm) of rain was measured. Many buildings and roads were rendered impassable. Sixty homes were flooded in the county, resulting in $2.3 million in damage. In Orange County, Texas, Imelda flooded 2,679 homes, resulting in $12 million in damage. Near Mauriceville, Cow Bayou reached its second-highest crest on record. In Jasper and Newton counties in Texas, an estimated $2.4 million in damage was incurred following the flooding of 15 homes.

In Houston, Imelda's rainfall caused many of the local bayous to overtop their banks and flood residential areas. More than 1,000 people were rescued from floodwaters. All bus and rail services were temporarily shut down in the city. A roof of a United States Postal Service building collapsed, leaving three people with minor injuries. George Bush Intercontinental Airport closed for about 90 minutes due to flooding on the runways, canceling 655 flights. Throughout

Houston, hundreds of homes were affected by flooding and more than 1,600 vehicles were towed. In Harris County alone, 422 people required high-water rescue; the Texas National Guard rescued 130 people. During the flood, nine barges escaped a shipyard, and at least two struck the Interstate 10 bridge over the San Jacinto River, causing visible damage to some of the columns supporting the highway. The bridge was subsequently closed to traffic in both directions. Significant flooding occurred in Splendora, inundating parts of FM 2090 and U.S. 59.

2.3.2 2020 Atlantic Hurricane Season

The 2020 Atlantic Hurricane Season officially began on June 1st and ended on November 30th. In that period, the season featured 31 tropical depressions, 30 of which became tropical or subtropical storms, surpassing the record set in 2005. Out of the 30 named storms, 14 intensified into hurricanes (second only to 2005), seven of which became major hurricanes (tying with 2005 for the most in one season) and two of which impacted the Texas coast. It should also be noted that the 2020 Atlantic Hurricane Season marked the fifth consecutive year with above average activity which exceeded the four-season record set from 1998-2001. The 2020 ACE index value was approximately 195 units. According to NOAA's National Hurricane Center Tropical Cyclone Report, the Atlantic tropical cyclones of 2020 collectively resulted in 333 deaths and more than $41 billion in damage.

A total of eleven named storms made landfall in the United States and the country's entire Atlantic coastline, from Texas to Maine, was placed under some form of watch or warning in relation to a tropical system at some point during the season. Texas was impacted by Hurricane Hanna (Cat. 1), Hurricane Laura (Cat. 4), and Tropical Storm Beta, which are described in greater detail, below.

Hurricane Hanna

In Texas, where the storm made landfall in July 2020, around 194,000 residents in the Rio Grande Valley and surrounding areas lost power due to Hanna. Hanna also dumped several inches of rain causing widespread flash flooding in the same region, while it also caused downed trees and ripped roofs from homes. Wind gusts reached up to 110 miles per hour (mph) (175 kilometers per hour (km/h)) and storm surge reached as high as 6.24 (ft) (2 meters (m)) at landfall. The Bob Hall Pier in Corpus Christi was extensively damaged and eventually collapsed partially due to high winds and storm surge. The Art Museum of South Texas's first floor and outdoor exhibits at the Texas State Aquarium were inundated by storm surge from Corpus Christi Bay. Areas affected by Hanna were already struggling due to a surge of COVID-19 cases in the region. Several marinas and boats on the coastline were severely damaged. Many streets and highways later became inaccessible for much of July 25 and 26.

Hanna caused significant crop damage, totaling to $176.6 million. In Port Mansfield, 40% of homes received severe structural damage. Near Laguna Madre, a few boat garages were damaged by high winds. The cities of Mission, McAllen, and Weslaco were placed under flash flood emergencies due to Hanna's rainbands. Roads in Mission became impassible due to flooding. In McAllen, a canal overflowed, flooding numerous roads. As Hanna moved further inland and weakened on July 26, the storm unleashed copious amounts of rainfall in South Texas, with rainfall totals reaching up to 15 in (38.1 cm). Even a day following landfall much of the areas near the coast in Corpus Christi remained submerged from storm surge and flash flooding. After sheltering for the storm, thousands of American Electric Power crews worked for days to restore power but were delayed to some areas due to high water, especially in the Rio Grande Valley. The NOAA NCEI estimates that Hanna caused over $1.1 billion in damage in the United States.

Hurricane Laura

Hurricane Laura caused widespread devastation throughout most of its path, with tropical-storm force winds going over almost all of the Antillean Islands; hurricane and tropical-storm force winds impacting parts of Florida, Louisiana, Texas, Mississippi, and Arkansas; and flooding, rain, and storm surge affecting a large portion of the storm's path. Losses are estimated at over $19 billion, where Texas alone suffered $975 million in damage.

On August 23, 2020, Governor Greg Abbott declared a state of emergency for 23 counties in eastern Texas. On August 25, mandatory evacuation orders were issued for low-lying areas of Chambers, Galveston, and Jefferson counties, and for the entirety of Orange County. This included the entirety of the Bolivar Peninsula and cities of Galveston and Port Arthur. Galveston city officials advised residents that all city services would cease at noon on

August 25 and that upon the arrival of tropical storm-force winds, emergency services would be suspended. A total of 50 busses were used to assist in evacuations. A voluntary evacuation order was issued for coastal areas of Brazoria and Harris counties. An estimated 385,000 people were under evacuation orders in the state.

In the southeastern part of the state, coastal waters began rising late in the evening on August 26, 2020. Wind gusts in both Houston and Galveston peaked at 38 mph (61 km/h). A wind gust of 79 mph (127 km/h) was recorded at the Kirbyville Remote Automatic Weather Station site near Call, Texas. Throughout the coast, a multitude of trees and power lines were downed, causing damage to homes, businesses, and other community buildings. The flooding compounded with downed trees and powerlines also led to the multiple blocked roads in Hemphill.

Tropical Storm Beta

Heavy surf and high waves from Beta destroyed part of a pier in Galveston, Texas while storm surge flooding left many areas of the Texas coast under water. Around the time of landfall, a wind gust of 48 mph (77 km/h) was recorded in Port Lavaca. Parts of I-69 and TX-288 were closed by flooding and high-water rescue teams responded to dozens of calls for help. By the time Beta had weakened to a tropical depression on September 22, over 100 high-water rescues had taken place in Houston as portions of the city became heavily inundated by the storm's high rainfall totals, exceeding 9 in (22.9 cm) in parts of the city. Dozens of streets and highways in the city, including parts of I-69, I-45, and TX-288 and U.S. 290, were closed by fast-rising water. Officials urged residents to stay home and avoid driving if possible. Texas Governor Greg Abbott issued disaster declarations for 29 counties. NOAA estimates that Beta caused a total of $225 million of damage in the United States.

2.3.3 2021 Atlantic Hurricane Season

The 2021 Atlantic Hurricane Season began on June 1st and ended on November 30th. This season included 14 tropical storms, three Category 1 storms (winds up to 95 mph), two Category 3 storms (winds up to 129 mph), and two Category 4 storms (winds up to 156 mph). The 2021 Atlantic Hurricane Season was recorded as the third most active season, behind the 2020 and 2005 seasons, and is the sixth year in a row to have above-normal hurricane activity. The ACE index value for the 2021 Atlantic Hurricane Season was approximately 145 units. Out of the 21 named storms, eight made landfall along the Atlantic coast of the United States, causing $70 billion in damage and one death. Hurricane Nicholas was the only storm to impact the Texas coast during the 2021 Atlantic Hurricane Season and is described in greater detail below.

Hurricane Nicholas

On the evening of Monday, September 14, 2021, Hurricane Nicholas made landfall between Matagorda Bay and Sargent Beach, Texas as a Category 1 hurricane with maximum sustained winds of 75 mph (120 km/h). Gusts up to 95 mph (153 km/h) were recorded at Matagorda Bay and 75 mph (120 km/h) at Port O'Connor, where 3 ft (1 m) of inundation was reported. An estimated three to 6 ft (1 to 1.8 m) of storm surge was observed along the upper Texas coast, with the highest surge reported around Galveston Bay. As a result, several roadways and highways were closed, including the only roadway connecting the City of Matagorda to Matagorda Beach (FM 2031). By early Tuesday morning, high water was reported along portions of Interstate Highway 45 (Gulf Freeway) between Houston and Galveston, Highway 225 in Pasadena, on Broadway Street in the City of Galveston, and on roadways in the area of the cities of Beaumont and Orange. In addition, several roadways were closed due to flooding in the Corpus Christi area earlier that day.

In the city of Houston, rainfall averaged 1 to 3 in (2.5 to 7.6 cm) in the north and west sides and 6 in (15.2 cm) locally in the south and east areas. The highest rainfall, recorded at 9.85 in (25 cm), was observed in Deer Park located east of Houston. On Tuesday, wind gusts of 50 mph (80 km/h) were recorded at Hobby airport located in south Houston. Over 500,000 homes and businesses in the southeast Texas area, including Houston, were without power on Tuesday morning.

2.3.4 2022 Atlantic Hurricane Season

The 2022 Atlantic hurricane season began on June 1st and ended on November 30th. This season included two tropical depressions, six tropical storms, four Category 1 storms (winds up to 95 mph), one Category 2 storm (winds up to 110 mph), and two Category 4 storms (winds up to 156 mph). The 2022 hurricane season was less active than initial predictions forecasted, where NOAA predicted an above-normal season but only 13 storms were named, compared to an average of 14 named storms per season. The 2022 ACE Index value was approximately 95 units, the lowest value since 2015. Three storms made landfall along the Atlantic and Gulf coasts of the United States. Major Hurricane Ian affected Florida and the southeastern coast of the United States, resulting in over $50 billion in damage and over 125 deaths. No storms impacted the Texas coast during the 2022 Atlantic Hurricane Season.

3 TAC Analyses

A key component of the TCRMP development process was the continued involvement of the TAC, described previously and in part in **Section 4.2**. This partnership was implemented through a series of regional online meetings where feedback on coastal needs, regional coastal vulnerabilities, and potential projects was solicited. Among other inputs, TAC members provided advice and comments that addressed project definitions, project effectiveness, and ideas on new projects for potential inclusion in the TCRMP.

3.1 Spring 2020 TAC Meetings

Prior to holding the Spring 2020 TAC meetings, the GLO Planning Team reached out to TAC members via an online SurveyMonkey survey to determine if there were project updates that could be provided for any Tier 1 projects in the 2019 TCRMP.

The Spring 2020 TAC meetings, held via the WebEx Virtual Platform in June 2020, served primarily to recap the 2019 TCRMP and give a status update for work that had occurred on the Texas coast since the publication of the TCRMP. The TAC was given an overview of the 2019 TCRMP initiatives and introduced to any recent progress for the 123 Tier 1 projects that had been developed by the GLO. Regarding the Tier 1 Projects, the GLO emphasized the funding opportunities available to stakeholders.

After giving an overview of the 2019 TCRMP and the project progress, the focus of the meetings shifted to the 2023 TCRMP, starting with updates to the 2023 TCRMP planning framework, the new resiliency design guides that were being developed at that time, and the next steps/schedule outlined for the planning process. Materials developed for the 2020 Spring TAC meetings, including the pre-meeting survey, are included in **Appendix C**. Major takeaways from TAC member comments made during the Q&A session are also included in **Appendix C**.

3.2 Spring 2021 TAC Meetings

The Spring 2021 TAC meetings (**Table 3-1**) were composed of six rounds of online Zoom meetings (one for each region with an additional meeting each for Regions 1 and 3, due to their size). The meetings ranged from two to three hours, where the first 30-40 minutes were used as a recap of the 2020 meetings and to introduce the TAC to the 2023 TCRMP process, enhancements, and updates. The next hour and a half were dedicated to four 20-minute breakout room sessions that focused on discussing the vulnerabilities facing the Texas coast. Finally, the meetings ended with a wrap-up discussion that included TAC input on what is and is not working in the TCRMP and on potential data sources that TAC members would like included in the development of 2023 TCRMP Actions.

The vulnerability discussion groups were divided into the eight vulnerabilities identified in the 2023 TCRMP *(Degraded or Lost Habitat, Bay Shoreline Change, Gulf Shoreline Change, Storm Surge, Inland Flooding, Tidal Flooding, Degraded Water Quality, Degraded Water Quantity)* where TAC members answered questions regarding any new issues that have arisen on the coast since 2019 and whether there are any issues impacting their region that are not currently highlighted by the eight vulnerabilities. During these meetings, scribes took notes on TAC members' comments, and these notes were compiled to create summaries for each region (see **Appendix C**).

From these meetings and according to TAC members' comments, each region's top priorities are as follows:

Region 1

Habitats are being lost or degraded due to increased SLR, erosion, storm impacts, and changes in water regimes (less water input, degraded water quality, and increased saltwater intrusion) throughout the region. The most impacted of these include wetlands (freshwater and brackish/saltwater), the Trinity River Delta, oyster reefs, rookery islands, and beaches/flats. Habitat fragmentation caused by increased development on one side and SLR and erosion on the other is leading to the conversion of freshwater coastal wetlands to brackish/saltwater wetlands or open water, especially along the bay shorelines and the GIWW. Coastal prairie habitat is also prone to conversion. This has become a major concern for coastal and migratory birds as wetlands, beaches, and tidal flats and vital habitats. Additionally, repeated inundation (i.e., tidal flooding, inland flooding, and storm surge events) is wiping out nest and chicks and deterring birds from utilizing what is available.

The 2020 hurricane season triggered significant erosion events, wiping out beaches and dunes along Galveston Island, Bolivar Peninsula, and Follet's Island. Furthermore, Gulf facing beaches are experiencing high amounts of recreational usage. Nourishment of both bay and gulf shorelines is preferred, but the region is sediment starved and there is a lack of sand resources available. A sediment and dredged material management plan is needed. Existing political hurdles also hinder the local communities' ability to carry out nourishment projects. As pressures increase, a greater need for agency coordination, project partner funding, and local capacity building to champion projects is needed to counteract the impacts. Additionally, communities need ongoing technical assistance to navigate the permitting process and the changing landscape of federal standards to implement their projects.

There is a need for enhanced modeling efforts of the regional flooding concerns (i.e., transition to larger-scale modeling, include changing weather patterns and increased rainfall events, etc.), particularly through more refined Advanced Circulation Model (ADCIRC) inputs. Compound flooding is a relatively new idea, but this issue is impacting 14 cities within Harris County and should be included in modeling efforts. Water quality and quantity issues should be addressed and managed from a watershed-wide perspective. The development of nutrient standards is important as agricultural runoff impacts the coastal region. This region also faces water rights issues, particularly for the City of Houston. Velocity and flows within the system are volatile and a balance is needed to address both storm surge and heavy rainfall events.

Region 2

Vulnerable habitats in this region include oyster reefs (shipping network impacts, upstream changes in the watershed, overharvest, sedimentation, and increased storm impacts), marsh/wetlands (increasing SLR, lack of freshwater, saltwater intrusion, habitat squeezing), tidal flats, seagrass beds (dredging, boat traffic), rookery islands (increasing SLR, increased storm impacts, ship wakes), and bays and waterways (erosion, population growth). As a result of the winter storm in February 2021, mangroves are being lost at an unprecedented rate. The residual impacts of this event and the loss of critical whooping crane habitat, especially within the Aransas National Wildlife Refuge (ANWR) where there is a significant decline in ecological function occurring, are additional concerns. More data on shoreline change rates within the bays is needed, especially in vulnerable areas such as pits, points, and isthmuses. Changes to navigational channels, and bay shorelines as a result, should be studied and watched as tidal flow, sedimentation patterns, and salinity regimes are impacted. On the Gulf side, Sargent Beach and the northern tip of Matagorda Island are experiencing high rates of erosion. This region is more rural and has less development than other regions and has historically seen minimal engagement of researchers and/or stakeholders.

There are several major rivers in this region that bring down rainfall from upstream areas. These "rain bombs" are occurring more often and the effects are hard to differentiate from the effects of storm surge. As a result, more research is needed on the recent phenomenon of compound flooding. Investments should be made into long-term instrumentation records and monitoring efforts. The watershed should be managed as a whole and not just focused solely on the coastal areas. Major storm surge concerns include toxic chemical releases, movement of toxic sediment and waste during intense surge events, and facilities at low elevations. Most of the time, cities like Seadrift and Palacios are not prepared to withstand heavy storm surges and it is important to maintain their natural defenses. There is a lack of sufficient drainage systems and infrastructure to handle the amount of precipitation coming in. Very little historical flood/rain event records are available and very little data on how often floods arise/main cause of floods exists. Additionally, the region is characterized by low-lying topography (2 ft (0.6 m) above sea level), so flooding is going to occur naturally and is exacerbated by continual development and growing population. Critical infrastructure in this region is prone to flooding during high tide (Beach Road from Matagorda to Matagorda Beach, Calhoun County SH 316, Matagorda Bay FM 2031).

Water quality monitoring efforts should be expanded to include taking averages of the whole water column instead of a fixed point in the middle of the water column and should include identifying more water quality parameters, such as non-point sources of pollution. Additional freshwater inflow is needed for the area, but excess nutrients are also brought in, which can lead to changes in dissolved oxygen content, pH levels, chlorophyll, and increase harmful algal blooms. Historically, the areas used for agricultural purposes were drained to create farmable land while rice farming in other areas kept freshwater flowing through wetlands (and provided vital habitats for whooping cranes). As both industries have reduced over the years, water management and water use inland are becoming major threats and are depleting habitats, such as wetlands. Nueces County has had a drought of record approximately every decade since the 1950's; better ways to manage water are needed, especially as droughts increase in severity.

Region 3

Vulnerable habitats in this region include mangroves, oyster reefs (also contributing to a decline in water quality), rookery islands, tidal flats, beaches, marshes, and seagrass. Mangroves were heavily impacted by the winter storm in February 2021 and it is uncertain how the loss of the mangroves will impact the overall ecosystem. Increased upland flooding moves freshwater down the watershed and impacts the oyster habitats, causing a disruption to oystering. Furthermore, it is becoming more challenging to meet the needs of competing interests (recreation, water quality, erosion, etc.) as oyster reefs are managed as a habitat and a fishery. Coastal development is driving habitat loss for whooping cranes, aplomado falcons, and Attwater's prairie chickens. There needs to be a better understanding of habitat migration and a focus on critical areas where a net loss is anticipated. Rookery islands are vulnerable to erosion (through high tides, increased water levels, vessel traffic, and washover), particularly in and around the bays and along the GIWW. Protection of rookery islands should be emphasized. Tidal habitat is also important for nesting birds (i.e., piping plovers, red knots) and is being degraded by SLR and runoff. The beaches in this region are rapidly eroding with a rate of about 3 to 4 ft of shoreline loss per year, likely due to inundation during high tide/nuisance flooding events. There seems to be confusion regarding the management of the beaches and who should coordinate nourishment efforts. This is a concern for critical species (i.e. nesting sea turtles) and beachgoers alike. Marsh loss is driven by erosion, increasing water levels, a lack of freshwater, and changes in salinity levels. Large algal blooms, likely due to stormwater and wastewater runoff from new developments and from increased non-point source pollution, are inhibiting seagrass growth. Seagrass is also being impacted by dredging and fill operations. Additionally, more frequent seagrass surveys are needed within the bays.

Erosion is a big vulnerability in this region, particularly for barrier islands and shorelines along navigational channels. Increased shipping/recreational boating activities, wave action, hurricanes and other coastal hazards, and strong prevailing winds are all driving the erosion. A more holistic approach is needed to manage the sediment in this region; incorporating green infrastructure/nature-based solutions (NbS) is essential to creating a long-term solution. Beneficial use should be addressed as part of this sediment management. Critical infrastructure is in danger of being lost due to increasing water levels and erosion occurring right along the structures. Public buy-in, outreach, coordination, and collaboration have been big challenges in this region to moving projects forward, as well as, getting funding and technical assistance to see projects through to the end. As population in this region increases, as well as the number of tourists visiting each year, a significant strain is placed on government resources (i.e., law enforcement) and natural resources, especially the beaches and dunes. A public campaign to educate people on walking and driving on the dunes and other sensitive habitats (i.e., the Nature Preserve in Port Aransas, marshes, tidal flats) would benefit everyone. This region needs a comprehensive mitigation plan with more regional level planning.

As the population continues to grow, a greater risk of storm surge (from hurricanes or other coastal hazards) impacts is anticipated, particularly for new construction, developments nearing the 350-foot setback zone, and canal communities. A clearer picture of the risk of increasing inundation should be presented to the public. Some communities do not have the human capacity to handle damages after a storm event, nor do they have the infrastructure (sewer, industrial, and municipal) to maintain and control water levels after a storm surge event. Aging infrastructure is not able to handle run-off from inland areas. Above ground storage tanks, both new and old, holding petrochemicals are vulnerable and should be addressed. Drainage issues should be managed holistically, using natural boundaries instead of jurisdictional boundaries; more communication is needed between upstream stakeholders and downstream stakeholders. Increasing development can exacerbate inland flooding issues, particularly for existing properties as new elevated developments are built. Furthermore, low-lying developments will create vulnerabilities to tidal flooding in areas that were not vulnerable before.

Planning efforts need to be long-range and should extend beyond where the water meets the land to encompass inland regions as tidal flooding and nuisance flooding are becoming more chronic and are occurring further inland. This is likely due to increasing SLR. Navigational channels are experiencing challenges a result of tidal flooding, such as poor drainage in combination with flooding and high tide leaving water in the ports. Stormwater runoff is creating issues as debris and illegal dumping increase and obstruct flow. Throughout the region, several wastewater treatment plants (WWTPs) need to be replaced or refreshed, but funding is an issue. From Nueces to Matagorda Bay, there are long-term increases in the salinity of the estuaries as growing populations exacerbate water quality concerns. Furthermore, the quantity of water in and of itself is not the only concern, but the timing too. Removal of upstream structures, such as dams can create a conundrum of water rights issues and expensive removal costs. Smaller waterbodies with relic dams that are not used for anything specific should be considered for removal to restore the natural movement of the water.

Region 4

Vulnerable habitats in this region include tidal flats (runoff, development, SLR, and lack of adequate restoration options available), rookery islands (erosion, lack of sediment in the bay, funding, and wave action produced by shipping activities), mangroves (lots of loss near Mansfield likely due to the winter freeze), wetlands (development, high tide events, storm surge, and lack of freshwater), seagrass beds (smothering through sediment placement activities, dredging, boating activity, and changes in water quality/salinity), and dunes (lack of vegetation, high tide events, storm surge, increasing amount of visitors, increasing storm events, and people driving over foredunes to access the beach). A way to identify areas of degraded habitat is needed in order to prioritize mitigation projects and more communication between agencies, partners, etc. when grant money or the need for projects arises would make this process more efficient. An issue with many projects in this region is that a lot of the land is privately owned and it is difficult to get feedback from those landowners. This region is sediment starved and is in need of a regional sediment plan to use the resources available within the region beneficially. Coordination between the USACE and projects that need fill would be useful. Along the bay shorelines in this area, there are concerns about ongoing dredging and material being placed in the open bay instead of being used beneficially, particularly for rookery islands. There are a lot of delays and unpredictability in the nourishment schedule as well as issues with funding. Erosion along the bay shoreline may be causing secondary impacts on the bay system/estuary. USACE is working to maintain the heavily utilized sections of the GIWW, but there is a lack of funding. Incorporating living shorelines should be emphasized as a way to combat shoreline erosion, but there is a lack of ability to articulate their value and the public misconstrues their intent. Along the Gulf shorelines in this region, development at the front of the barrier islands is impeding overwash from supplying marshes with sediment during storm events. During the 2020 storm season in addition to the winter storm in 2021, a big portion of dune systems along the northern tip of South Padre Island and in the northern part of the South Padre city limits were lost, making both areas more vulnerable to storm surge events. The beaches along the northern portion of South Padre Island are experiencing 7-14 ft of erosion per year.

During storm surge events, several of the roadways along South Padre Island are closed until the water recedes. Increasing surge events, in conjunction with RSLR, will start to impact the low-lying communities and habitats on the backside of the South Padre Island. Compound flooding should be investigated in this region, particularly for areas with localized drainage as there is a lot of water but nowhere for it go. There was significant tidal flooding and damage to docks during the 2020 storm season, such as areas near Adolph Thomae Jr. Park (storm and wind-drive tide combined). More awareness of how flood planning projects impact other areas (i.e., water quality, habitats, etc.) is needed. The City of South Padre Island is trying to be more proactive, but there needs to be more management regarding flooding events rather than just recording the flooding. There is an issue with communication that should be considered, there are a lot of drainage districts and inconsistencies (i.e., there are plenty of drainage districts in some areas and only a few in other areas). Additionally, data is needed on the impacts of tidal flooding (i.e., vertical topographic data).

Nutrients are flowing into the Lower Laguna Madre via the lower Colorado and the Brownsville Ship Channel, there is a large amount of illegal dumping occurring within the southern part of Baffin Bay, and the reclamation center in Port

Isabel has been shut down in the last few years and there is no other pump out station for commercial/recreational vessels, impacting water quality within the region. However, without water quality criteria to target, water quality will continue degrading. Salinity issues due to the lack of freshwater inflow are occurring in Laguna Atascosa, while the Laguna Madre is receiving too much freshwater (increased storm runoff and wastewater discharge) and both of these issues should be monitored. Projects that reroute water flows are pulling water from one area and moving it to another area that may already have too much freshwater inflow (Laguna Madre). Changes in farming activity and increasing development impact water flows, displacing runoff onto roads, ditches, etc.

Table 3-1. Spring 2021 TAC Meeting Dates, Times, and Number of Attendees

Date	Time	Region	Number of TAC Attendees
May 20, 2021	1pm CT	4	66
May 26, 2021	9am CT	3	76
June 8, 2021	1pm CT	1	73
June 10, 2021	1pm CT	2	52
June 15, 2021	1pm CT	3	37
June 17, 2021	1pm CT	1	30

A full discussion of the results from the Qualtrics assessments is included in **Section 5.1**.

3.3 Fall 2021 TAC Meetings

The Fall 2021 TAC meetings were held on November 5 and November 18, 2021. As the meetings were virtual and were not regionally specific, two dates were offered to all TAC members to attend. This round of TAC meetings updated TAC members on the current progress of planning enhancements such as modeling, ecosystem services, expanded project benefits, and the resiliency design guides. Results from the Spring 2021 Qualtrics Survey were also presented. The main purpose of the meeting was to inform the TAC members on the process of developing the proposed 2023 Actions and to briefly describe each of the ten proposed Actions. This also included a summary of example projects from the 2019 TCRMP Tier 1 projects that are applicable to proposed Actions, examples of potential opportunities for collaboration between the GLO and other agencies/entities, the vulnerabilities addressed by each Action, and the datasets used as inputs into each Action. At the end of each meeting, time was reserved for TAC members to ask questions or provide any verbal feedback, as desired. The presentation given at the meetings and other meeting materials are included in **Appendix C** and a recording of the November 18th meeting can be found here: https://www.youtube.com/watch?v=LNwWvsL5Hs0.

Poll Questions

Throughout the meeting, TAC members were asked to participate in a series of poll questions to provide feedback on the Spring 2022 TAC meeting platform, the TCRMP Planning Framework, and their interest in attending the Actions Workshops. The results of the polls are presented below (**Figure 3-1** to **Figure 3-6**).

Question 1: Would you attend a Spring 2022 TAC Meeting in-person?

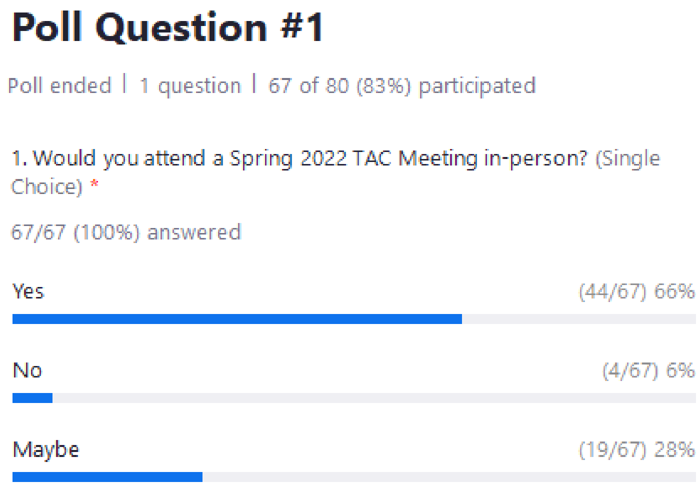


Figure 3-1. Results of Poll Question 1 from the November 5, 2021 TAC Meeting

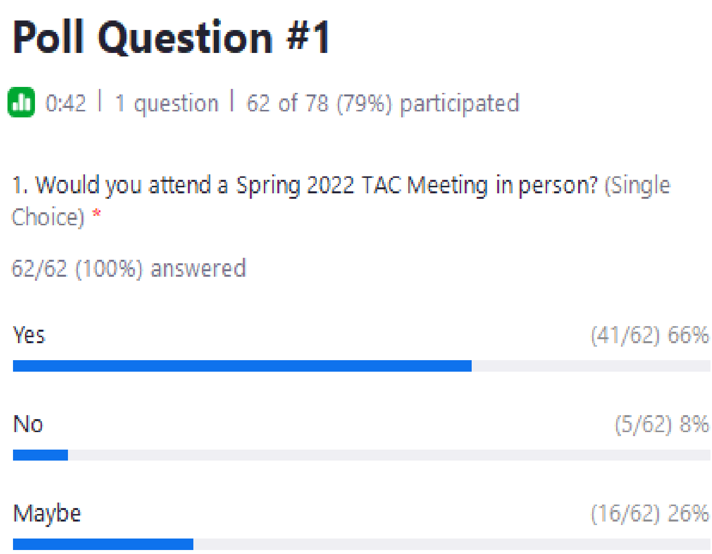


Figure 3-2. Results of Poll Question 1 from the November 18, 2021 TAC Meeting

Question 2: As a member of the TAC, I find the Coastal Resiliency Framework useful:

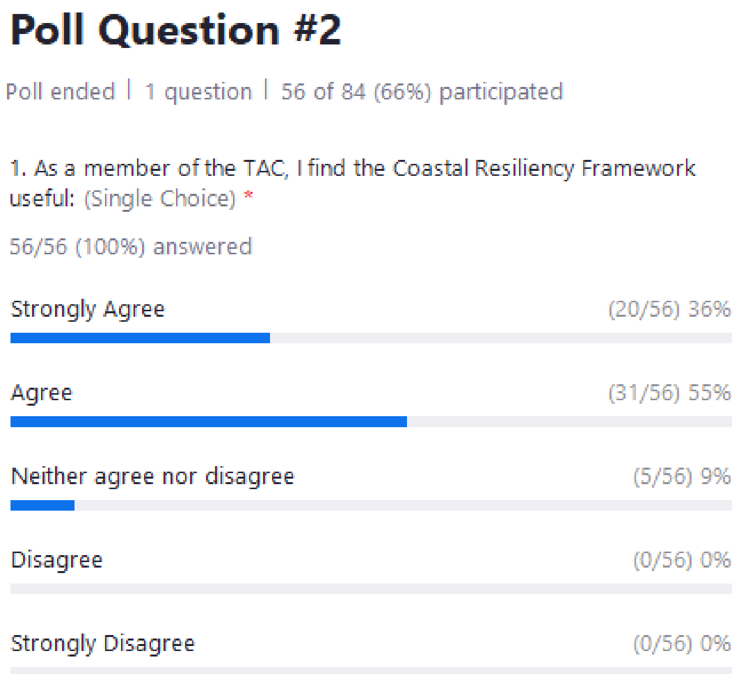


Figure 3-3. Results of Poll Question 2 from the November 5, 2021 TAC Meeting

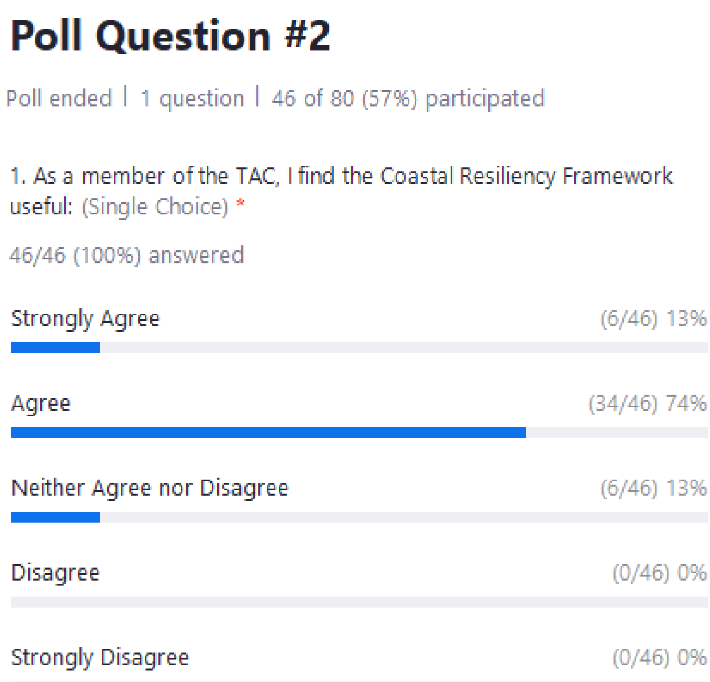


Figure 3-4. Results of Poll Question 2 from the November 18, 2021 TAC Meeting

Question 3: Are you interested in attending any of these Action Workshops?

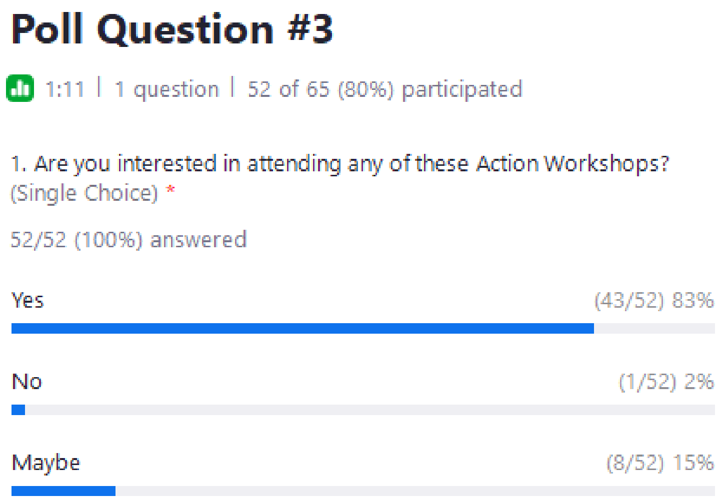


Figure 3-5. Results of Poll Question 3 from the November 5, 2021 TAC Meeting

Figure 3-6. Results of Poll Question 3 from the November 18, 2021 TAC Meeting

Meeting Minutes

November 5, 2021

- Craig Casper: I am curious why the drivers are Social, Economic, and "Natural" and not "Ecological"? The strategy uses the term Ecological.
  - Josh Oyer (GLO): Drivers are those that result in pressures and cause an increase in vulnerability...the strategies are ways we implement actions that alleviate those vulnerabilities. Pressures are driven by social, economic and natural forces.
  - Craig Casper: Natural encompasses MORE than ecological forces. I got it. Thank you!

- Dianna Ramirez: Another funding source is the Galveston Bay Estuary Program, small amounts but lots of categories including Natural Resource users, outreach, research & development, etc.
- Ashley Ross: I have to go to another meeting. Very helpful updates! Looking forward to meeting in the spring and to the action workshops.
- Craig Casper: This has been an excellent meeting. It was informative and inclusive. Based on what I have seen the scope and process have been well executed. Thank you!
- Anitra Thorhaug: When will this presentation be available? will it be sent to us? thanks.
  - Josh Oyer: Will likely come with the same email with the survey links and the slide deck will also be provided.
- Anitra Thorhaug: In the modeling, could you include seagrass in your different habitats?
  - Jim Gibeaut: Oyster reefs are only included if they're intertidal. Seagrass is not currently included because it is subtidal, it's a much more difficult problem to address with remote sensing and modeling how they would respond to SLR is difficult. There's not enough data or knowledge about the processes that would occur as a result of seagrass in the face of SLR.
- Anitra Thorhaug: What's the best way to get information out to people? Spectral signatures of seagrass along the Texas coast.
  - Josh Oyer: Please send any new information to me.

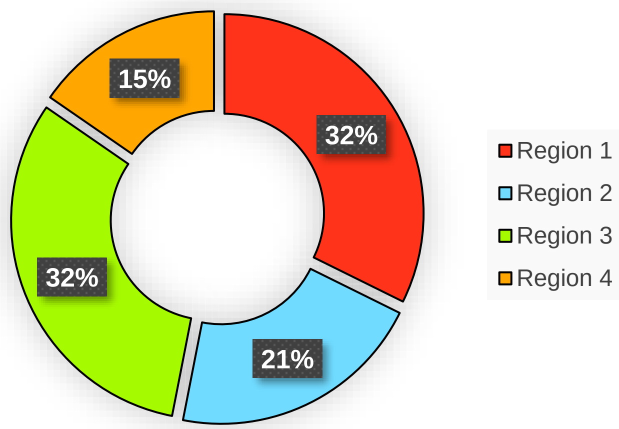
November 18, 2021

- Brandon Hill: Have you started to consider how the Gulf Coast Protection District (GCPD) may factor into the TCRMP effort?
  - Josh Oyer: GLO is non-federal sponsor for upper coast protection features that are part of the GCPD. In general, this is yet to be determined by GLO upper-level management, but we are anticipating the Ecosystem Restoration projects to be adopted as Tier 1 projects.
  - Tony Williams: The GLO has been involved in the development of the GCPD and they are still fairly new. It's something that we're looking at, but it is very much to be determined at this point. Orange County proposed levee project is their first item they need to address, will greatly increase resiliency of that area; then work on Coastal Protection Study. Aware of restoration opportunities available and the Coastal Storm Risk Management (CSRM) efforts in Galveston. They're just getting their feet under them. It would be helpful if their members could be involved in the TAC.
  - Brandon Hill: Pleased with the amount of cross organizational coordination in TCRMP effort. Ongoing efforts in city to increase coordination between operations and research folks. I'll be sure to work with the GCPD on getting the surveys filled out and looped in with these efforts.
- Will Norman: Action areas are very comprehensive, and think they are accurate. Would just suggest and commend y'all for continuing to do such a good job of getting this information out to the stakeholder community as soon as possible.
- Mel Vargas: Will the slide deck be available?
  - Josh Oyer: Yes, it will be sent out as a PDF and the meeting was recorded. Both will be available for TAC members.

Meeting Attendees

As the meeting was held virtually and was not region specific, a summary of the attendees is included below. This details the number of attendees per region and the organizational make-up of the attendees per region and lists the local stakeholders in attendance by region. A list of meeting attendees is also included in **Appendix C**.

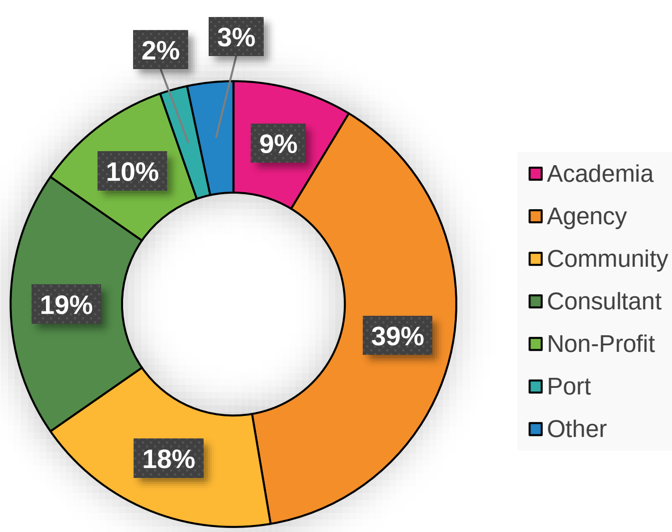
Total Attendees



Region	Number of Attendees*
1	42
2	27
3	41
4	20
Region Unknown	60

***Some TAC members/attendees represent or are interested in multiple regions and are included in the count for each region of interest.**

Total Attendees by Organization Type



Organization Type	Number of Attendees
Academia	13
Agency	58
Community	27
Consultant	29
Non-Profit	15
Port	3
Other*	5

***This organization type represents stakeholders such as drainage districts or specialized research groups.**

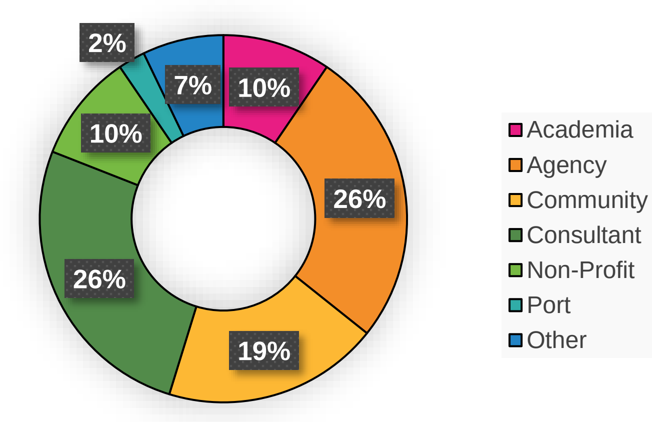
Region 1

Attendees by Organization Type

***Some TAC members/attendees represent or are interested in multiple regions and are included in the count for each region of interest.**

****This organization type represents stakeholders such as drainage districts or specialized research groups.**

Organization Type	Number of Attendees*
Academia	4
Agency	11
Community	8
Consultant	11
Non-Profit	4
Port	1
Other**	3

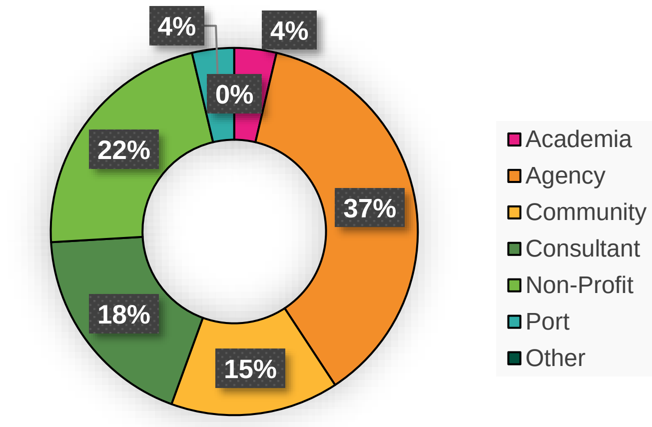


Local stakeholders with representatives that attended one or both of the TAC meetings include:

- City of League City
- Harris County Flood Control District
- City of Galveston
- Orange County Drainage District
- Brazoria County
- Jefferson County
- Port Houston
- Galveston Bay Foundation
- Jupiter Data Factory LLC
- Galveston Parks Board
- City of El Lago
- City of Friendswood

Region 2

Attendees by Organization Type



Organization Type	Number of Attendees*
Academia	1
Agency	10
Community	4
Consultant	5
Non-Profit	6
Port	1
Other**	0

***Some TAC members/attendees represent or are interested in multiple regions and are included in the count for each region of interest.**

****This organization type represents stakeholders such as drainage districts or specialized research groups.**

Local stakeholders with representatives that attended one or both of the TAC meetings include:

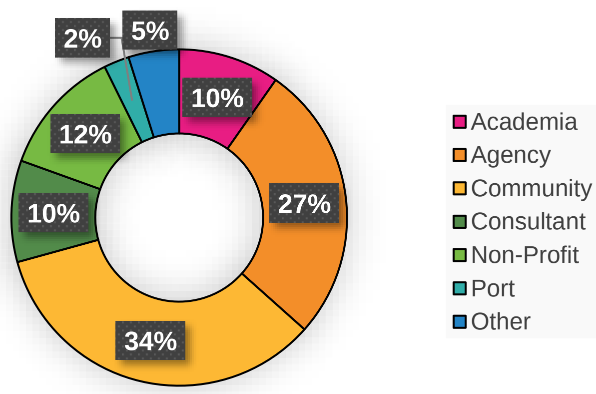
- Matagorda Bay Foundation
- Katy Prairie Conservancy
- San Antonio Bay Partnership
- City of Port Lavaca
- Calhoun County
- Coastal Bend Bays and Estuaries Program (CBBEP)
- Port of Palacios

Region 3

Attendees by Organization Type

Organization Type	Number of Attendees*
Academia	4
Agency	11
Community	14
Consultant	4
Non-Profit	5
Port	1
Other**	2

***Some TAC members/attendees represent or are interested in multiple regions and are included in the count for each region of interest.**
****This organization type represents stakeholders such as drainage districts or specialized research groups.**



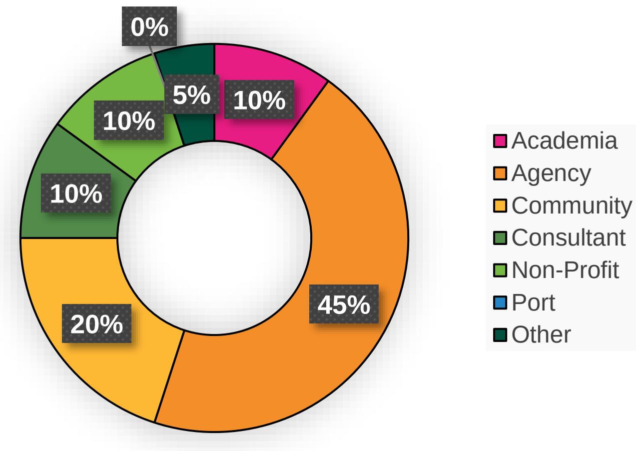
Local stakeholders with representatives that attended one or both of the TAC meetings include:

- City of Corpus Christi
- Interhold Corporation
- Aransas County
- Port of Corpus Christi Authority
- Corpus Christi Metropolitan Planning Organization
- City of Aransas Pass
- Nueces County
- Laguna Gulf
- San Patricio County
- Town of Fulton
- San Antonio Bay Partnership
- CBBEP
- City of Rockport
- City of Port Aransas

Region 4

Attendees by Organization Type

***Some TAC members/attendees represent or are interested in multiple regions and are included in the count for each region of interest.**
****This organization type represents stakeholders such as drainage districts or specialized research groups.**



Organization Type	Number of Attendees*
Academia	2
Agency	9
Community	4
Consultant	2
Non-Profit	2
Port	0
Other**	1

Local stakeholders with representatives that attended one or both of the TAC meetings include:

- City of South Padre Island
- Laguna Gulf
- CBBEP

Next Steps

As part of the continuing effort to incorporate TAC member feedback into the TCRMP process, the GLO held ten Actions Workshops in early 2022. Ten 1.5-hour workshops were made available over a five-week period in late January through mid-February. These workshops were intended for TAC members to have a more thorough understanding of each of the proposed actions and provide feedback on the action itself, the data sources included as part of the action, and areas along the Texas coast which may benefit from projects derived from the action. The purpose of this process was to refine the proposed Actions and highlight potential target areas for each action. The schedule of Actions Workshops is included below.

Workshop	Action	Date (2022)	Time
1	Managing Coastal Habitats	Jan 18	9-10:30 a.m.
2	Managing Gulf Shorelines	Jan 20	1-2:30 p.m.
3	Managing Bay Shorelines	Jan 25	9-10:30 a.m.
4	Improving Community Resilience	Jan 27	1-2:30 p.m.
5	Adapting to Changing Conditions	Feb 1	9-10:30 a.m.
6	Managing Watersheds	Feb 3	1-2:30 p.m.
7	Growing Key Knowledge and Experience	Feb 8	9-10:30 a.m.
8	Enhancing Emergency Preparation and Response	Feb 10	1-2:30 p.m.
9	Addressing Under-Represented Needs	Feb 22	9-10:30 a.m.

Workshop	Action	Date (2022)	Time
10	Maintaining Coastal Economic Growth	Feb 24	1-2:30 p.m.

3.4 Summer 2022 TAC Meetings

The Summer 2022 TAC meetings were held in the month of June, in five rounds, with both virtual and in-person modes of instruction. The five rounds were for regions 1A, 1B, 2, 3, and 4, in that order. Coastwide projects (designated as Region 0) were included in all the regions mentioned.

Region	Date (2022)	Time	Location
Region 1A	June 1	9:00 a.m. – 4:00 pm	Beaumont, TX
Region 1B	June 2	9:00 a.m. – 4:00 pm	League City, TX
Region 2	June 9	9:00 a.m. – 4:00 pm	Victoria, TX
Region 3	June 28	9:00 a.m. – 4:00 pm	Port Isabel, TX
Region 4	June 29	9:00 a.m. – 4:00 pm	Corpus Christi, TX

Each of the five meetings lasted 6-7 hours, including breaks. The main goal of this set of meetings was to collect responses and insights of members of the TAC regarding potential projects proposed for inclusion in the 2023 TCRMP. TAC members were provided with a set of informative documents which included the meeting agenda, an information packet, a quick reference guide for the Geographic Information System (GIS) Online project dashboard, a survey packet, and a quick reference guide for the online evaluation survey. The information packet, developed by the GLO and AECOM, consisted of background information and the TCRMP planning framework, important terminology, and one-page project descriptions with information about each potential project in the region. This one-page project-specific material included a vulnerability score table, description, need for, and benefits of the project, stakeholder information, project type, land ownership, location, status, funding and cost amounts, and type of action that the project falls under.

The first 30-40 minutes of the meeting were used to inform the TAC members about the current phase of the TCRMP, including the eight vulnerabilities (*Degraded or Lost Habitat, Bay Shoreline Change, Gulf Shoreline Change, Storm Surge, Inland Flooding, Tidal Flooding, Degraded Water Quality, Degraded Water Quantity*) that were used to designate a level of risk attached to a potential project location. Instructions on how to submit surveys through the virtual links, QR codes, or through the information packet were also given. The meetings consisted mainly of a brief introduction to each project in the region, followed by an interactive session in which project proponents and stakeholders explained their project further to the TAC and answered any additional questions. An ArcGIS Online project dashboard was displayed throughout the meeting, showing different data layers and map informatics related to the project being discussed. During these meetings, scribes took notes on TAC members' comments, questions, and answers to create summaries for each region. TAC members attending the meetings were invited to evaluate the potential projects for their respective abilities to address the eight vulnerabilities, and to indicate project feasibility and priority for the 2023 TCRMP using online or hardcopy surveys. The meetings ended with a wrap-up summary of the region, conclusions, and a note on the next step following collection of survey responses. Example meeting materials are included in **Appendix C**.

3.5 Fall 2022 TAC Meeting

The Fall 2022 TAC meetings were held on November 2nd and November 10th. As these meetings were not regionally specific, both meetings were provided virtually and were open to all TAC members to attend either session. The primary purpose of this round of TAC meetings was to present the final Tier 1 project list for inclusion in the 2023 TCRMP to the TAC members. Attendees were also provided with a summary of the evaluations and final scoring system used to determine the Tier 1 projects (see **Section 8.3** for more information). The meeting was also used to provide an update on the ongoing modeling tasks and to preview some of the outcomes that have been produced up to this point. Finally, the TAC was presented with an overview of the 2023 TCRMP outline. The meeting concluded with time for the TAC members to ask questions or provide feedback.

The presentation given on the November 2nd meeting is included in **Appendix C** and is the same presentation that was given at the November 10th meeting. Additional items that can be found in **Appendix C** include: meeting minutes collected at both meetings, the TAC feedback materials, which were provided as comments to the draft Tier 1 cutsheets, and the meeting attendee lists.

Recordings of each of the meetings can be found using the links below:

November 2nd meeting: https://youtu.be/6FLpF9OQGpk

November 10th meeting: https://youtu.be/Zkmy9tNIIE0

4 Technical Assessment Methodology

The planning process from its inception in 2016 through 2023 is shown in **Figure 4-1**, which gives a high-level summary of the technical and planning tasks. In general, the planning process follows a repeated cycle of TAC evaluation of vulnerabilities, technical tasks to refine project inputs and data about the Texas coast, TAC reviews and refinements of potential projects, and rollout of the draft and final versions of the TCRMP.

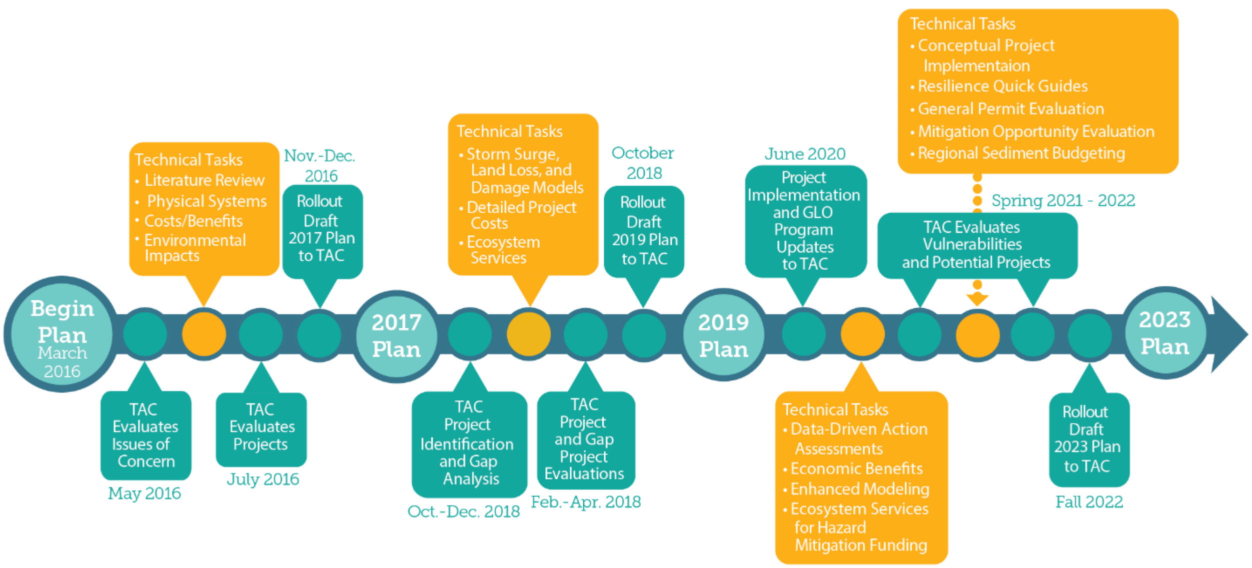


Figure 4-1. Complete TCRMP Technical Methodology

4.1 Technical Process Overview and Regional Approach

The technical process, shown in **Figure 4-2**, is structured around the planning process presented above in **Figure 4-1**, and overviews the 2023 TCRMP development since publication of the 2019 TCRMP. The technical process was composed of four main elements (i.e., progress projects to implementation, project screening, TAC analysis, technical analysis of actions and projects), followed by the refinement of previously developed resiliency strategies. The four main elements are described in detail in **Sections 5** through **8**, with **Section 8** including information on the refinement of the 2023 Tier 1 projects.

Beginning with the Tier 1 projects prioritized in the 2019 TCRMP and a comprehensive list of coastal resiliency projects proposed since 2019, the GLO planning team conducted multiple screenings to select new projects or monitor the status of ongoing projects. This process is described in **Section 8**.

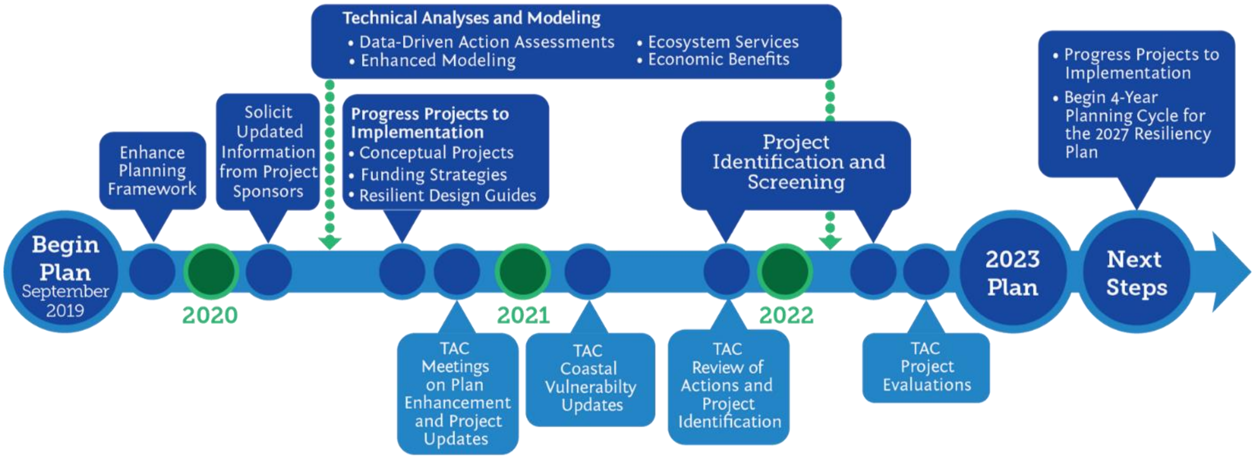


Figure 4-2. The 2019-2023 Planning Process

The Texas coast was divided into four regions (**Figure 4-3**) to facilitate presentation of coastal vulnerabilities and potential solutions. The four regions are generally based on major bay systems and habitats as described in **Table 4-1**. These regions also align with other previous and ongoing coastal planning studies conducted by the GLO and the USACE.

Figure 4-3. TCRMP 2023 – Planning Regions

Table 4-1. The Four Coastal Regions

Region No.	Region Name	Description	Counties
1*	Sabine Pass to Galveston Bay	Mouth of Sabine River at the Texas-Louisiana border to the mouth of the Brazos River near Cedar Lakes	Brazoria, Chambers, Galveston, Harris, Jefferson, and Orange
2	Matagorda Bay	Entire Matagorda Bay system from the Brazoria-Matagorda County line to eastern edge of San Antonio Bay	Calhoun, Jackson, Matagorda, and Victoria
3	Corpus Christi Bay	San Antonio Bay to Baffin Bay	Aransas, Kleberg, Nueces, Refugio, and San Patricio
4	Padre Island	Southern edge of Baffin Bay to the Texas-Mexico border	Cameron, Kenedy, and Willacy

Source: Coastal Texas Protection and Restoration Study: Final Reconnaissance 905(b) Report (USACE, Galveston District, Southwest Division).

*Due to high population density and region size, Region 1 may be subdivided into Regions 1A (from the Sabine River to the west side of Galveston Bay) and 1B (from the west side of Galveston Bay to the Brazos River).

Subregions

The subregion boundaries developed for TCRMP planning purposes were delineated according to U.S. Geological Survey (USGS) Hydrologic Unit Code (HUC)-10 watersheds, bounded landward by the GLO, Coastal Zone Boundary.

These subregions:

- Highlight similarities in coastal attributes;
- Coincide neatly with the bay systems;
- Provide for local-level analysis and combine to make larger units for landscape-level analysis; and
- Allow for contiguous coverage across the Texas coast.

Figure 4-4 shows the 2023 subregions, which have been changed since the 2019 TCRMP. From the original 68 subregions used in the 2017 and 2019 TCRMPs, several subregions were combined to remove smaller areas. Gulf beaches and dunes were originally included as their own individual subregions in the 2017 and 2019 TCRMPs and in the 2023 TCRMP, the Gulf-facing beaches and dunes are included as part of the next landward subregion along the Gulf shoreline. For those regions containing Gulf-facing beaches and dunes, it is assumed that the foredune complex and the entire Gulf-facing beach falls within each subregion. The planning regions extend to the gulfward boundary of the state, three leagues (10.35 miles) out into the Gulf of Mexico. There is a new total of 48 subregions.

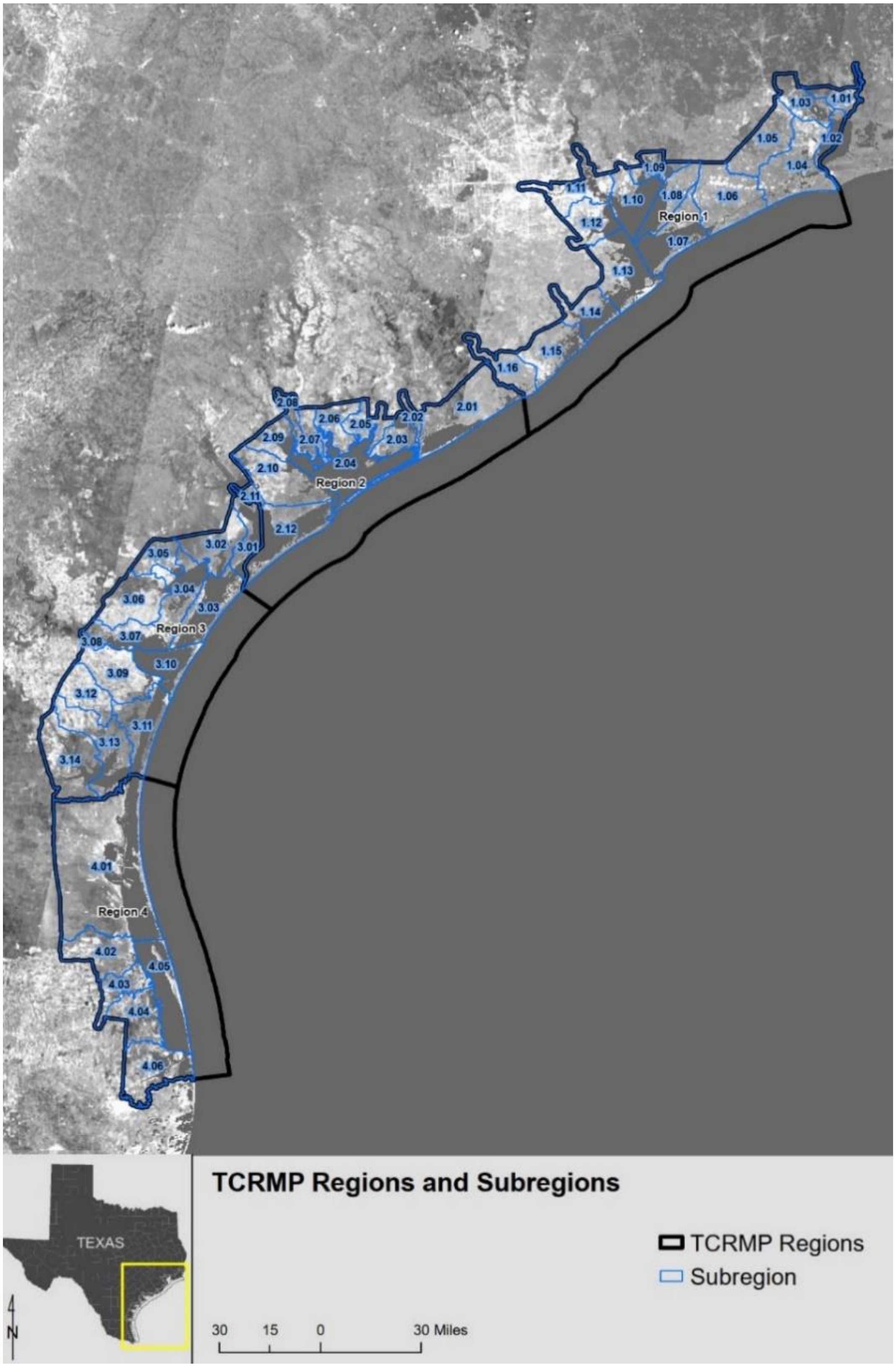


Figure 4-4. Texas Coastal Subregions

The list of subregions is provided in **Table 4-2**. Maps showing the location of each subregion are provided in **Figure 4-5** through **Figure 4-8**.

Table 4-2. Planning Subregions

Region	Subregion ID	Subregion Name	Descriptions
1	1.01	Adams Bayou-Sabine River, Cow Bayou	Bordered on the east by the Sabine River; does not include Sabine Lake; Includes the city of Orangefield and the Orange County Airport; includes the Adams Bayou Unit of the Lower Neches Wildlife Management Unit.
	1.02	Old River Bayou	Includes the Old River Unit of the Lower Neches WMA, western portion of Sabine Lake, and the eastern shore of the GIWW from the mouth of the Neches to the Port Arthur Ship Channel.
	1.03	Tenmile Creek-Neches River	Includes the Neches River, Port Neches, and the Port of Beaumont; the Port of Beaumont is the nation's fourth largest seaport by tonnage; several large industrial facilities (ExxonMobil refinery, Goodyear Beaumont, DuPont); Includes the Nelda Stark Unit of the Lower Neches WMA.
	1.04	Salt Bayou	Includes the cities of Nederland, Groves, and Port Arthur; includes the GIWW from Spindletop Ditch to the Port Arthur Ship Channel, and the Taylor Bayou canal; Includes the Gulf-facing beach stretching from the Sabine River at the Texas-Louisiana border to approximately 22 miles southwest.
	1.05	Hillebrandt Bayou, Lower Neches Valley Authority Canal-Taylor Bayou	Includes most of the city of Beaumont and agricultural lands to the south of Beaumont; encompasses all of Hillebrandt Bayou and the intersection of the south and north forks of Taylor Bayou; Includes the towns of Winnie, Hamshire, and Taylor Landing.
	1.06	Spindletop Ditch	Includes the southern portion of the McFaddin National Wildlife Refuge (NWR), most of the Anahuac NWR, and High Island; includes the GIWW from Spindletop Ditch to the East Bay delta, and the eastern portion of Rollover Bay; Includes the Gulf-facing beaches from the western end of Subregion 1.04 to approximately 20 miles southwest (previously Rollover Pass).
	1.07	Cane Bayou	Includes Bolivar Peninsula from Bolivar Pass to Bolivar Roads; includes Port Bolivar, Crystal Beach, and Caplen; includes all of East Bay, the Moody NWR, and the western portion of the Anahuac NWR; Includes the Gulf-facing beaches from the western end of Subregion 1.06 (previously Rollover Pass) along Bolivar Peninsula to the Galveston Ship Channel (Bolivar Roads).
	1.08	East Fork Double Bayou	Includes the town of Anahuac except portion adjacent to Lake Anahuac; includes the Anahuac Channel and the Trinity River where it spills into Trinity Bay, the Trinity River channel, and Double Bayou (east and west forks); includes the eastern portion of the Trinity delta and Trinity Bay.
	1.09	Old River-Trinity River	Includes the Trinity River from Mac Bayou to the Anahuac Channel; includes Lake Anahuac and the portion of the city of Anahuac adjacent to Lake Anahuac; Includes most of the Trinity River delta, Dutton Lake, Lost Lake, Old River Lake, Lake Charlotte.
	1.10	Adlong Ditch-Cedar Bayou, Cedar Bayou-Frontal Galveston Bay	Includes Cedar Bayou and the eastern portion of Baytown; most of this subregion does not include bay shoreline; Includes the northeast portion of Galveston Bay from the Houston Ship Channel to the Trinity River delta; includes the Galveston/Trinity Bay shoreline from just east of Baytown to Beach City; Includes spoil islands along the Galveston Ship Channel.

Region	Subregion ID	Name	Descriptions
	1.11	Buffalo Bayou-San Jacinto River	Includes Buffalo Bayou from central Houston to Galveston Bay, and most of the City of Baytown; includes the San Jacinto River from Lake Houston to Galveston Bay; includes the Port of Houston and the Houston Ship Channel to Morgan's Point; the Port of Houston is the nation's second largest port by tonnage.
	1.12	Clear Creek-Frontal Galveston Bay	Includes the northwestern portion of Galveston Bay from Morgan's point to Kemah; includes Clear Lake; includes portions of Friendswood, League City, Webster, Seabrook, La Porte and the Ellington Field Joint Reserve Base (EF JRB).
	1.13	Dickinson Bayou	Includes Galveston Island from Bolivar Roads to just north of Jamaica Beach; Includes the Texas City dike and the Galveston Ship Channel from Bolivar Roads to Middle Pass; Includes the southwestern portion of Galveston Bay and the eastern portion of West Bay; Includes the cities of Galveston, Texas City, La Marque, and Dickinson; Texas City houses one of the largest petrochemical refinery complexes in the United States; Includes the Gulf-facing beaches from the Galveston Ship Channel (Bolivar Roads) along Follets Island to Galveston Island State Park.
	1.14	Halls Bayou, Mustang Bayou	Includes Galveston Island from just north of Jamaica Beach to San Luis Pass; Includes the city of Liverpool; Includes Chocolate Bayou and Chocolate Bay, and most of West Bay; Includes the northeastern portion of the Brazoria NWR; Several chemical processing plants and water reservoirs are located in this subregion; Includes the Gulf-facing beaches from Galveston Island State Park along Follets Island to San Luis Pass.
	1.15	Lower Oyster Creek	Includes Follet's Island and barrier landforms from San Luis Pass to the Brazos river; Includes the towns of Brazosport, Surfside, Quintana, Freeport, and Lake Jackson; Does not include the Brazos River; Includes most of the Brazoria NWR and the portion of the Justin Hurst WMA east of the Brazos River; Home to several chemical processing plants including Dow chemical company's largest facility; Includes the Gulf-facing beaches from San Luis Pass to the Brazos River.
	1.16	Dry Bayou-Brazos River, Lower San Bernard River	This subregion encompasses the Brazos River from the Brazoria reservoir to its mouth at the Gulf of Mexico and the San Bernard River from where it enters the coastal region to its terminus; Includes the Justin Hurst WMA; Includes a small portion of the Dow chemical facility; Includes the GIWW from the Brazos River to the San Bernard River; Includes the Gulf-facing beaches from the Brazos River to the San Bernard River.
2	2.01	East Matagorda Bay, Water Hole Creek-Caney Creek, Peyton Creek-Live Oak Bayou	Includes the Cedar Lakes area and the terminus of the San Bernard River, as well as East Matagorda Bay; Includes most of the San Bernard NWR and Big Boggy NWR; Includes the bay fringing marshes of Matagorda peninsula east of the Colorado River and fringing marshes and shoreline adjacent to the GIWW along the north shore of East Matagorda Bay to just north of the town of Matagorda; Includes the GIWW from the San Bernard River to the city of Matagorda; Does not include the Colorado River; Includes the towns of Bay City and Sargent, and residential development along Caney Creek; Includes Lake Austin, Chinquapin, and Live Oak Bayou; Large swaths of undeveloped lands, including fresh and estuarine marsh and upland areas; The Lyondell Bassell chemical plant is located adjacent to Little Boggy Creek; Includes the Gulf-facing beaches from the San Bernard River to the Colorado River.

Region	Subregion ID	Name	Descriptions
	2.02	Jones Creek-Colorado River	Narrowly encompasses the Colorado River from where it enters the coastal zone to its outlet at the Gulf of Mexico; Includes most of the town of Matagorda; Includes the GIWW from Matagorda to just east of Baxter Island; Excludes much of the estuarine marsh adjacent to the Colorado River between the GIWW and the Gulf of Mexico.
	2.03	East Branch Mad Island Slough-Matagorda Bay	Includes Matagorda Peninsula from the Colorado River to the Matagorda Ship Channel; Includes much of the marsh complex on the east end of Matagorda Bay, but excludes Oyster Lake; Also includes the South Texas Nuclear Plant and cooling water reservoir; Includes the Gulf-facing beaches from the Colorado River along the Matagorda Peninsula to the Matagorda Ship Channel.
	2.04	Matagorda Bay	Includes almost all of the open water areas of Matagorda Bay east of the Lavaca River to the Gulf of Mexico, but not all of the adjacent shoreline and fringing marshes along Matagorda Peninsula; Includes Lavaca Bay, Keller Bay, Carancahua Bay, Tres Palacios Bay, and Oyster Lake; Includes the Gulf-facing beaches from the Matagorda Ship Channel to Pass Cavallo.
	2.05	Tres Palacios River	Includes the towns of Blessing, Palacios, and Collegeport, and the Matagorda Bay shorelines at Turtle Bay and Tres Palacios Bay.
	2.06	East Carancahua Creek	Includes the Matagorda Bay shorelines at Carancahua Bay and the southwestern portion of Turtle Bay.
	2.07	Cox Creek	Includes the northeastern shoreline of Lavaca Bay, and extensive swaths of undeveloped land; The town of Point Comfort, and the Alcoa Point Comfort aluminum facility and Formosa Plastics are located adjacent to Lavaca Bay; includes the towns of Lolita, La Ward, and Olivia.
	2.08	Keller Branch-Lavaca River	Includes the Lavaca River until it enters Lavaca Bay, the southern portion of Lake Texana, and Swan Lake, as well as the northern portion of Formosa Plastics.
	2.09	Arenosa Creek, Placedo Creek	This subregion consists mainly of wetlands and agricultural fields between the Lavaca River and the town of Placedo; includes the northeastern portion of Port Lavaca; Includes the northern portion of Lavaca Bay and all of Placedo Creek.
	2.10	Chocolate Bayou, Powderhorn Lake-Matagorda Bay	Includes the southern portion of Port Lavaca and extensive agricultural fields to the northwest and southwest, towards the towns of Bloomington and Long Mott, respectively; Includes Chocolate Bay and the western portions of Lavaca Bay and Matagorda Bay down to Matagorda Island; Includes most of Port O'Connor, Indianola, and Magnolia Beach; Includes the Whitmire Unit of the ANWR and a small portion of the marshes along the north end of Matagorda Island unit of the ANWR; Includes the Gulf-facing beaches from Pass Cavallo to Sunday Beach Pass.
	2.11	Black Bayou-Green Lake	Does not actually include much of Green Lake; Includes the portion of the Victoria Barge Canal south of Green Lake; Includes Mission Lake and the adjacent wetlands and agricultural fields.

Region	Subregion ID	Subregion Name	Descriptions
	2.12	San Antonio Bay-Espiritu Santo Bay	Includes most of Matagorda Island, excluding a small portion of the marshes along the north end; Includes the towns of Seadrift and the southern portion of Port O'Connor; Includes the GIWW from Matagorda Bay to San Antonio Bay; includes the eastern portion of San Antonio Bay; includes the Matagorda Island Unit of the ANWR; includes the Second Chain of Islands, Ayres Bay, and Bay Cove; Includes the Gulf-facing beaches on Matagorda Island from Sunday Beach Pass to Cedar Bayou.
3	3.01	San Antonio River-Guadalupe River	Includes Hynes Bay, the western portion of San Antonio Bay, and Mesquite Bay, and the bayous and marshes between Hynes Bay and Mission Lake; Does not include any part of Matagorda or San Jose Island; Includes most of Blackjack Peninsula, the ANWR, and most of the GIWW and associated dredge spoil islands along Blackjack Peninsula; Includes the towns of Austwell and Tivoli; Extensive whooping crane activity in this area.
	3.02	Saint Charles Bay, Copano Creek	Includes the northern and western portions of Blackjack Peninsula, Lamar Peninsula, and the extensive agricultural fields surrounding Austwell; Includes all of St. Charles Bay and the adjacent shorelines and marshes along the eastern half of Lamar Peninsula and western portion of Blackjack Peninsula; Includes a large portion of the ANWR, as well as Goose Island State Park; Extensive whooping crane activity in this area; Includes the towns of Lamar and Holiday Beach; Includes the northeastern corner of the Copano Bay shoreline.
	3.03	Aransas Bay	Includes all of Aransas Bay and the portion of the GIWW between Blackjack Peninsula and Dagger Island; includes the southwest corner of Blackjack Peninsula and a small portion of the ANWR; Includes all of San Jose Island; Includes the cities of Fulton, Rockport, and Aransas Pass; Includes the Gulf-facing beaches along San Jose Island from Cedar Bayou to Aransas Pass.
	3.04	Copano Bay	Includes all of Copano Bay and Port Bay, agricultural fields near Bayside, and the back half of Live Oak Peninsula; includes the city of Gregory, Copano Village, and the northern portion of Ingleside; Does not include Mission Bay.
	3.05	Mission River	Includes the Mission River and all of Mission Bay and extensive range lands and agricultural fields in Refugio county.
	3.06	Lower Aransas River, Chiltipin Creek	Includes the cities of Sinton, Taft, and Tradewinds; Southern portion of subregion primarily agricultural land; Northwest portion contains the majority of the lower Aransas River, which is bordered by extensive freshwater wetlands; The Aransas River drains into Copano Bay.
	3.07	Nueces Bay-Corpus Christi Bay	This subregion is bordered by the Nueces River, but only includes a portion of the river at its confluence with Nueces Bay; Includes all of Nueces Bay and the northern portion of Corpus Christi Bay and extensive marshes along the western portion of subregion; Northern portion dominated by agricultural lands; Contains the cities of Portland and Ingleside in the eastern portion.
	3.08	Bayou Creek-Nueces River	Contains the Nueces River; Development is extensive on the southern bank of the river; On the northern bank, estuarine and palustrine marshes are dominate land cover.
	3.09	Oso Creek	Includes the cities of Corpus Christi and Chapman Ranch; The Port of Corpus Christi is the fifth largest in the U.S.; Includes Oso Bay and the bay shorelines of Corpus Christi Bay.

Region	Subregion ID	Name	Descriptions
	3.10	Frontal Corpus Christi Bay	Includes Mustang Island and a small portion of the northern end of North Padre Island; Includes the open water portion of Corpus Christi Bay; includes the islands to the south of the Corpus Christi Ship Channel; Includes the City of Port Aransas; Includes the Gulf-facing beaches along Mustang Island from Aransas Pass to Access Road 4 near Whitecap Beach.
	3.11	Upper Laguna Madre	Includes the northern portion of Padre Island National Seashore; Includes a portion of the city of Corpus Christi; Extensive development on the northern bay margins, including Flour Bluff and North Padre Island; Includes the Gulf-facing beaches along the northern portion of North Padre Island from Access Road 4 near Whitecap Beach to Boggy Slough near Baffin Bay.
	3.12	Petronila Creek	Contains the cities of Petronila and Tierra Grande; Majority of land used for cultivated crops; includes the northern branch of Petronila Creek.
	3.13	Alazan Bay-Baffin Bay	Northwest portion primarily composed of cultivated crops; Southeast portion contains Baffin Bay and Alazan Bay, which are fringed by estuarine and palustrine marshes; includes the lower portion of Petronila Creek as it flows into Alazan Bay.
	3.14	Chiltipin Creek-San Fernando Creek, Lower Santa Gertrudis Creek, Jaboncillos Creek, Cayo del Grullo	Includes the Kingsville Naval Air Station (NAS); Contains primarily agricultural land; Includes Baffin Bay and Laguna Salada; includes Loyola Beach and Riviera Beach.
4	4.01	Middle Laguna Madre	Includes a large portion of Padre Island National Seashore and part of the Port Mansfield Channel, which separates North Padre and South Padre Island; Includes the Saltillo Flats and Red Fish Bay; Includes the city of Armstrong; Includes the Gulf-facing beaches along the southern portion of North Padre Island form Boggy Slough to Mansfield Cut.
4	4.02	East Main Drain-Laguna Madre	Includes the city of Port Mansfield and the city of San Perlita; includes extensive agricultural lands and windmills; includes the Raymondville Drain and the Willacy/Hidalgo Drain as they enter the Laguna Madre.
4	4.03	Upper Pilot Channel-Laguna Madre, Lower Arroyo Colorado	Includes extensive estuarine marshes on the bay side of the Lower Laguna Madre and is composed of primarily cultivated croplands on the western side of the subregion; Includes the city of Rio Hondo; Includes the southern portion of the Arroyo Colorado.
4	4.04	Laguna Atascosa	Includes the Laguna Atascosa NWR, which is composed primarily of freshwater wetlands surrounding the Laguna Atascosa; Includes Arroyo City, most of Laguna Vista, and Bayview.
4	4.05	Lower Laguna Madre	Includes South Padre Island and the southern portion of Padre Island National Seashore; Includes the southern portion of the Port Mansfield Channel, which separates North Padre and South Padre Island; Includes the open bay waters of the Lower Laguna Madre; Includes portions of the Lower Rio Grande Valley NWR and Laguna Atascosa NWR; Includes the Gulf-facing beaches along South Padre Island from Mansfield Cut to the Brownsville Ship Channel (Brazos Santiago Pass).

Region	Subregion ID	Subregion Name	Descriptions
	4.06	Brownsville Ship Channel, Outlet Rio Grande	Includes the Port of Brownsville on the southernmost tip of Texas, which facilitates trade between the U.S. and Mexico; Includes the cities of Los Fresnos, Port Isabel and the eastern portion of Brownsville; Includes the estuaries of Bahia Grande, South Bay, and portions of the Lower Laguna Madre; includes the Lower Rio Grande Valley NWR, portions of the Laguna Atascosa NWR, and Boca Chica State Park; Includes the northern bank of the Rio Grande, which is among the longest river systems in North America and constitutes the border between Mexico and the United States; Includes the Gulf-facing beaches from the Brownsville Ship Channel (Brazos Santiago Pass) to the Rio Grande at the U.S.-Mexico border.

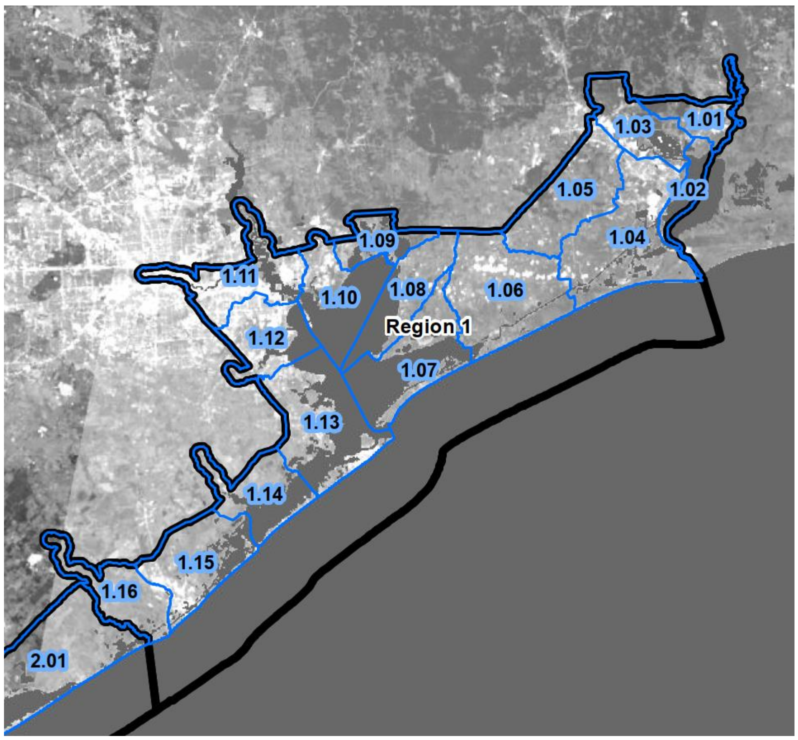


Figure 4-5. Region 1 Subregions

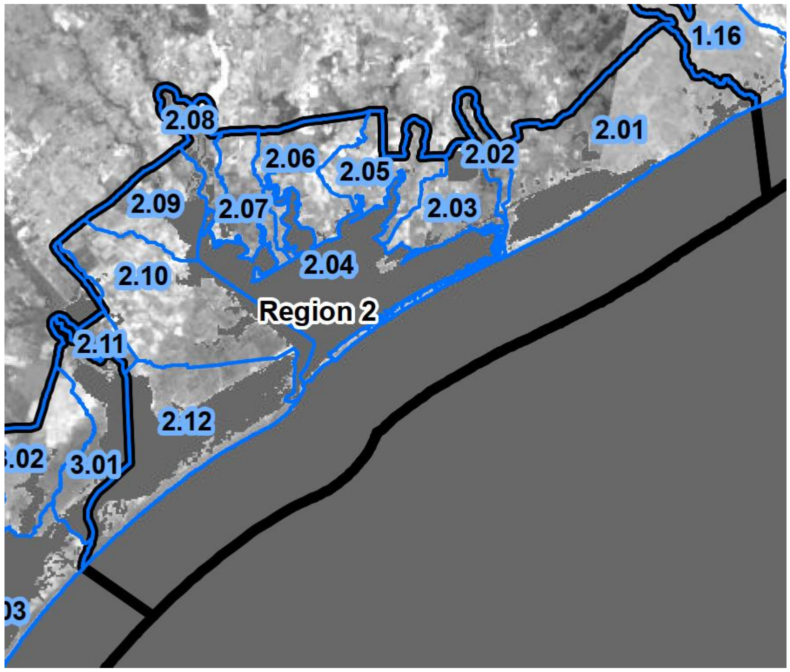


Figure 4-6. Region 2 Subregions

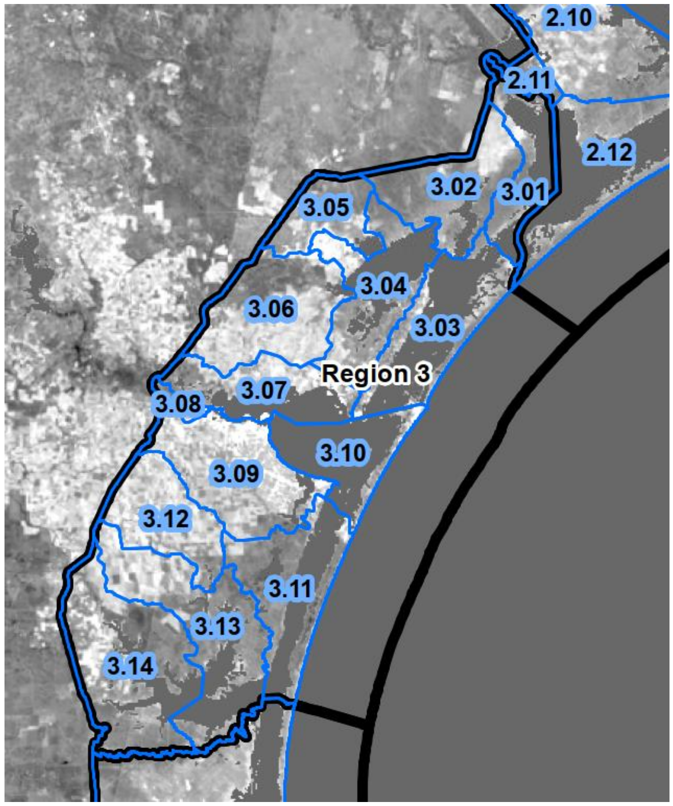


Figure 4-7. Region 3 Subregions

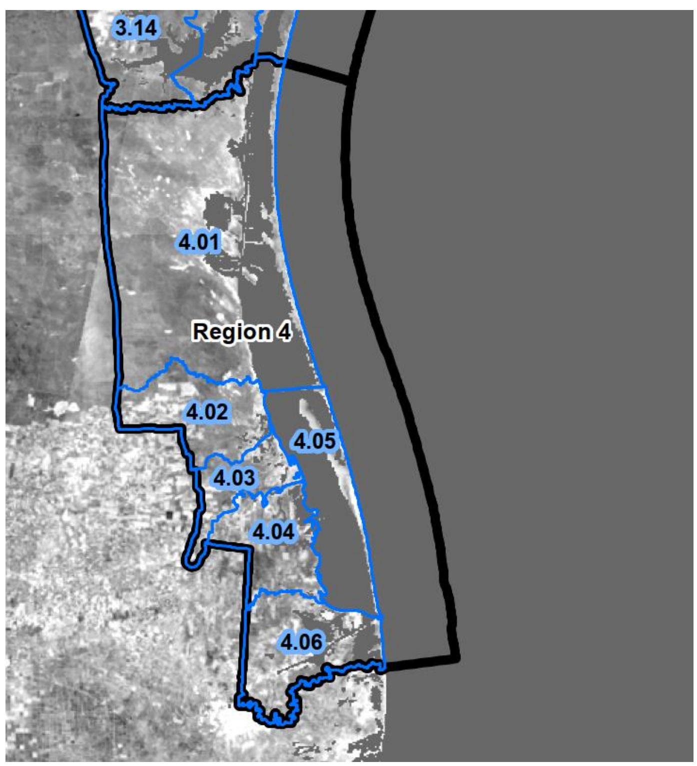


Figure 4-8. Region 4 Subregions

4.2 Coastal Resiliency Framework

The Coastal Resiliency Framework was used to guide the coastal planning efforts. The framework attempts to relay the development of vulnerability along the coast, how vulnerability is assessed, and the steps taken to improve the coast by reducing areas of risk or vulnerability. The various elements of the framework are shown in **Figure 4-9** and described in detail below.

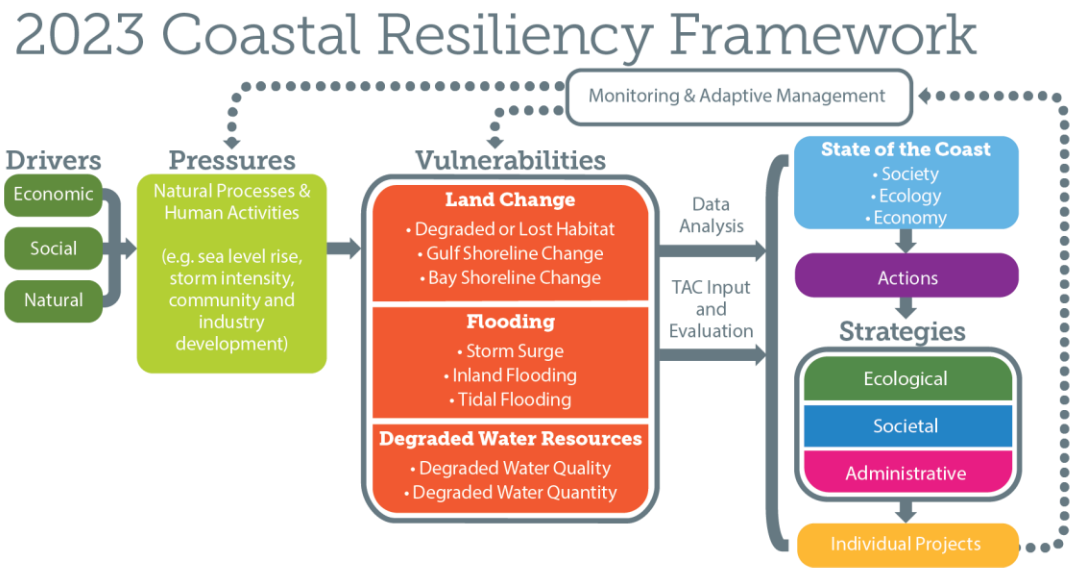


Figure 4-9. 2023 Coastal Resiliency Framework

- **Drivers** – Social, economic, or natural influences on the current conditions of the coast that are largely external to the coastal system and are instigated by need, including demand for food, health, clean water, energy, and a healthy environment.
- **Pressures** – Pressures are the human activities and natural processes, typically large-scale and long-term, which may lead to the development of vulnerabilities along the coast. Examples of coastal pressures include coastal resource consumption (e.g., oil and gas extraction, fishing), population growth, and RSLR.
- **Vulnerabilities** – Natural and human-induced disturbances which, if left unaddressed, will have or will continue to have adverse impacts on infrastructure, natural resources, economic activities, and the health and safety of Texas residents. Example vulnerabilities include degraded or lost habitat and bay shoreline change.
- **Data Analysis** – The Planning Team reviewed existing data, and any updated documents, community plans, project databases, studies, and datasets since the publication of the 2019 TCRMP. This information was used to identify new projects to include in the project database and carry forward to project evaluation and prioritization.
- **TAC Input and Evaluation** – The TAC provided feedback on coastal vulnerabilities leading to the current state of the coast; this feedback was later used to assess expected project performance, including priority, feasibility, and ability to mitigate for or improve coastal vulnerabilities. The positioning of this arrow emphasizes how influential stakeholders are on the TCRMP Planning Team's decision making.
- **State of the Coast** – The current condition of the Texas coast, analyzed through societal, ecological, and economic lenses. The information was gathered through physical and environmental assessments, literature reviews, TAC input, as well as anecdotal information about coastal communities and environments, and used to inform how resiliency strategies can be implemented to address Texas coastal vulnerabilities.
  - **Society** relates coastal communities of Texas and the coastal vulnerabilities they face. For the 2023 TCRMP, there is more of a focus on Low- to Moderate-Income (LMI) areas and the overall social vulnerability of Texans, as well as the impact that the future demographic landscape of Texas may have on the state's risk to coastal vulnerabilities.

  - **Ecology** stems primarily from the TAC's input and describes the existing state of Texas coastal ecosystems, ongoing habitat degradation, and the endangerment of coastal organisms.
  - **Economy** includes the current concerns of coastal businesses and industries ranging from both tourism and ecotourism to commercial and recreational fishing, ports and harbors (trade), and refineries.
- **Actions** – Actions frame the concept of multiple projects functioning together to benefit coastal resiliency at multiple scales by utilizing relevant, up-to-date coastal datasets and stakeholder inputs from the TAC to synthesize information regarding current vulnerabilities threatening the Texas coast. Additionally, this "data first" approach will equip project proponents with the tools needed to identify and utilize specific resiliency strategies by proposing specific projects to combat coastal vulnerabilities on a local and regional scale. Each action will include multiple projects that work together to mitigate the same coastal pressures and associated vulnerabilities. The actions are described in **Section 5.7**, below.
- **Strategies** – Categories of restoration and protection measures for coastal resiliency. Collectively, the resiliency strategies and their proposed projects address the vulnerabilities identified over the course of the planning process. The resiliency strategies are classified into three primary categories: Ecological Resiliency, Societal Resiliency, and Administrative Resiliency, described further in **Section 4.2.2** below.
- **Individual Projects** – Recommended Tier 1 projects to be implemented as part of the TCRMP.
- **Monitoring & Adaptive Management** - The administration, supervision, operation, maintenance, and preservation of the projects being constructed.

4.2.1 Vulnerabilities

The 2023 TCRMP considers eight vulnerabilities along the Texas coast. Using inputs from the Spring 2021 TAC meetings and the Qualtrics Survey, these vulnerabilities were refined. Of the eight vulnerabilities, Degraded or Lost Habitat, Gulf Shoreline Change, and Bay Shoreline Change fall under vulnerability due to land change, while Inland Flooding, Storm Surge, and Tidal Flooding fall under vulnerability due to flooding, and Degraded Water Quality and Degraded Water Quantity fall under vulnerability due to degrading water resources.

- **Degraded or Lost Habitat –** This vulnerability is brought on by the deterioration or loss of coastal ecosystems due to changes in conditions such as water quality, land use, sea level, water supply, and sediment supply. These changes can weaken the natural defenses from storm surge or other coastal flood events that are provided by wetlands, mangroves, coastal prairies, and other coastal habitats, decreasing the value that coastal ecosystems provide. Once degraded or lost, these ecosystems are less able to adapt to changing future conditions.

- **Gulf Shoreline Change –** This vulnerability is derived from the erosion of barrier islands and Gulf-facing beaches and dunes. These coastal features are the first line of defense from coastal storms and are prone to erosion, overwash, and breaching. Losses of these systems place homes, businesses, industries, and exposed ecosystems at risk of being affected by high tides and storm surge. Among other factors, increased onshore development and construction of coastal structures in the littoral zone can contribute to sediment losses or restricted transport along the Gulf shoreline. The amount of sediment (or lack thereof) available for restoration can contribute to this vulnerability.

- **Bay Shoreline Change –** This vulnerability is related to the increase of erosion along bay shorelines in response to pressures such as RSLR, loss of shoreline vegetation, decline in sediment supply to the bay, and increasing vessel size and traffic along coastal waterways. These pressures are also exacerbated by increasing volatile weather patterns along the coast.

- **Inland Flooding –** Extreme rainfall events, riverine overflow, and increased runoff contribute to this vulnerability, creating risk to coastal communities and inland urban areas. Inland flooding can be exacerbated when buildings are not sufficiently elevated, stream flow and function is obstructed, large amounts of impervious materials are used in development, or when vegetated or open space areas are removed.

- **Storm Surge –** Coastal storm surge can cause significant negative impacts on Gulf and bay shorelines, coastal communities, and ecosystems. As barrier islands, beaches and dunes, and bay shorelines are eroded and vital coastal habitats are diminished, more wave energy and surge can propagate inland. Storm surge can also directly contribute to beach, dune, and bay shoreline erosion, affect beach and dune morphology, cause flooding or damage to buildings and structures, and endanger evacuation routes.

- **Tidal Flooding –** More communities are seeing increased risks from nuisance flooding to roadways and nearshore developments, caused by higher water levels as tides advance inland as a result of SLR and local subsidence (collectively known as "RSLR"). Tidal flooding can be exacerbated when buildings and streets are not sufficiently elevated, shoreline habitat buffers are lost, drainage pathways are obstructed, beaches and dunes are not properly nourished, or when shoreline erosion continues unchecked.

- **Degraded Water Quality –** As runoff from upstream farming, ranching, and industrial activities re-enters watersheds, the quality of freshwater reaching coastal waterways is becoming more and more degraded. Increased impervious surfaces and loss of coastal wetlands in coastal communities can lead to increased stormwater runoff and alter vital processes that maintain and control water quality in coastal waterways. Among others, water quality concerns increase when healthy estuarine and freshwater wetlands are not protected, oil or hazardous chemical spills occur, development takes place in floodplains, and/or runoff pollution is not well managed.

- **Degraded Water Quantity –** The availability of freshwater to coastal ecosystems is being reduced as water is increasingly being diverted upstream for farming, ranching, and industrial activities. Increasingly volatile weather events, such as more frequent droughts and extreme rainfall events, are adding to the negative effects related to water quantity along the Texas coast. Degraded water quantity concerns develop when freshwater inflows and/or hydrologic functions within watersheds are not adequately managed or normalized to accommodate for both flood and drought conditions.

4.2.2 Resiliency Strategies

TCRMP development efforts—including TAC input, literature review, and GLO Planning Team analyses—collectively produced a set of recommended projects proposed along the Texas coast. The similarity in project types recommended resulted in the development of resiliency strategies representing a category of approaches or methodologies that can be used to restore and protect the Texas coast and enhance its resiliency. These strategies provide a means to view coastal resiliency in a holistic manner that recognizes and elevates the synergies possible for future projects.

The strategies were developed and proposed in order to provide focal areas for the GLO to target as it works to restore, enhance, and protect the coast and to give stakeholders and interested parties an understanding of the methods recommended to enhance the coast, while allowing for flexibility in the types of projects that are used to achieve these goals. Collectively, the strategies identify the need to restore specific coastal systems in Texas, pinpoint the areas of greatest need in these systems, and present several proposed policies- or project-type solutions.

The resiliency strategies are separated into three broad categories: ecological, societal, and administrative, described below. These resiliency strategies and categories are the same that were developed for the 2019 TCRMP.

Ecological Resiliency

Ecological Strategies are those that relate most directly to the enhancement (e.g., protection and restoration) of natural coastal environments.

- **Beach Nourishment & Dune Enhancement** – Provides renourishment of sediment to beach and dune complexes to address erosion, shoreline loss and limited sediment supply. This includes Gulf-facing and back bay beaches.
  - Vulnerabilities Potentially Addressed: Degraded or Lost Habitat; Bay Shoreline Change; Gulf Shoreline Change; Storm Surge; Tidal Flooding.

- **Wetland Planning, Restoration, and Monitoring** – Restores, conserves, and protects ecologically significant wetlands through shoreline protection, material placement, hydrologic restoration, and other conservation and restoration practices.
  - Vulnerabilities Potentially Addressed: Degraded or Lost Habitat; Bay Shoreline Change; Gulf Shoreline Change; Storm Surge; Tidal Flooding.
- **Upland Planning, Conservation, and Monitoring** – Restores, conserves, and protects ecologically significant coastal uplands through land acquisition, hydrologic restoration, and other conservation and restoration practices.
  - Vulnerabilities Potentially Addressed: Degraded or Lost Habitat; Bay Shoreline Change; Inland Flooding; Degraded Water Quality; Degraded Water Quantity.
- **Oyster Reef Planning, Restoration, and Monitoring** – Provides for the identification and restoration or re-establishment of productive oyster reefs.
  - Vulnerabilities Potentially Addressed: Degraded or Lost Habitat; Bay Shoreline Change; Gulf Shoreline Change; Storm Surge; Degraded Water Quality.
- **Rookery Island Protection, Restoration, and Creation** – Provides for the identification and restoration or re-establishment of rookery island nesting habitats to support colonial waterbird populations.
  - Vulnerabilities Potentially Addressed: Degraded or Lost Habitat; Bay Shoreline Change.
- **Freshwater Inflow and Tidal Exchange Enhancement** – Provides for the identification and mitigation of hydrologic and water quality impairments within the major delta, lagoon, and bay systems along the coast.
  - Vulnerabilities Potentially Addressed: Degraded or Lost Habitat; Degraded Water Quality; Degraded Water Quantity.

Societal Resiliency

Societal Resiliency Strategies are those that relate most directly to the enhancement (e.g., protection and improvement) of manmade coastal infrastructure and communities.

- **Water-based Transit Enhancement** – Addresses water-based navigation infrastructure improvement needs along the coast and identifies new opportunities to support the Beneficial Use of Dredge Material (BUDM) in State-owned waters.
  - Vulnerabilities Potentially Addressed: Degraded or Lost Habitat; Bay Shoreline Change; Storm Surge.
- **Land-based Transit Enhancement** – Addresses land-based transit infrastructure improvement needs in and around coastal communities and identifies opportunities to incorporate future conditions and ecological considerations into final design.
  - Vulnerabilities Potentially Addressed: Degraded or Lost Habitat; Bay Shoreline Change; Gulf Shoreline Change; Storm Surge; Inland Flooding; Tidal Flooding.
- **Storm Surge Suppression** – Relays results of federal, state, and regional storm surge suppression studies and identifies how other projects in the TCRMP interact with the proposed protections. Smaller-scale projects may also be included, if applicable.
  - Vulnerabilities Potentially Addressed: Storm Surge.
- **Community Infrastructure Planning and Development** – Proposes proactive, resilient planning opportunities in coastal communities and identifies projects to support communities' needs while considering future conditions.
  - Vulnerabilities Potentially Addressed: All.

Administrative Resiliency

Administrative Resiliency Strategies are those that relate most directly to the enhancement of policies, large-scale planning efforts, and other non-structural solutions that nonetheless impact coastal resiliency. These resiliency strategies can potentially address all the vulnerabilities assessed in the TCRMP.

- **Programs** – Identifies GLO-administrated or supported programs related to coastal management for the purpose of proposing or requesting dedicated annual funding.
- **Policies** – Identifies legislative and/or administrative changes to uphold coastal resiliency principles.
- **Plans** – Identifies completed, ongoing, or proposed plans that guide the screening, design, and/or implementation of proposed coastal resiliency projects.

4.3 Resiliency Design Guides

The Resiliency Design Guides were developed by project type and feature general design guidance that should be considered when developing projects aimed towards coastal resiliency related to such areas as project concept development, permitting, design, and monitoring and maintenance. Project-specific design should be assessed for local relative sea level trends, wave conditions, ecological factors, during each project's engineering and design (E&D) phase to refine these planning level design templates. Generally, the GLO recommends that a 50-year service life be assumed for each project during final design.

For the 2023 TCRMP, a series of resiliency design guides were designed to help communities with the design, permitting, construction, and maintenance of coastal resiliency projects. The series included guides for Beaches and Dunes, Delta Management, Oyster Reefs, Rookery Islands, Shoreline Stabilization, Wetland Protection, Stormwater Retrofits, and Funding Programs. These guides can be found in **Appendix D** and on the TCRMP website, www.glo.texas.gov/crmp. A brief description of each guide is included below.

4.3.1 Beaches and Dunes Guide

Beach and dune nourishment are NbS that protect coastal communities and upland infrastructure from impacts due to storm surge and waves. The beach and dunes act as a buffer between upland systems and the water, dissipating wave energy before it can reach vulnerable buildings and infrastructure. These projects also often provide both recreational and environmental benefits. This guide describes key considerations for such projects, and is divided into the following sections:

- **Site Background -** Identify stakeholder, funding sources, and project risks; collect data and review previous studies; and characterize the general physical setting of the study area.
- **Existing & Future Conditions -** Develop an understanding of existing conditions and long-term trends, such as RSLR, to identify issues and establish project goals.
- **Beach Design -** Develop the project design and success criteria, and evaluate alternatives, extent of nourishment, sand needs (quality and quantity), and renourishment interval.
- **Dune Design -** Understanding Texas dunes, their geomorphology, and the strategies necessary to create, restore, and maintain them.
- **Sand Sourcing -** Identify potential sand sources (short- and long-term), assess sediment compatibility, and evaluate the logistics associated with use of that sand.
- **Permitting -** Coordinate with regulatory agencies to implement a project while avoiding and minimizing project impacts.
- **Planning & Construction -** Assess needs for and limitations of construction, develop Plans and Specs, bid and award the contract, and oversee construction.
- **Monitoring -** Regularly assess beach (and sand source, or borrow) conditions to track project performance, fulfill permit requirements, and guide adaptive management.

4.3.2 Delta Management Guide

Deltas and estuaries are some of the most diverse ecosystems within the coastal system, providing vital habitat for fisheries, migratory and colonial birds, and oyster reefs. A delta is the low-lying area of land at or near the mouth of a river resulting from the accumulation of sediment from the river and an estuary is a partially enclosed coastal body of water that receives discharge from a river. The degradation of these habitats is influenced by long-term chronic stressors, such as water quality impairment, pollutants, shoreline armoring, etc. This guide includes:

- **Conceptual –** Develop project goals and identify existing constraints. These are important steps that will shape future planning for a delta or estuary management project.
- **Engineering and Management –** Develop a plan for management and policy activities that is based on engineering and environmental factors.
- **Permitting –** Plan for and complete necessary permitting activities to ensure management plans have a robust design and do not adversely impact the surrounding environment or socioeconomic activity. An engineer should also be identified during this step to complete permit-level (and subsequent) design/installation plans.
- **Monitoring –** Monitoring site conditions tracks the success of delta and estuary management using metrics aligned with goals.
- **Watershed Planning –** Manage watershed inputs to reduce stressors on the delta and estuarine environment.
- **Restoration Alternatives –** Manage watershed inputs and implement restoration activities to support healthy delta and estuarine environments and reestablish more natural hydrology.
- **Engineering Considerations for Delta and Estuary Management:**
  - *Structural* – The location of needs within the watershed and project goals as well as the project budget and timeline will be the primary considerations when selecting which approach to use in a delta/estuary management project.
  - *Non-Structural* – Ecological management strategies are useful when trying to preserve or enhance the natural environment and can be used in conjunction with structural and policy management strategies to further protect habitats.
  - *Ecological* – Identify the connections between ecological components to inform project design.
  - *Study/Policy* – Environmental studies and policies can establish project requirements, such as monitoring and permitting, and should be incorporated early in the project timeline to reduce long-term cost.
- **Resiliency for Delta and Estuary Management –** Understanding the relationship between delta and estuarian vulnerabilities with the concerns they raise, their effect on deltas and estuaries, and possible solutions.

4.3.3 Oyster Reef Guide

Oyster reefs are a valuable resource for coastal communities, offering many benefits to aquaculture, water quality, and shoreline protection. Oyster reefs can naturally keep pace with RSLR and therefore are a valuable tool to maintain the health of coastal ecosystems. This guide will provide concise guidance on how to plan for and design oyster reef enhancement and construction projects, particularly under future RSLR scenarios. The contents of this guide are organized into the following sections:

- **Conceptual –** Develop project goals and identify existing constraints. These are important factors that will shape the design and construction of an oyster reef project.
- **Engineering/Design –** Develop a detailed plan for configuration and construction of an oyster reef based on the project goals and site constraints to provide a strong basis for a healthy oyster reef.
- **Permitting –** Plan for and complete necessary permitting activities to ensure the project has a robust design and does not adversely impact the surrounding environment or socioeconomic activity. An engineer should also be identified during this step to complete permit- level (and subsequent) design/installation plans.

- **Monitoring –** Continued monitoring of an oyster reef enhancement or construction project using metrics aligned with project goals can aid in tracking the success of the reef after construction.
- **Engineering Considerations for Oyster Reef Enhancement:**
  - *Structure Type* – The site characteristics including hydrodynamic and substrate conditions as well as the project budget and timeline will be the primary considerations when selecting what type(s) of structures to use in an oyster reef project.
  - *Tidal Location* – The location and water depth of project will play a considerable role in whether a reef is subtidal or intertidal; however, the sizing of project components can also affect whether the reef is exposed at lower tide conditions. The level of reef submergence can affect how quickly oysters will colonize and grow as well as the efficacy of the reef for wave attenuation and shoreline protection.
  - *Harvesting* – Oyster harvesting allowances will likely be dependent on local agency determinations (i.e., TPWD, any economic or recreational goals for a project, and any water quality concerns identified for a particular site.
  - *Costs* – These costs are estimates for planning purposes only and may require significant refinement based upon specific site conditions. Economies of scale may reduce costs for large-scale projects.
- **Example Sketches for Oyster Reef Enhancement –** Includes a profile view illustrating spacing of oyster reef components and typical elevations relative to tidal datums and a plan view illustrating arrangement of oyster reef components, identify any project constraints, dominant wave, and current directions.
- **Resiliency for Oyster Reef Enhancement –** Understanding the relationship between oyster reef vulnerabilities with the concerns they raise, their effect on oyster reefs, and possible solutions for resiliency and enhancements.

4.3.4 Rookery Island Guide

Historically, the Texas coast has supported many waterbird nesting islands called rookery islands. These islands are critical nesting habitats for many species of coastal birds. Changes to Texas bays from RSLR, extreme weather events, erosion, habitat conversion for human uses, and sediment management practices have resulted in a decrease in waterbird nesting and foraging areas and have left coastal birds more susceptible to inland predators. The purpose of this guide is to provide concise guidance and best practices on how to design, restore, and create Texas coastal rookery islands. To engage in a Rookery Island Creation or Restoration project, refer to the following sections in the guide:

- **Conceptual –** Develop project goals and identify existing constraints. These are important factors that will shape the design and construction of a rookery island enhancement or creation project.
- **Engineering/Design –** Develop a detailed plan for configuration or enhancement of a new or existing rookery island that is based on the project goals and site constraints to provide a strong basis for a healthy rookery island.
- **Permitting –** Plan for and complete necessary permitting activities to ensure the project has a robust design that does not adversely impact the surrounding environment or socioeconomic activity. An engineer should also be identified during this step to complete permit- level (and subsequent) design/installation plans.
- **Monitoring –** Continued monitoring of a rookery island restoration or creation project using metrics aligned with project goals can aid in tracking the success of the island after construction.
- **Profile and Plan View –** Outlines a profile view of a healthy rookery island and a plan view showing possible designs for BUDM placement and ways to enhance existing rookery islands or build new rookery islands.
- **Engineering Considerations for Rookery Islands:**
  - *Wave Climate* – The site characteristics, including waves and hydrodynamic conditions, as well as the project budget and timeline, will be the primary considerations when designing a rookery island enhancement project.

- *BUDM* – BUDM can be used to build up the base elevation of existing rookery islands or to create new islands. The project manager will need to coordinate with the BUDM supplier (USACE or a private entity) regarding the availability and quality of BUDM sources.
- *Vegetation* – Rookery island enhancement and stabilization will take time as vegetation is planted and allowed to grow.
- *Costs* – Costs are based on averages of four rookery island enhancement projects from the 2019 TCRMP that have engineering designs and are beyond the conceptual phase.

- **Resiliency for Rookery Island –** Understanding the relationship between rookery island vulnerabilities with the concerns they raise, their effect on rookery islands, and possible solutions for their creation and restoration.

4.3.5 Shoreline Stabilization Guide

Shoreline stabilization is one method to help reduce the risks posed by flooding and erosion. These risks to coastal communities are generally expected to increase with future RSLR and more extreme weather events and coastal flooding. The purpose of this guide is to provide concise guidance on how to plan for and design coastal shoreline stabilization features, particularly under future RSLR scenarios. This guide is divided into:

- **Shoreline Stabilization Techniques** – This section provides conceptual examples of shoreline stabilization techniques and typical cross-shore profiles.
- **Shoreline Stabilization Alternatives:**
  - *Bulkhead* – Traditional engineered structures like bulkheads can sever the connection between the coast and water.
  - *Vegetation Only* – Nature-based features protect land from erosion, provide crucial habitat for fish and wildlife, and more readily adapt to future coastal conditions than engineered structures.
  - *Living Shoreline (with Breakwater)* – Living shorelines are hybrid green-gray features that reduce erosional impacts while generating ecosystem benefits.
  - *Horizontal Levee* – Horizontal, or "living," levees are storm surge protection features that are more gently sloped than traditional levees and vegetated using native plants.
- **Costs** – These costs are estimates for planning purposes only and may require significant refinement based upon specific site conditions. Economies of scale may reduce costs for large-scale projects.
- **Green and Gray Techniques** – An outline of green, hybrid, and gray techniques that demonstrates their capacity to address coastal vulnerabilities and describes each alternative's benefits and drawbacks.
- **Resiliency Considerations** – When selecting and designing a shoreline stabilization feature, there are three broad aspects of resiliency to consider to determine the most effective technique for a particular site: resiliency to future RSLR and related impacts, existing and intended shoreline conditions, and planning for adaptive capacity. Resiliency measures will depend on the lifespan of the project. Many shoreline stabilization features have a lifespan ranging from ten to 50 years.
- **Engineering** – This section provides a general framework for the engineering steps needed to: Select an appropriate shoreline stabilization from several alternatives; Design the feature to protect against future RSLR; Plan for future maintenance and potential retrofits. Different shoreline stabilization features have various benefits and drawbacks, and there is no one-size fits all approach. The process of selecting and designing a particular feature follows three steps.
  - *Step 1: Site Assessment and Concept Development* – In the first step, the engineer will prepare a comprehensive list of techniques to choose from for a particular site before recommending stabilization alternatives.

- *Step 2: Alternatives Analysis and Preliminary Design* – In the second step, the engineer will conduct a more detailed evaluation to compare the different benefits and drawbacks of the shoreline stabilization techniques developed in Step 1. Conceptual designs will then be developed for each selected alternative based upon site-specific design criteria. Once a preferred alternative is selected, preliminary design may begin.
- *Step 3: Final Design and Construction* – A single alternative should be selected after evaluating the conceptual designs. Final engineering design and planning for construction, post-construction monitoring, and maintenance may begin.

4.3.6 Wetland Protection Guide

Coastal wetlands provide vital habitat for fisheries, shorebirds, and marine organisms, improve water quality, and can provide flood storage and prevent shoreline erosion. Wetland degradation in coastal Texas is primarily influenced by wave energy, low freshwater and sediment input, RSLR, extreme weather events and associated coastal flooding, and increased coastal development. The purpose of this guide is to provide concise guidance on how to plan for and manage resilient wetlands. Its sections are outlined below:

- **Conceptual** – Protecting existing wetlands and creating new wetlands should be undertaken with a careful understanding of the site characteristics and design components. This overview applies to projects establishing new wetlands or projects enhancing existing wetlands.
- **Engineering/Design** – Develop a detailed plan for configuration and construction of engineered wetlands based on the project goals and site constraints to provide a strong basis for a healthy wetland habitat.
- **Permitting** – Plan for and complete necessary permitting activities to ensure the project has a robust design and does not adversely impact the surrounding environment or socioeconomic activity. An engineer should also be identified during this step to complete permit- level (and subsequent) design/installation plans.
- **Monitoring** – Continued monitoring of a wetland restoration or creation project using metrics aligned with project goals can aid in tracking the success of the wetland after construction.
- **Profile and Plan View** – Outlines a profile view showing wetland components and typical elevations relative to tidal datums and a plan view showing wetland components relative to shoreline.
- **Engineering Considerations for Wetland Protection:**
  - *Wave Climate* – The site characteristics including waves and hydrodynamic conditions as well as the project budget and timeline will be the primary considerations when planning a wetland protection project.
  - *BUDM* – To build up the base elevation of existing marshes or build new marshes, the BUDM can be employed by a technique to add the material to the wetland called Thin Layer Placement. The project manager will need to coordinate with USACE regarding the availability and quality of BUDM sources (~12+ months).
  - *Vegetation* – Vegetation can only be planted once the sediment has sufficiently accumulated to achieve a suitable water depth for the plants, considering tidal range. Leaving corridors for wetlands to expand and/or migrate will also be important. The timing of the project is important to consider the sourcing, availability, and seasonality of appropriate native plants.
  - *Costs* – These costs are estimates for planning purposes only and may require significant refinement based upon specific site conditions. Economies of scale may reduce costs for large-scale projects. Land acquisition should also consider future migration areas as sea levels increase.
- **Resiliency for Wetland Protection** – Understanding the relationship between wetland vulnerabilities with the concerns they raise, their effect on wetlands, and possible solutions for their protection.

4.3.7 Stormwater Retrofit Guide

Stormwater retrofits are constructed in the existing urban environment to improve runoff quality and help mitigate flooding. Retrofits include new installations or upgrades to existing stormwater management measures where there is a lack of water quality treatment and/or management of runoff rates. These measures can target trash, sediment, nutrients, bacteria, or other concerns. Often, retrofits can be completed in tandem with other capital projects including roads, parks, and downtown revitalization efforts to achieve multiple benefits and manage cost.

Retrofits are prioritized in areas of identified water quality problems or flood zone, then, multiple retrofit options can be evaluated to determine the most appropriate measure for the site, soil conditions, topography, existing infrastructure, and community goals. All retrofit sites are unique, and no single solution fits all conditions. In the end, the final project should be aesthetically pleasing, satisfy the desired stormwater goals, and have minimal maintenance needs. This guide provides concise guidance on how to plan for, identify, locate, design, construct, and maintain retrofit projects. Sections in this guide include:

- **Retrofit Planning** – Meeting with local government staff, reviewing water quality data and local drainage problems, obtaining maps and plans, considering community master plans, performing field reviews of potential sites, identifying stakeholders, defining if within a Watershed Protection Plan or Total Maximum Daily Load watershed and sketching potential retrofit concepts.
- **Water Quality/Flood Mitigation Assessment** – Modeling the estimated water quality improvements and flood reduction benefits, estimating the stream/habitat benefits, evaluating potential water supply benefits, and considering other public benefits (streets, utilities, parks, etc.)
- **Retrofit Inventory and Evaluation** – Refining conceptual designs, estimating construction and life-cycle costs, identifying potential funding sources/grants, and prioritizing top performing retrofit sites.
- **Design and Permitting** – Performing field surveys, assessing potential cultural and environmental resources, defining soil conditions, obtaining local government guidance, preparing construction plans, sharing plans with stakeholders and obtaining input, finalizing funding sources, and coordinating with the regulatory agencies to obtain approvals.
- **Construction** – Defining construction access, public outreach, initiating the contractor selection process, completing contracts, installing construction phase erosion controls, building the improvements, and revegetating the site.
- **Inspection and Maintenance** – Performing periodic site inspections after major storm events, ensuring proper drainage and vegetation management, removing accumulated sediment and debris, operating a project database to track maintenance requirements, and hosting education outreach events.
- **Retrofit Techniques** – Stormwater retrofits can improve water quality and reduce flood flow rates in existing urbanized areas. As noted above, one size does not fit all, potential retrofit sites are unique and, in some situations, only one type of solution will work while in other areas multiple solutions could function well.

4.3.8 Funding Program Guide

The GLO is working to implement the Tier 1 projects included in the TCRMP by helping stakeholders identify possible funding sources using its newly developed Funding Programs Guide. The main barriers to project implementation are a lack of funding and difficulty for stakeholders to find, prepare for, and write grant applications. Attached in **Appendix D**, the Funding Program Guide gives a list of state and federal funding opportunities that may be considered by project proponents to fund coastal resiliency projects. The funding opportunities are sorted by five general categories: conservation, disaster mitigation, restoration, management, research, and non-point source pollution reduction. Typical project types funded, special requirements, funding details, and application time ranges are shown by funding opportunity on the guide.

5 Technical Assessments

5.1 TAC Vulnerabilities Assessment Results

The eight vulnerabilities considered within the 2023 TCRMP (previously called Issues of Concern or IOCs in the 2017 TCRMP and 2019 TCRMP) are summarized below and detailed further in **Section 4.2.1**.

- Land Change
  - Degraded or Lost Habitat
  - Bay Shoreline Change
  - Gulf Shoreline Change
- Flooding
  - Storm Surge
  - Inland Flooding
  - Tidal Flooding
- Degraded Water Resources
  - Degraded Water Quality
  - Degraded Water Quantity

5.1.1 Qualtrics Surveys

Each TAC member was invited to assess the impact of the eight vulnerabilities within each of the 48 coastal subregions identified in the 2023 TCRMP through a Qualtrics Survey. TAC members were encouraged to only assess subregions with which they had some familiarity, as the results of this assessment were used to help prioritize 2023 TCRMP projects. After a TAC member selected which subregions to assess, the individual was then invited to rank the eight vulnerabilities in each selected subregion according to their levels of concern, and to provide any additional information regarding their assessment of the subregion. In their level of concern ranking, TAC members could select one of six options for each vulnerability, including "?" if they did not have enough knowledge to evaluate the vulnerability for that subregion, or "1" through "5," with "1" corresponding to a low level of concern and "5" corresponding to a high level of concern. Survey questions can be found in **Appendix E**.

The Qualtrics Survey also presented a series of maps that gave additional information for each of the subregions, including TCRMP Regions and Subregions, Shoreline Change, Storm Surge Inundation, Land Cover, Conservation Areas, Conservation Areas by Region, Critical Infrastructure, and Social Vulnerability Index (SVI); data sources for the map layers can be found in **Table 5-1**.

Table 5-1. Data Sources to Develop Qualtrics Map Data Layers

Layers	Data Source
Subregion Areas/Watershed	USGS HUC-10 Watersheds
Essential Facilities (Schools, Medical Care Facilities, Emergency Centers, Police/Fire Stations)	Homeland Infrastructure Foundation-Level Data (HIFLD)

Layers	Data Source
Critical Facilities (Hazardous Materials Facilities, Waste Water Treatment Plants, Oil Refineries, Power Plants, Waste Sites and Outfalls)	HIFLD and CB&I
Transportation Systems (Evacuation Routes, Highways/Railways, Bridges, Bus/Port/Ferry/Airport)	TxDOT
Maintained Channels	USACE
Rookery Islands	Audubon
Wildlife Refuges	U.S. Fish and Wildlife Service (USFWS)/TPWD
Environmentally Sensitive Areas	GLO
Building Stock Building Count, Square Footage Distribution, Dollar Exposure Value	RSMeans 2018 values/Census 2010 data
Digital Elevation Model (DEM)	HRI
National Flood Hazard Layer (NFHL) 1% Annual Flood Risk	FEMA
Shoreline Change Rates	The University of Texas at Austin (UT) Bureau of Economic Geology (BEG) Gulf Shoreline Change Rates, 1950s-2012, and Bay Shoreline Change Rates, 1930s-2010s.
SLR Scenarios (Spatial Distribution of Future Land Cover, Land Loss Open Water Conversion)	NOAA/HRI
Spatial Distribution of Present Land Cover	USFWS - NWI + NOAA – Coastal Change Analysis Program (C-CAP)
Percent Developed Imperviousness	USGS National Land Cover Database (NLCD)
Demographics (Population Distribution, Income Distribution, Building Age/Occupancy)	Census Bureau
Ocean-related Economics (Average Annual Employment, Business Establishments and Wages)	Bureau of Labor Statistics (BLS)

Layers	Data Source
Storm Surge Impacts (Storm Surge Water Depth, Building Count, Dollar Exposure Value)	HRI/AECOM

At the end of the Spring 2021 TAC meetings (described in detail in **Section 3**), the Qualtrics Survey described above was sent out to the TAC members. In July 2021, the survey was closed and TAC member comments from both the meetings and survey were compiled to produce summaries of regional concerns related to each of the eight vulnerabilities (see **Appendix E**). Listed below (**Table 5-2** through **Table 5-5**) are the average level of concern for each vulnerability per subregion based on stakeholder insight ("1" being the lowest level of concern and "5" being the highest level of concern).

There were 82 survey respondents in total; on average, Region 1 had about 14 responses per subregion, Region 2 had about 10 responses per subregion, Region 3 had about 16 responses per subregion, and Region 4 had about 10 responses per subregion. A map showing the distribution of responses is shown in **Figure 5-1**.

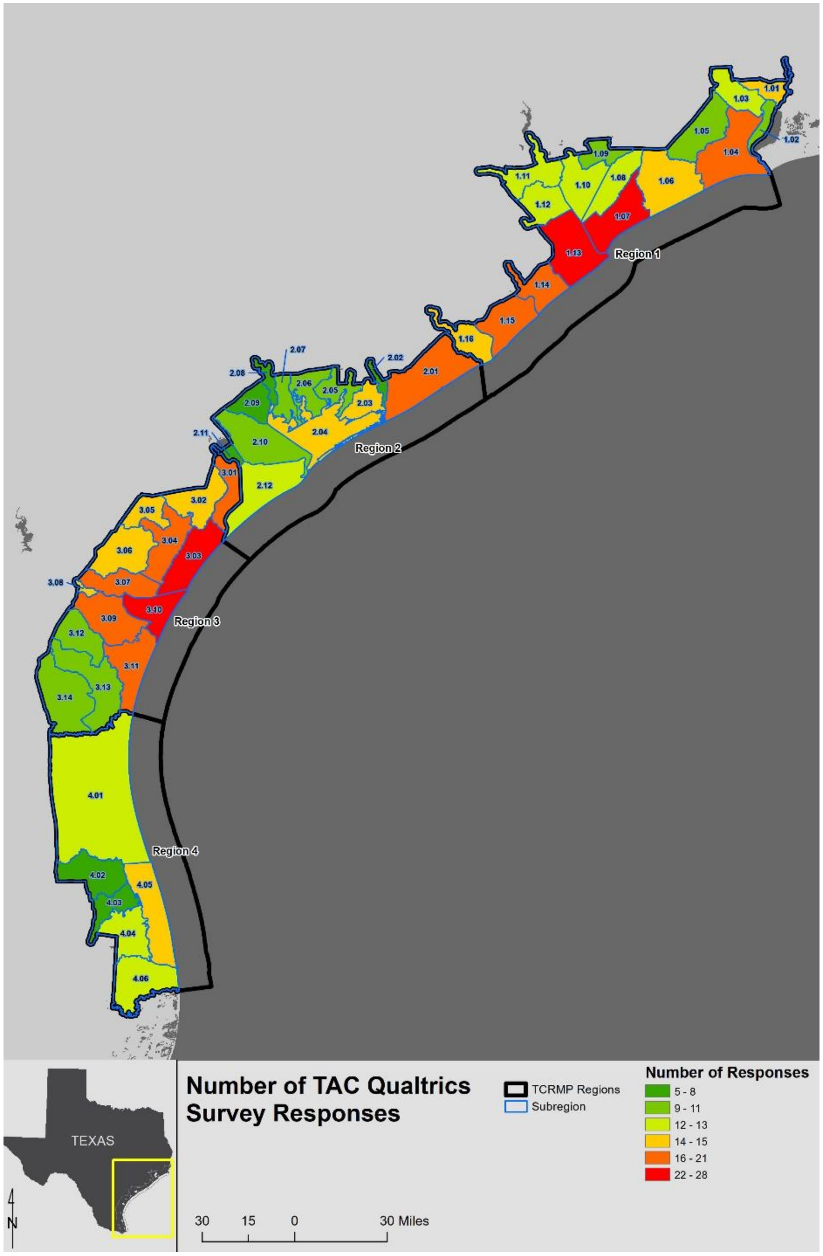


Figure 5-1. Number of TAC Responses by Subregion

From these responses, across all subregions, the order for concern of the vulnerabilities based on average scores is, from highest to lowest: Gulf Shoreline Change (removing subregions for which there is no Gulf shoreline), Degraded or Lost Habitat, Storm Surge, Bay Shoreline Change, Degraded Water Quality, Inland Flooding, Tidal Flooding, and Degraded Water Quantity.

In order from highest to lowest vulnerability score, the top three concerns within Region 1 are Storm Surge, Gulf Shoreline Change, and Inland Flooding. Within Region 2, the top three concerns from highest to lowest vulnerability score are Bay Shoreline Change, Degraded Water Quality, and Degraded or Lost Habitat. Within Region 3, the top three concerns from highest to lowest vulnerability score are Gulf Shoreline Change, Degraded or Lost Habitat, and Bay Shoreline Change. Within Region 4, the top three concerns from highest to lowest vulnerability score are Gulf Shoreline Change, Degraded or Lost Habitat, and Degraded Water Quality.

From a vulnerability perspective, the subregions of highest concern (average score over 3.5) for each vulnerability are below. The vulnerabilities are listed from highest to lowest and the subregions are listed in sequential order within each vulnerability.

Gulf Shoreline Change: 1.06, 1.07, 3.10, 4.01, 4.05, 4.06

Degraded or Lost Habitat: 1.03, 1.06, 1.11, 1.12, 3.03, 3.10, 4.03, 4.06

Storm Surge: 1.06-1.08, 1.11-1.14, 3.03, 3.10, 4.05

Bay Shoreline Change: 1.08, 1.09, 1.12, 3.03, 3.10

Degraded Water Quality: 1.10, 1.11, 4.03

Inland Flooding: 1.02, 1.03, 1.05, 1.08, 1.10-1.13

Tidal Flooding: 1.11-1.13

Degraded Water Quantity: No subregions had an average score higher than 3.5 for this vulnerability; the subregions of highest concern (average score between 3 and 3.5) are: 1.11, 1.12, 3.07, 3.08, 4.03, and 4.06.

Results for each region are shown in **Table 5-2** to **Table 5-5**. Some Gulf Shoreline Change values were recorded in subregions without a Gulf shoreline; those values have been stricken through and were not included when calculating the Qualtrics Survey results.

Region 1 Results

Table 5-2. Region 1 Qualtrics Survey Results - Average Level of Concern for Vulnerabilities by Subregion

Subregion	Degraded or Lost Habitat	Bay Shoreline Change	Gulf Shoreline Change	Storm Surge	Inland Flooding	Tidal Flooding	Degraded Water Quality	Degraded Water Quantity
1.01	2.92	2.33	~~2.08~~	3.13	3.27	2.73	2.86	2.17
1.02	3.09	3.33	~~2.13~~	3.33	3.64	3.00	2.73	2.40
1.03	3.56	3.20	~~1.71~~	3.33	3.54	2.77	3.08	2.27
1.04	3.31	2.60	3.31	3.28	3.00	2.94	2.67	2.93
1.05	2.90	1.86	~~2.00~~	2.75	3.92	2.64	2.73	2.89
1.06	3.79	2.83	3.77	4.00	3.23	3.27	3.00	2.58
1.07	3.32	3.45	3.68	3.84	2.78	3.44	2.61	2.36
1.08	3.31	4.08	~~1.89~~	3.67	3.58	3.27	3.25	2.82
1.09	3.36	3.80	~~1.33~~	3.09	2.67	2.64	2.83	2.83
1.10	3.50	3.31	~~1.63~~	3.23	3.54	3.23	3.58	2.58
1.11	3.54	3.27	~~2.17~~	4.50	4.23	3.83	3.93	3.18
1.12	3.58	3.80	~~2.17~~	4.31	4.07	3.62	3.50	3.10
1.13	3.40	3.45	3.20	3.81	3.58	3.60	3.04	2.79

Subregion	Degraded or Lost Habitat	Bay Shoreline Change	Gulf Shoreline Change	Storm Surge	Inland Flooding	Tidal Flooding	Degraded Water Quality	Degraded Water Quantity
1.14	3.16	3.39	3.31	3.53	2.88	3.42	2.94	2.73
1.15	2.61	2.65	2.93	3.00	2.67	3.07	2.44	2.43
1.16	2.88	2.85	3.31	3.20	3.07	3.07	2.71	2.69

Region 2 Results

Table 5-3. Region 2 Qualtrics Survey Results - Average Level of Concern for Vulnerabilities by Subregion

Subregion	Degraded or Lost Habitat	Bay Shoreline Change	Gulf Shoreline Change	Storm Surge	Inland Flooding	Tidal Flooding	Degraded Water Quality	Degraded Water Quantity
2.01	3.05	2.65	2.88	2.44	2.13	2.56	2.38	2.27
2.02	2.22	1.67	~~2.25~~	2.13	2.00	1.86	2.67	2.88
2.03	2.60	2.46	~~2.00~~	2.33	2.15	2.23	2.36	2.43
2.04	2.63	2.79	1.91	2.31	1.60	2.17	2.50	2.27
2.05	2.17	2.40	~~1.14~~	2.70	2.75	2.00	2.67	2.45
2.06	2.42	2.50	~~1.29~~	2.33	2.22	1.89	2.50	2.42
2.07	2.42	2.40	~~0.67~~	2.38	1.88	1.75	2.75	2.25
2.08	2.44	2.43	~~0.80~~	2.29	2.29	1.71	2.88	2.75
2.09	2.56	3.00	~~1.40~~	2.86	2.57	2.29	3.00	2.56
2.10	3.18	3.20	~~2.11~~	2.88	2.50	2.50	2.80	2.60
2.11	2.33	2.75	~~1.33~~	2.75	2.60	2.00	2.33	2.00
2.12	2.56	2.77	2.00	2.08	1.90	1.92	2.07	2.08

Region 3 Results

Table 5-4. Region 3 Qualtrics Survey Results - Average Level of Concern for Vulnerabilities by Subregion

Subregion	Degraded or Lost Habitat	Bay Shoreline Change	Gulf Shoreline Change	Storm Surge	Inland Flooding	Tidal Flooding	Degraded Water Quality	Degraded Water Quantity
3.01	3.10	3.39	~~2.36~~	2.82	2.64	2.71	2.70	2.67
3.02	3.00	3.40	~~2.80~~	3.43	3.15	2.92	2.61	2.44
3.03	3.81	3.63	2.92	3.52	3.14	3.37	3.43	2.97
3.04	3.05	3.17	~~2.30~~	3.44	2.79	2.93	3.00	2.47

Subregion	Degraded or Lost Habitat	Bay Shoreline Change	Gulf Shoreline Change	Storm Surge	Inland Flooding	Tidal Flooding	Degraded Water Quality	Degraded Water Quantity
3.05	2.56	2.93	~~2.00~~	2.36	2.46	2.46	2.60	2.40
3.06	2.53	2.69	~~1.43~~	2.00	2.31	2.00	2.78	2.44
3.07	3.12	3.06	~~1.86~~	2.75	2.20	2.44	3.10	3.33
3.08	3.00	2.85	~~2.13~~	2.69	2.71	2.20	2.81	3.24
3.09	3.16	2.74	~~1.82~~	2.89	3.17	2.83	3.33	2.89
3.10	3.89	3.58	3.58	3.62	2.41	3.21	3.28	2.88
3.11	3.17	2.91	3.25	3.05	2.18	3.05	2.65	2.43
3.12	2.50	2.38	~~1.75~~	1.36	2.18	1.71	3.08	2.67
3.13	2.64	2.82	~~2.00~~	2.56	2.20	2.67	3.33	2.69
3.14	2.75	2.73	~~1.80~~	2.00	2.30	2.00	3.08	2.71

Region 4 Results

Table 5-5. Region 4 Qualtrics Survey Results - Average Level of Concern for Vulnerabilities by Subregion

Subregion	Degraded or Lost Habitat	Bay Shoreline Change	Gulf Shoreline Change	Storm Surge	Inland Flooding	Tidal Flooding	Degraded Water Quality	Degraded Water Quantity
4.01	3.14	2.91	3.73	3.20	3.00	2.75	2.91	2.67
4.02	3.22	3.00	~~3.25~~	3.00	3.14	2.71	2.56	2.33
4.03	3.70	3.14	~~3.00~~	2.63	3.00	2.63	3.70	3.20
4.04	3.33	3.09	~~2.43~~	2.82	2.73	2.73	3.25	3.00
4.05	3.44	3.27	3.80	3.53	2.42	3.29	3.23	2.92
4.06	3.92	3.50	3.67	3.45	3.27	3.00	3.46	3.08

Summary

Based on average scores, the Gulf Shoreline Change vulnerability was the greatest concern when considering the whole coast, followed by Degraded or Lost Habitat, and Storm Surge. Gulf Shoreline Change ranked within the top three greatest vulnerabilities for Regions 1, 3, and 4. Degraded or Lost Habitat ranked within the top three for Regions 2, 3, and 4. Bay Shoreline Change scored highly in Regions 2 and 3 as a high concern. Other primary concerns included Inland Flooding and Degraded Water Quality in Regions 1 and 2, respectively.

In addition to overall averages, z-scores were computed for each of the vulnerabilities to determine how the score value in a given subregion compared to the full regional or coastwide dataset for that same vulnerability. A z-score of +/- 1 indicates that the vulnerability score is +/- 1 standard deviation from the mean. A summary of the z-scores is provided in **Appendix E**.

The GLO prepared maps showing the survey scores for subregions normalized by region and by the whole coast, to compare how a given subregion performed against other subregions for the same vulnerability. These maps can be found in **Appendix E**. For example, the Bay Shoreline Change results are shown below by average vulnerability score and with scores normalized by region and over the whole coast in **Figure 5-2** to **Figure 5-4**.

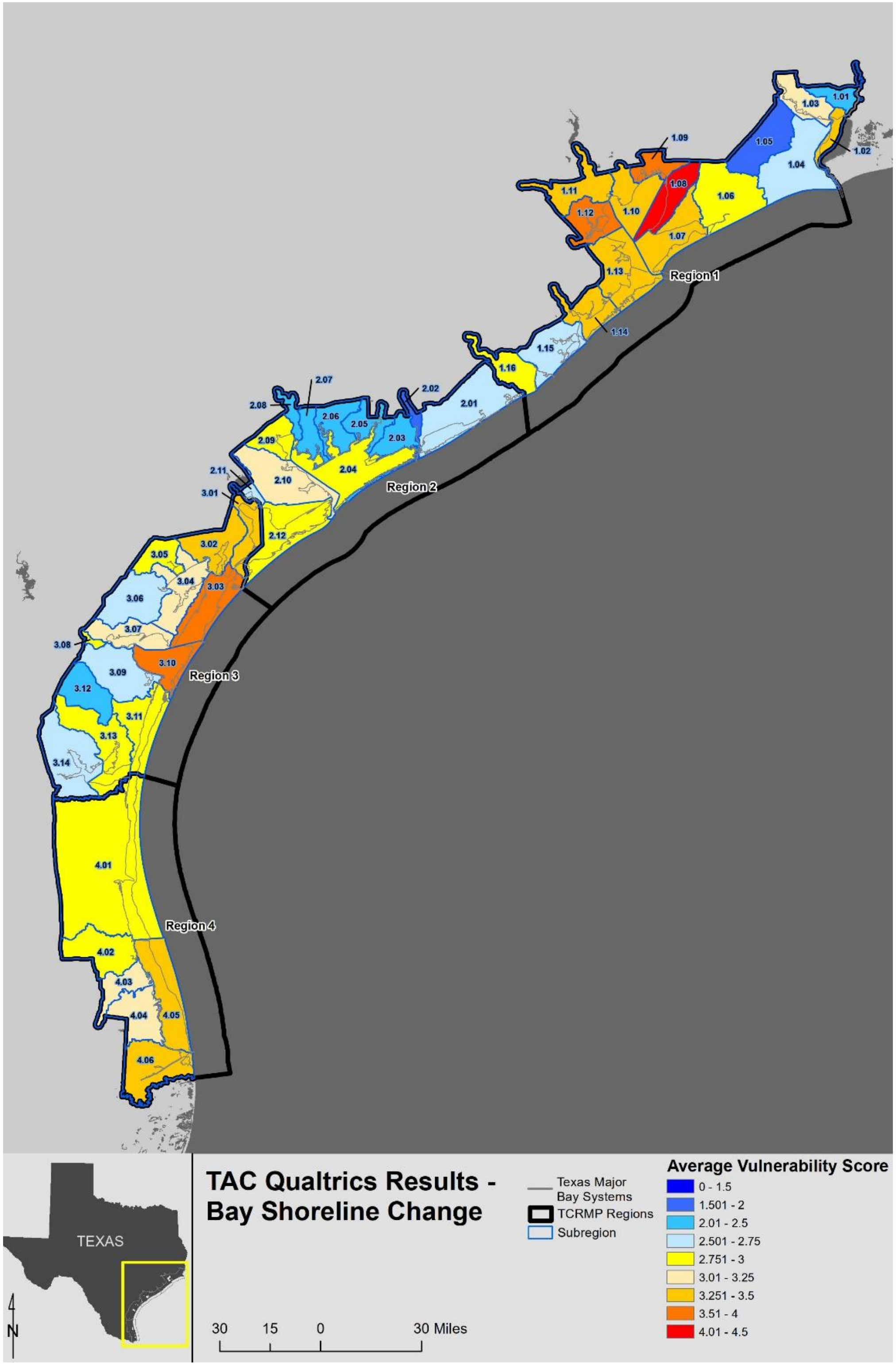


Figure 5-2. TAC Vulnerability Assessment Results for Bay Shoreline Change - Average Vulnerability Scores

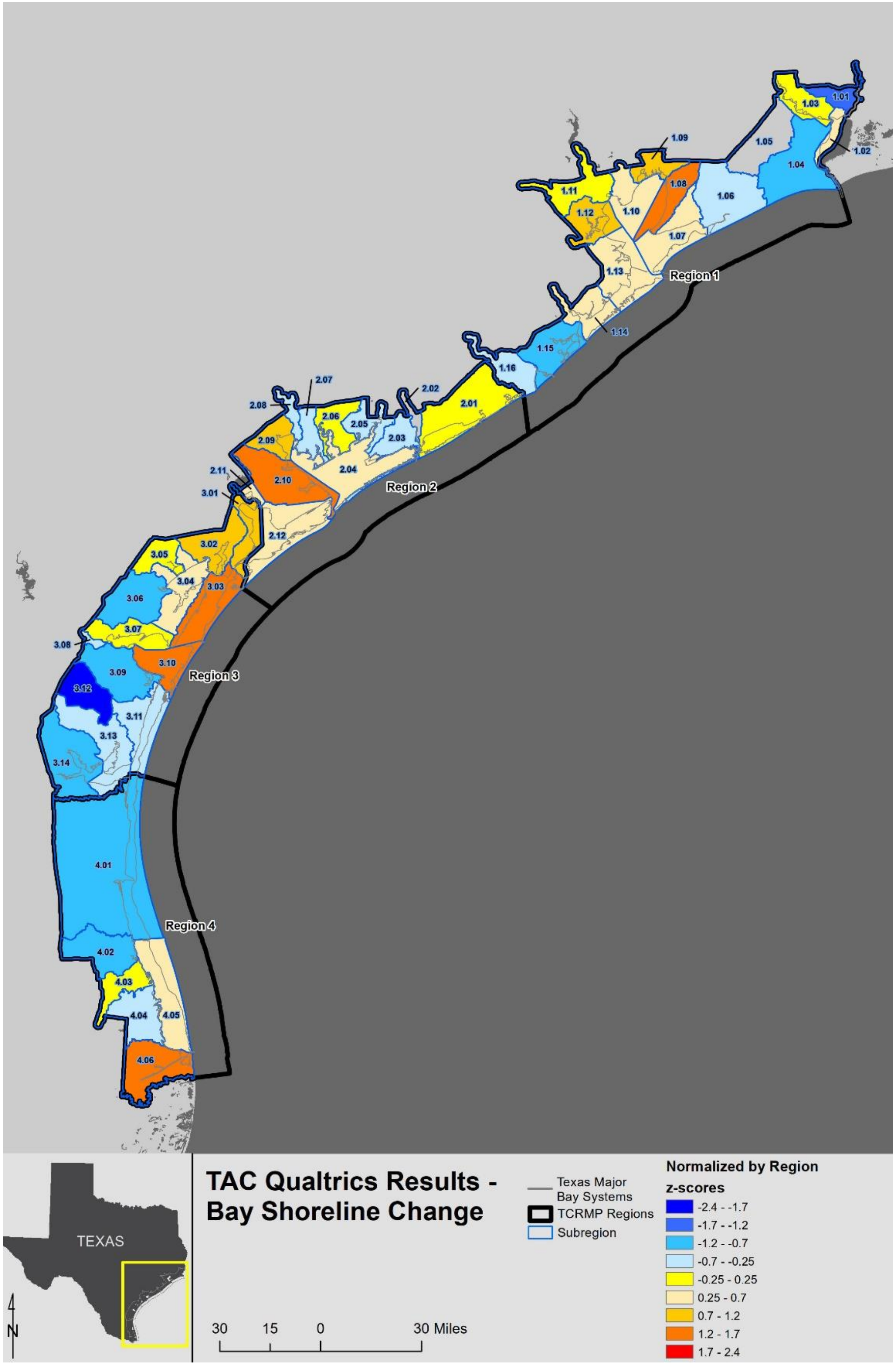


Figure 5-3. TAC Vulnerability Assessment Results for Bay Shoreline Change - Vulnerability Scores Normalized by Region

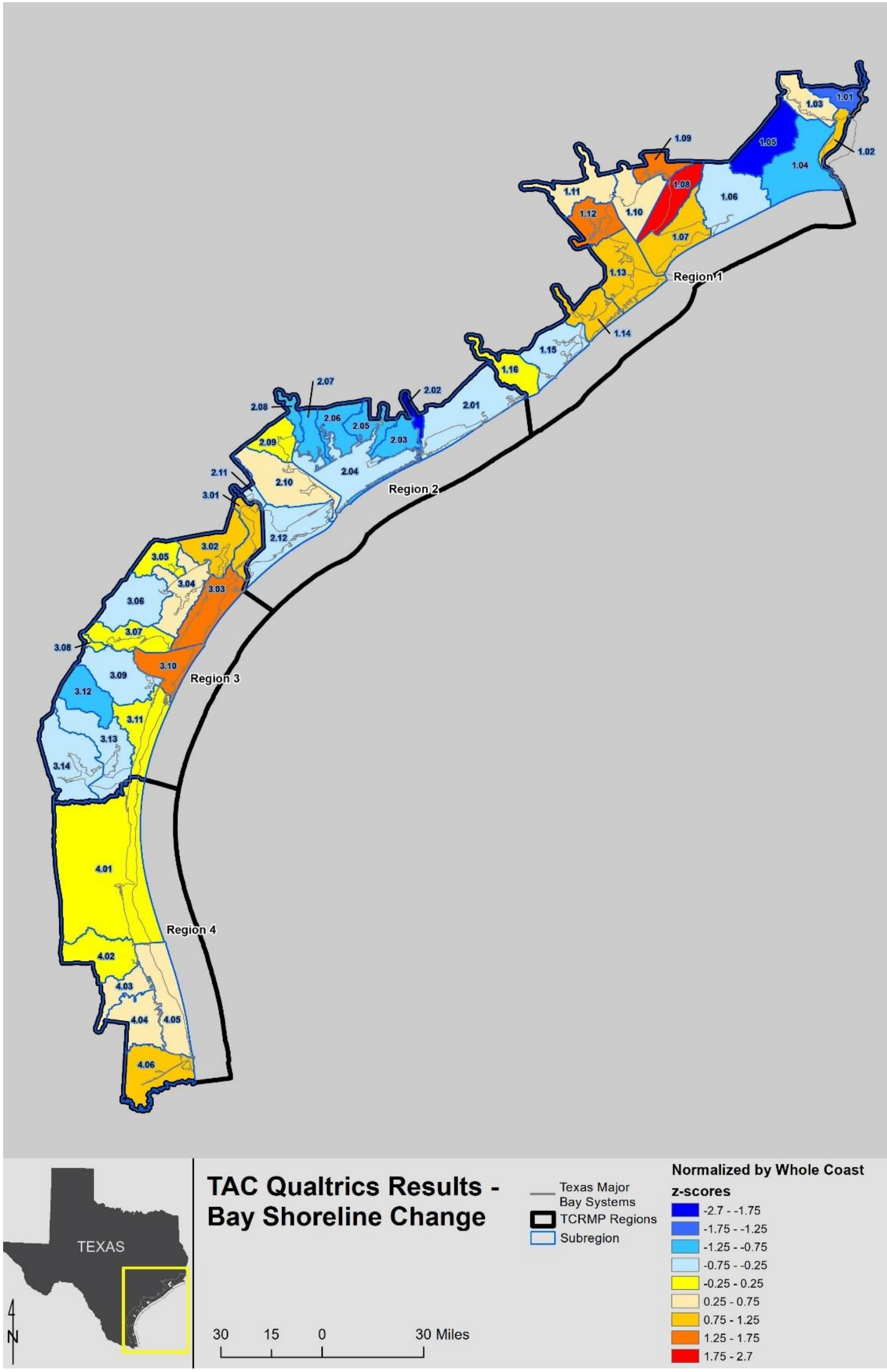


Figure 5-4. TAC Vulnerability Assessment Results for Bay Shoreline Change - Vulnerability Scores Normalized by Whole Coast

5.2 Infrastructure and Critical Facilities

The 2023 TCRMP identified coastal projects that address many of the major concerns along the Texas coast with respect to ecological resiliency. The 2023 TCRMP expands upon this work by including projects to help improve the resiliency of Texas's coastal infrastructure.

To initially identify communities' coastal infrastructure needs, the GLO referenced the Texas Coastal Infrastructure Study, a state-led planning process that worked with communities throughout coastal Texas to compile a list of community infrastructure needs in 2024-2025.

Table 5-6 describes the typical coastal infrastructure projects that will be considered during the planning process. In most cases, capital improvement projects, such as neighborhood street reconstruction or maintenance facility renovations, were not considered unless they could be shown to directly relate to the TCRMP's strategies and goals.

Table 5-6. Coastal Infrastructure Project Identification

Societal Resiliency Strategies	New Project Sources	Typical Projects Considered
Water-based Transit Enhancement	• Port of Houston Authority and USACE Houston Ship Channel Mega Study • Calhoun Port Authority and USACE Matagorda Ship Channel Improvement Project • Cataloguing local, state, and federally maintained channels is ongoing	✓ Opportunities for BUDM ✓ State and locally maintained navigation channels, such as the Texas GIWW
Land-based Transit Enhancement	• TxDOT Project Lists • GLO Texas Coastal Infrastructure Study	✓ Major Evacuation Routes ✓ Coastal Highway Elevation ✓ Coastal Highway Repairs ✓ Causeways
Storm Surge Suppression	• USACE Sabine-to-Galveston Study (Orange, Port Arthur, Freeport systems) • USACE Coastal Texas Study (the Tentatively Selected Plan will be available in early 2018 and will propose improvements for the Houston-Galveston, Matagorda and South Padre Island systems) • Gulf Coast Community Protection and Recovery District (GCCPRD) Storm Surge Suppression Study	✓ Results of ongoing federal, state, and regional studies for large-scale CSRM systems ✓ Local levees and storm surge suppression systems may be considered
Responsible Development	• Erosion Response Plans	✓ Large-Scale (Regional) Drainage Projects or Studies ✓ Utility Planning ✓ Critical Facility Planning ✓ Setbacks

In addition to compiling new “traditional” infrastructure projects from the sources mentioned, the GLO worked with planners, engineers, and local sponsors to determine how ecologically resilient coastal infrastructure projects can be implemented. These projects would combine the best engineering technology with appropriate ecological improvement methods to improve the longevity of projects. Part of this process is expanding the mindset of coastal infrastructure to include an all-encompassing vision that includes “gray” and “green” projects working together in complementary fashion under the current multiple lines of defense concept. This concept provides the linkage between Texas’s barrier islands, bays, ecological systems, and community infrastructure, as it iterates that all elements work together to mitigate risk, often called multiple lines of defense (**Figure 5-5**). Historically, these elements have all been thought of individually, but as part of the 2023 TCRMP, the goal is to shift the formerly independent thought process and to begin implementing holistic solutions.

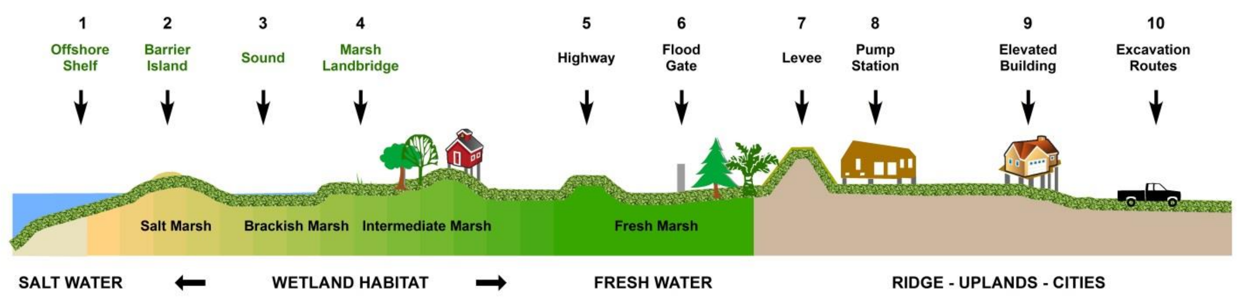


Figure 5-5. Multiple Lines of Defense

In addition to assessing potential areas to incorporate multiple lines of defense, the GLO Planning Team assessed the locations of critical facilities along the coast, and the vulnerability of this infrastructure to SLR and coastal flooding (**Figure 5-6** and **Figure 5-7**). The critical facilities shown are those identified in the Texas Coastal Infrastructure Study. This information was provided at a regional level to the TAC when the TAC was identifying new potential projects.

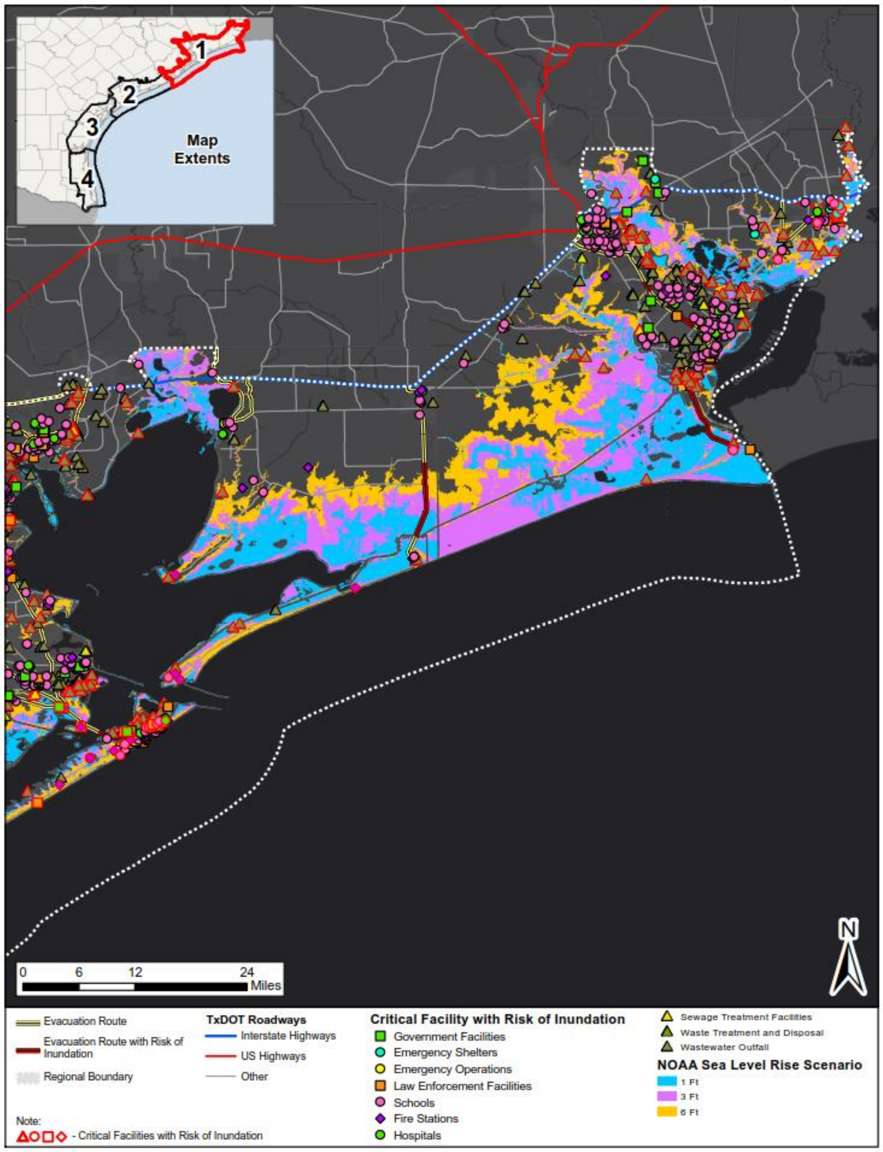


Figure 5-6. Critical Facilities at Risk of Inundation due to SLR, Region 1A

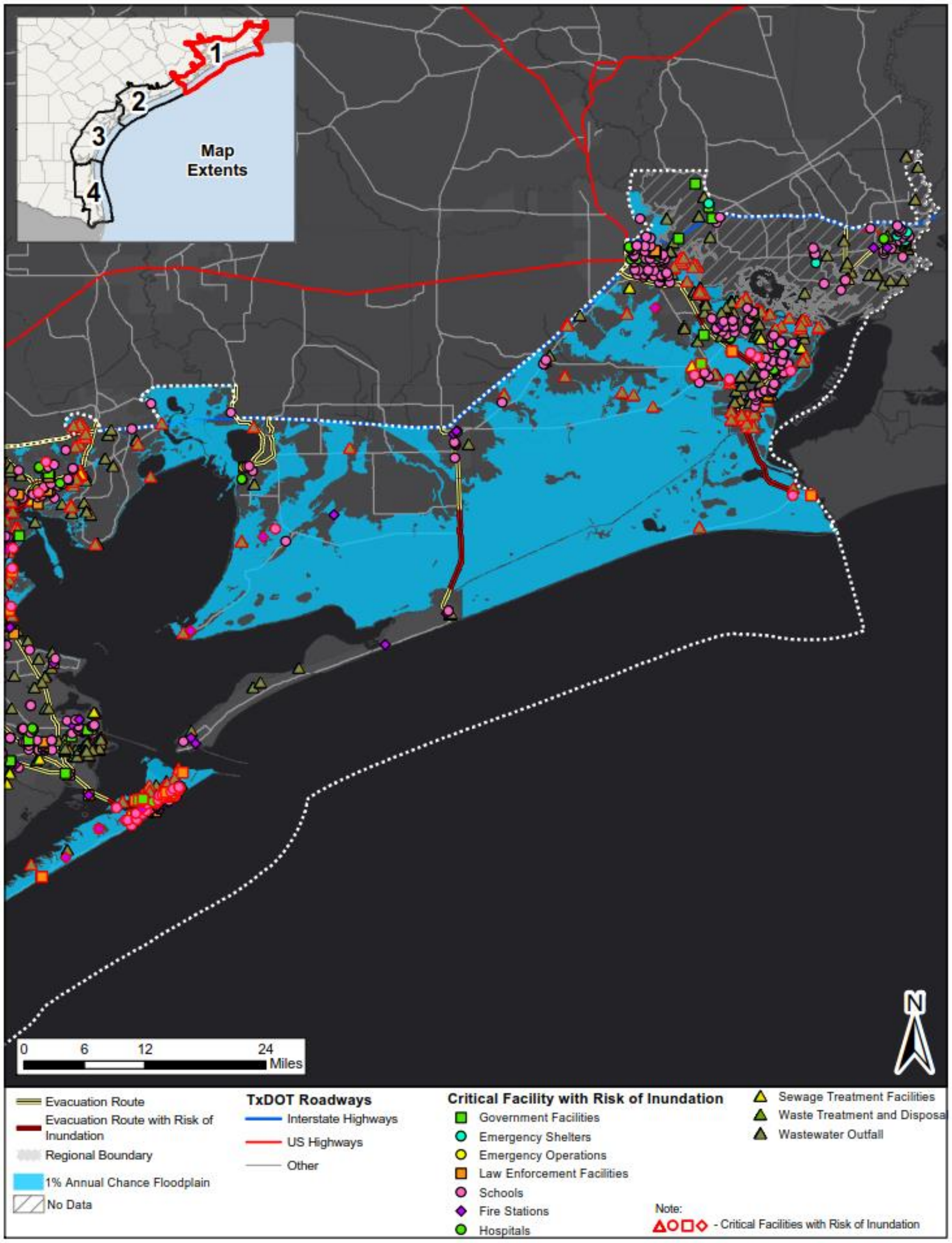


Figure 5-7. Critical Facilities at Risk of Inundation due to Coastal Flooding, Region 1A

5.3 GLO General Permit

Typically, to complete each beach nourishment project, a standard (i.e., individual) permit must be obtained from the USACE for each construction project. This permit requirement contributes to a significant portion of the project timeline, due to the length of time (often months to years) required to permit the projects, thus exposing communities to the possible hazards of future hurricane seasons and other coastal vulnerabilities. To expedite the permit approval process, AECOM began working with the GLO, in coordination with the USACE and USFWS, to determine if it would be possible to develop a general permit that would allow beach nourishment projects to be completed on Texas Gulf and bay shorelines through a more efficient permitting process. Providing a timely permitting option would also be expected to increase opportunities to beneficially use dredged material when it becomes available for construction, rather than losing the opportunity due to the length of time required to obtain a traditional permit.

Current Status and Trends of Beach Nourishment Projects in Texas

AECOM reviewed beach nourishment projects that have occurred in Texas over the past 30 years to identify typical annual beach nourishment quantities, sand sources, construction locations, seasonality of projects, and trends. In general, AECOM's findings indicate the following:

- Projects are typically less than one mile (1.6 km) in length;
- Projects occur during every season, but the majority are constructed between October and March;
- The majority of projects are BUDM projects on gulf shorelines, using sand from navigation channel maintenance or jetty dredging;
- Among the four Texas coastal regions defined in the TCRMP, at least one beach nourishment project is typically completed per region every one to two years;
- The largest single project is 3.4 million cubic yards (CY) (2.6 million cubic meters [m^3]), scheduled to be complete in 2022; and
- From 2010-2019, Texas averaged approximately 500,000 CY (380,000 m^3) of material used annually for beach nourishment.

5.3.1 Environmental Impacts

A general permit is usually only issued for structures, work, or discharges in jurisdictional waters of the United States that will result in minimal adverse effects on the aquatic environment and can be issued on a nationwide, regional, or state basis. Project-specific actions must be verified to meet the terms and conditions specified in the general permit. To assess environmental impacts, AECOM performed a literature review of benthic studies, monitoring data from coastal projects (Gulf of Mexico, Atlantic Ocean, International), and past permits/lease agreements for beach nourishment projects from the 1970s to present day. AECOM's assessment entailed reviewing potential impacts and recovery at both material source locations and placement sites for:

- Benthic organisms
- Birds (particularly piping plovers and red knots)
- Sea turtles

AECOM's review also included determining if the impacts to these species and their habitats or recovery times could be correlated to the sand source location (upland versus submerged). In general, more data existed for submerged sources.

Species/Habitat Impacts

In most cases, only best practices to minimize impacts to species/habitats can be recommended. For the projects reviewed, there is minimal pre-, during, and post-construction monitoring data available to substantiate the effectiveness of the best practices. Best management practices are often based on a mixture of scientific research (such as might be conducted by an academic institution for a particular species), local knowledge, and anecdotal experience. A summary of the best practices by species type is provided below:

- Benthic organisms
  - *At submerged sand sources* – Locate borrow sources in sites that are likely to refill quickly based on net direction of bedload transport, littoral drift, or areas with high accretion rates; avoid creating deep pits with steep side slopes; avoid substantially altering depositional patterns and water quality. When benthic organisms begin to return to submerged source sites, they tend to recover in stages based on the type of organism and substrate characteristics. Sources located in high-energy environments tend to recover more quickly due to the natural prevalence of opportunistic species at these sites, usually over the course of 2 to 3 years (Stage 1). Sources located in lower energy environments tend to recover more slowly, because the stability of the environment allows recruitment of equilibrium species, usually over the course of 5 to 10 years (Stage 2).
    - Stage 1 (2-3 years) – Abundance and biomass recovery of opportunistic species (shorter lifespans, faster reproductive cycles, faster recruitment), such as annelids.
    - Stage 2 (5-10 years) – More stable/equilibrium species (longer living, slower reproductive cycles, slower recruitment times), such as bivalves and mollusks.

    Overall infaunal community structures take longest to recover because this entails redevelopment of the original biodiversity.
  - *At placement site* – Construction that avoids spring recruitment periods (April-June) was associated with faster recovery; well-matched sediment in regard to grain size, sorting, carbonate content, and percent fines were associated with faster recovery rates; vertical overburdens (layers) of sand that are constructed in thinner layers (2 to 3 ft) may allow benthic organisms to avoid burial by burrowing closer to the surface. It is possible and potentially recommended to phase construction based on when recruitment seasons occur for key prey sources – for instance, avoiding construction during fall recruitment because this will allow greater seasonal larvae supply and provide a more abundant benthic community. In general, beaches in areas with more active longshore transport are associated with faster rates of recovery.
    - Highly mobile species (crabs, worms, etc.) generally exhibit higher rates of survival than less mobile species (clams). Therefore, beaches where bird populations prey on highly mobile species are more likely to have faster recovery rates.
    - In the studies evaluated, intertidal benthic abundance, biomass, and taxa declined following beach nourishment for at least two months post-nourishment. However, partial resurgence of benthic communities was typically noted within two years, using either direct monitoring of benthic organisms or using shorebird return as an indication of secondary productivity.
- Birds
  - *At submerged sand source* – Not typically monitored. Birds are largely considered a mobile species that will leave while construction is ongoing, and impacts are often not monitored outside of direct impacts during construction.
  - *At placement site* – Train construction personnel to recognize species; all material placement above Mean High Water should be constructed during the winter (November-April) season; establish buffer zones if nesting activities are discovered; train personnel to visually inspect workspace prior to beginning daily work; continue to allow natural accretion at inlets; avoid staging/driving equipment on beaches and flats; employ a trained species observer.
    - The wintering behavior of piping plovers shows that plovers begin to arrive in Texas beginning in July and reach a maximum abundance in October, corresponding to the summer recruitment period of benthic organisms. Piping plovers begin to migrate to breeding grounds as early as February, with some remaining in Texas through late spring (March to May). Late fall/early spring construction activities are

nonetheless preferred, as it also corresponds to winter decreases in benthic organism abundance and could provide a more stable food source for plovers during the next wintering season.

- Sea turtles
  - *At submerged sand source* – The most relevant issue is the impact of dredging; employ trained species observers onboard the dredge; use a dredge head designed to deflect sea turtles; disengage pumps when the dredge is not in contact with the seabed; screen all inflow material; relocate any turtles encountered during construction; report all dredge takes and strandings; train construction personnel to recognize, report, and prevent impacts. Sea turtles are largely considered a mobile species that will leave while construction is ongoing, and impacts are often not monitored outside of direct impacts during construction.
  - *At placement site* – Avoid construction during sea turtle nesting season; train construction personnel to recognize, report, and prevent impacts; avoid staging/driving equipment on beaches and flats; use well-matched sediment in regard to grain size, sorting, carbonate content, compaction, and percent fines; monitor siltation barriers for sea turtle entrapment; reduce vessel speed to no wake/idle near the beach site; employ a trained species observer during construction. As noted, sea turtles are largely considered a mobile species that will leave while construction is ongoing, and impacts are often not monitored outside of direct impacts during construction.

5.3.2 Sand Source Location Impacts

AECOM reviewed available literature to determine if impacts to benthic organisms, birds, and sea turtles are more or less likely depending on whether the sand is sourced from an upland or submerged site, where submerged sites included both BUDM sites, such as from navigation channel maintenance, and offshore borrow pits. Several studies alluded to initial findings indicating that impacts may be less when material for beach nourishment is sourced from a submerged source as opposed to an upland source (potentially due to the presence of marine microfauna and invertebrates in submerged sand) and if the equilibrium beach profile and compaction are similar to the original beach. Sea turtles, for example, are less likely to nest on areas of unnatural beach profile due to compaction or escarpment. Benthic organisms may recover more quickly at a site if the grain size, sorting, carbonate content, and percent fines are similar in character to the pre-construction beach. Only one study was conducted where material had been retrieved from an upland source and used for beach nourishment; the findings did not indicate negative impacts to benthic fauna. However, other studies described material sources as being submerged (dredged) materials, so it is difficult to draw conclusions related to suitability of upland versus submerged sources.

5.3.3 Data Gaps

There are many studies that document monitoring results for dredging activities at borrow sources, including pre-, during, and post-construction findings, for past projects in the Gulf of Mexico and throughout the U.S. to substantiate claims about expected rates of benthic organism recovery at borrow sites. There seems to be sufficient data to characterize benthic organism response at borrow sites.

There are fewer studies, and therefore still some data gaps, for monitoring benthic organism recovery after beach nourishment at placement sites (using upland and submerged sources), as well as for bird species (particularly piping plovers and red knots) and sea turtle recovery on the Gulf Coast. However, some findings from non-Texas sources may reasonably be extended to Texas gulf beaches to determine expected placement site response, assuming similar conditions in beach sediment and possibly morphology. It should be noted that most of the monitoring studies were conducted for either Gulf of Mexico, Atlantic Ocean, or International sand source and placement sites; due to the lack of bay placement site monitoring data, it is unclear if the conclusions represented in the completed gulf/ocean studies can be translated to bay sites.

Several permits, particularly those issued in the past decade, included monitoring requirements for the species/habitats and sand source locations indicated. However, in more than one instance, monitoring was not completed with the regularity proposed and/or data were not made readily available to the public. Due to the lack of data, it is difficult to draw representative and defensible conclusions as to the efficacy of permit limitations on improving species/habitat performance post-construction. It is likewise challenging to make recommendations as to permit limitations and monitoring requirements that can be shown to result in minimal adverse impacts and improve species/habitat recovery.

5.3.4 Findings Related to Monitoring at Beach Placement Sites

In an ideal scenario, monitoring would begin one to two years prior to construction and continue during and post-construction for at least five consecutive years in total. It is recommended that monitoring events occur at least twice annually during spring and fall recruitment or migration and wintering seasons, with a minimum of five surveys (e.g., one survey per week for five weeks) per monitoring event. Monitoring would include high-resolution aerial photographs, topographic and bathymetric surveys, Mean Lower Low Water (MLLW) shoreline, and tide gage data reporting. It is also beneficial to sample and characterize source/placement material for percentage of sand/clays/fines and typical, respective sediment sizes. For benthic organisms, while abundance counts are informative, determining potential mechanisms of impact (such as studying the stomach contents of fish for habitat suitability in regard to the amount of available food source) rather than changes to mean abundances may be more informative for these target biota that are highly variable in space and time. For birds and sea turtles, species counts are usually sufficient, understanding that these species are highly mobile and will typically leave the placement site while construction is ongoing.

5.3.5 Conclusions and Recommendations

Best practices for beach nourishment placement activities undertaken at gulf/ocean beach shorelines are well understood at the permitting level and should be incorporated into project planning and design as much as possible. In general, findings indicate that recovery for benthic organisms at beach placement sites is more rapid than at dredge sites, and there are several studies from Atlantic Ocean shorelines (New Jersey, Delaware, North Carolina, South Carolina, Florida) indicating partial or complete recovery of benthic communities within two years post-construction or sooner, as determined either through direct monitoring of benthic abundances or indirect monitoring of bird response at placement sites. Similar studies for Gulf Coast beaches are limited; however, it is expected that Texas beaches would experience similar rates of recovery if best practices to protect benthic, bird, and sea turtle species are incorporated into project planning and design. Furthermore, mobile species (crustaceans, worms) are typically the fastest benthic organisms to recover, along with spiders and insects. These species provide the primary food source for piping plovers, which further supports the likelihood of piping plover population recovery on an accelerated timeframe. Red knots prefer a diet of mollusks and clams, which typically take longer to recover (in the 5- to 10-year range). However, in some cases, red knots will adjust their diets to consume other species, such as mud snails, that are more mobile and may be higher in abundance or density than their preferred food source.

Full and detailed results of AECOM's data gathering exercise can be found in **Appendix F**.

5.4 Sediment Management

AECOM conducted an analysis to produce generalized sediment estimates for regions of the Texas coast to assist stakeholders in long-term shoreline management and resilience planning. The study leverages UT-BEG shoreline change rates and equilibrium profiles along the coast. Due to the unique settings along the expansive coastline, the coast was divided into 14 regions that have relatively homogenous characteristics (**Figure 5-8**).

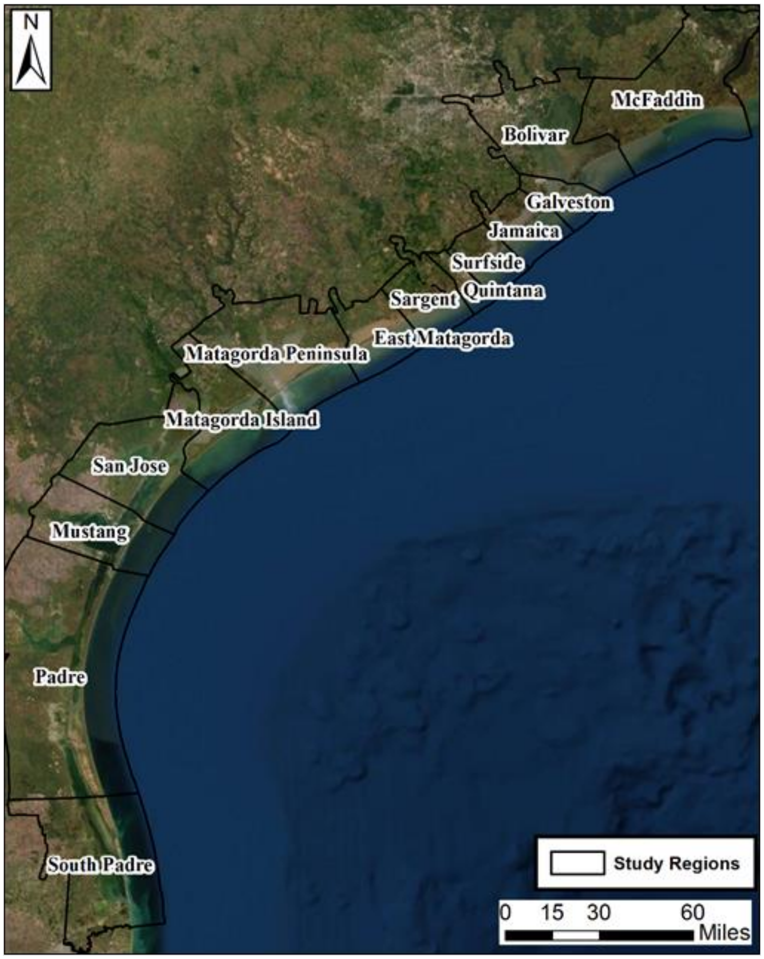


Figure 5-8. Regions along the Texas coast for use in sediment analysis

To establish a volume change estimate for each region, the regional equilibrium profiles were shifted based on annual shoreline change rates, and the corresponding changes to volume were calculated. More detailed information regarding the study methods and assumptions can be referenced in the full report, *Sediment Estimates for the Texas Coast*, included in **Appendix G**. This section provides a brief summary of findings, conclusions, and interprets how the results could be considered for application in the TCRMP.

An integral part of shoreline management involves understanding the sediment needs required to sustain a stable shoreline condition over time. This study intends to produce generalized sediment estimates for regions of the Texas coast to assist the GLO and any stakeholders in long-term shoreline management and resilience planning. To do this, total regional volumetric change rates were generated by applying the UT-BEG Shoreline Change Rates to equilibrium profiles along the coast (**Figure 5-9**). Historic nourishment records will be leveraged to remove nourishment deposition from the overall sediment needs for each applicable region.

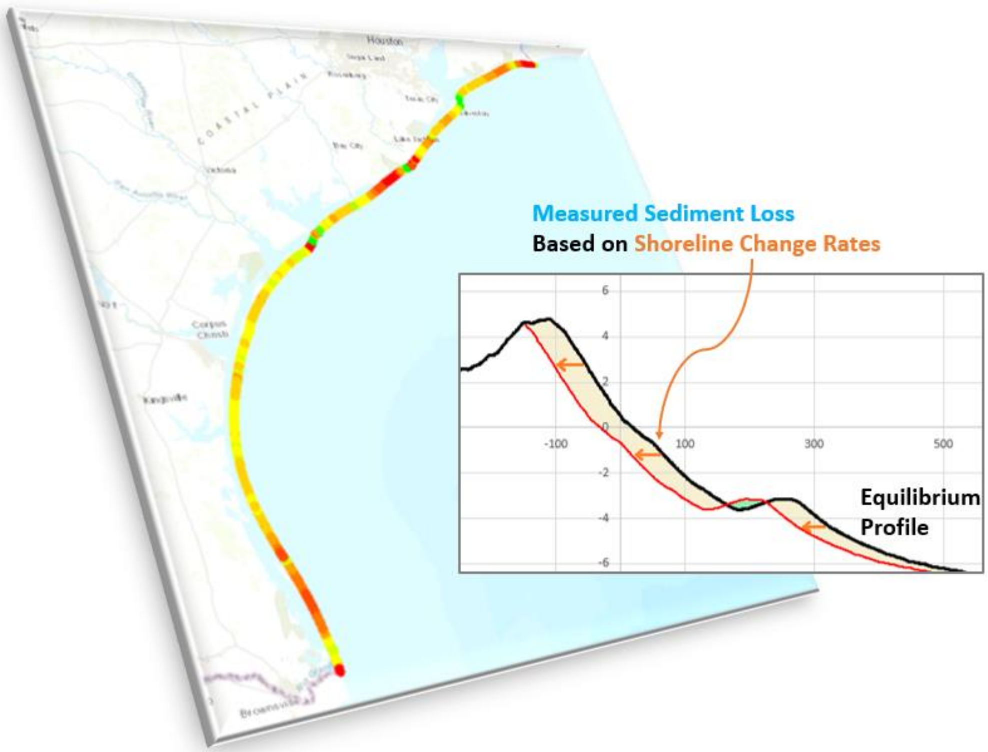


Figure 5-9. Illustration of UT-BEG Shoreline Change Rates along Texas coast contributing to volume change calculations

5.4.1 Study Findings

Data produced in this study includes regional Depth of Closure (DOC) estimates, equilibrium profiles, regional nourishment volume estimates, and regional volume change results. Information regarding source data, methodology, and assumptions can be referenced in the full report, *Sediment Estimates for the Texas Coast*. Review and discussion of each of these datasets are provided in the following subsections.

Texas Shoreline Conditions

The Texas coast consists of a variety of shoreline conditions, comprised primarily of developed and undeveloped barrier islands, peninsulas, and deltaic headlands. These barrier island systems front expansive estuarine/marsh complexes that are connected to the Gulf of Mexico by approximately 20 permanent and ephemeral inlets. Net longshore sediment transport along the coast can be generalized as northeast to southwest from Sabine Pass to Central Padre Island, and south to north from the Rio Grande to Central Padre Island. Due to the relatively low tidal range and wave climate, shoreline features tend to be very low relief, with the highest features being well-established, older dune fields.

The Texas coast experiences an overall net retreat of shoreline position, with the most severe transgressional rates occurring on the upper coast. It is estimated by UT-BEG that the net land loss due to shoreline retreat between 1930 and 2019 was approximately 6,627 ha (16,375 ac). They also determined that rates of shoreline transgression were approximately 5.6 ft/yr (1.7 m/yr) from Sabine Pass to the Colorado River and 3.2 ft/yr (1 m/yr) from the Colorado River south to the Rio Grande. Two of the primary drivers of shoreline retreat along the coast are subsidence and eustatic SLR. These factors produce an overall volumetric loss of sediment to the shelf, where it is periodically recovered for nourishment activities.

Depth of Closure

The DOC is a critical factor in the design process for beach assessment or nourishment projects. DOC is defined as the short-term limit of significant sediment transport in the offshore zone. The DOC estimates for the Texas coast were generated based on Birkemeier's DOC equation (1985) and developed by a USACE study that applied cumulative and annual Wave Information Studies hindcast data. **Table 5-7** provides DOC estimates identified in this study for each region.

Table 5-7. DOC estimates for Texas coast

Site	DOC (ft, MLW)	DOC (ft, NAVD88)
McFaddin	-8.42	-8.57
Bolivar	-9.29	-9.45
Galveston	-9.67	-9.87
Jamaica Beach	-11.77	-11.98
Surfside Beach	-15.91	-16.12
Quintana	-15.56	-15.75
Sargent Beach	-14.79	-15.15
East Matagorda	-16.18	-16.45
Matagorda Peninsula	-16.90	-17.17
Matagorda Island	-16.97	-17.29
San Jose Island	-17.37	-17.69
Mustang Island	-18.25	-18.57
Padre Island	-17.98	-18.56
South Padre Island	-19.59	-20.17

Equilibrium Profile

In this study, equilibrium profiles were developed for most regions along the Texas coast where survey data was available. These profiles were developed based on survey datasets, averaging the elevations along each profile relative to the shoreline, assumed to be mean sea level for each case. Review of these equilibrium profiles shows that there is a large regional variation of profile geometry along the Texas coast, as shown in **Figure 5-10**.

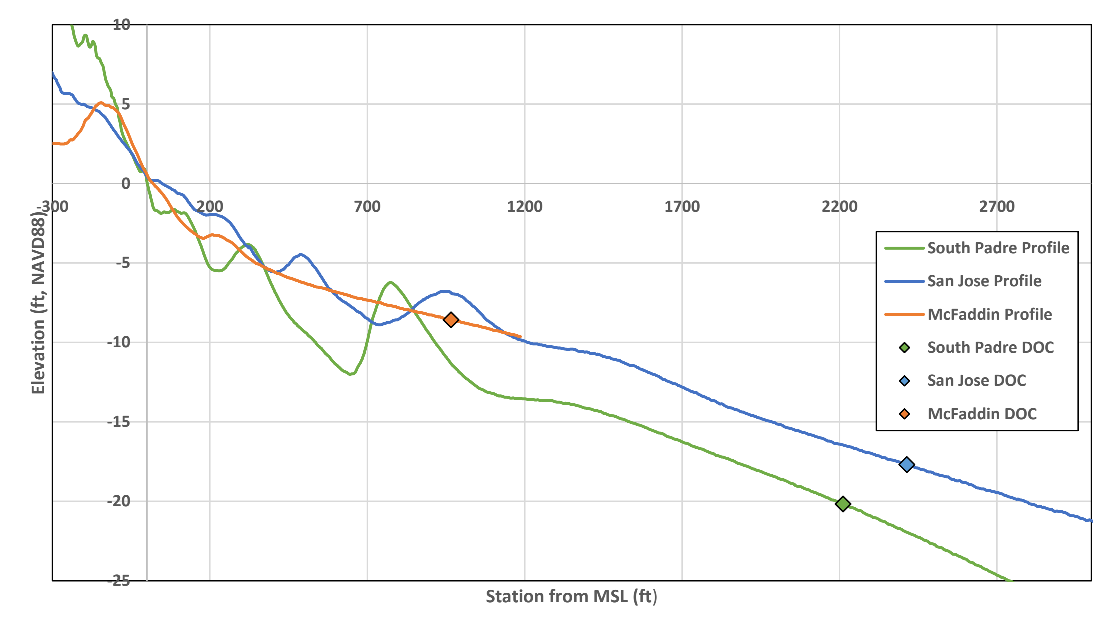


Figure 5-10. Example of DOC relative to equilibrium profiles for different locations in Texas

Nourishment

Total nourishment volumes per region were computed based on CEPRA data collected by GLO, detailed information taken from an AECOM Beach Nourishment Memo (**Appendix F**), and American Shore and Beach Preservation Association data gathered for Texas. All regions except Matagorda Peninsula, Matagorda Island, and San Jose Island had some nourishment activity. A compiled record of all Gulf coast nourishment projects in the state is provided in Appendix C of the full report, *Sediment Estimates for the Texas Coast* (**Appendix G**). A summary of the total and annualized nourishment volumes is provided in **Table 5-8**.

Table 5-8. Regional nourishment volumes

Region	Total Nourishment Volume (CY)	Nourishment Volume Rate (cy/yr)
McFaddin	662,000	10,508
Bolivar	6,280,999	99,698
Galveston	3,912,164	62,098
Jamaica Beach	450,434	7,150
Surfside Beach	1,163,351	18,466
Quintana	311,977	4,952
Sargent Beach	232,000	3,683
East Matagorda	876,337	13,910
Matagorda	0	0
Matagorda Island	0	0
San Jose Island	0	0
Mustang Island	10,100	160
Padre Island	2,421,200	38,432
South Padre Island	4,827,150	76,621

This study assumed that the nourishment volumes influenced the UT-BEG shoreline change rates in particular regions. These shoreline change rates, influenced by nourishment, would be expected to skew the volume estimates produced in this study. Once the volume estimates were generated based on the regional equilibrium profiles, shoreline length, and shoreline change rate, the nourishment volume was removed from the result. To do this, the annualized nourishment volumes were subtracted from the volume change rate. This process is shown in **Table 5-9**. Updated regional UT-BEG shoreline change rates were also back-calculated based on the adjusted volume change rates.

Out of the 14 regions, only Galveston and Matagorda Peninsula showed a positive volumetric change rate (before correction for nourishment), although Galveston's positive change rate was very modest and became a negative volume change once nourishment was subtracted. The remaining 12 regions tend to break into two groups: volumetric loss rates between 2,000,000 - 10,000,000 cy/yr, and volumetric losses greater than 12,000,000 cy/yr. The McFaddin, Padre, and South Padre Island regions had the three highest volume loss rates of the regions, but also notably are the three largest regions with respect to shoreline length, which impacts the total volume.

Table 5-9. Regional Total Volume Change Results Corrected for Historic Nourishment Volumes

Region	Volume Change Rate Without Nourishment (cy/yr)	Nourishment Volume Rate (cy/yr)	Volume Change Rate Adjusted for Nourishment (cy/yr)	BEG Shoreline Change Rate Adjusted for Nourishment (ft/yr)
McFaddin	-1,334,515	10,508	-1,345,023	-12.31
Bolivar	-93,371	99,698	-193,070	-4.21
Galveston	5,921	62,098	-56,177	-1.86
Jamaica Beach	-255,840	7,150	-262,990	-4.14
Surfside Beach	-192,131	18,466	-210,597	-3.29
Quintana	-311,725	4,952	-316,677	-12.85
Sargent Beach	-335,557	3,683	-339,240	-4.59
East Matagorda	-718,642	13,910	-732,552	-7.93
Matagorda Peninsula	276,033	0	276,033	2.31
Matagorda Island	-450,411	0	-450,411	-2.91
San Jose Island	-307,101	0	-307,101	-3.59
Mustang Island	-192,454	160	-192,614	-2.34
Padre Island	-916,450	38,432	-954,882	-2.66
South Padre Island	-1,706,007	76,621	-1,782,628	-8.60

Volume Analysis

Regionally weighted UT-BEG shoreline change rates were applied to horizontally shifted by 1-foot (inland) equilibrium datasets to generate the volume change per horizontal foot for each region in the analysis. The volumetric change rates also considered the influence of nourishment contributions, as shown in **Table 5-9**. One additional facet to this study was an evaluation of the volumetric changes within a particular region by separating the accretion and erosion portions of those shorelines. In other words, the negative shoreline change contributions were calculated separately from the positive shoreline change contributions. In these cases, consideration of nourishment was ignored.

Results shown in **Table 5-10** provide more detailed information regarding volume changes in each region, segregated by areas of accretion and areas of erosion. These results provide a more holistic view of the mechanics present in each region. Overall, the analysis indicates that the regional shorelines are primarily in a state of erosion, but some localized areas of significant accretion exist within some of these regions. While most regions exhibit accretional shoreline lengths of approximately 12–35% of the total regional shoreline, the Jamaica Beach and Quintana regions show little or no accretion for any length of regional shoreline. Additionally, the Galveston region is almost evenly split between accretional and erosional shoreline conditions, which is a factor that Galveston considers in shoreline management by using some accretion areas as a sand source for eroding areas.

Table 5-10. Regional Erosion and Accretion Volume Change Results

	Accretion				Erosion			
Region	Shoreline Length (ft)	Percent of Regional Shoreline (%)	Weighted BEG Shoreline Change Rate (ft/yr)	Volume Change Rate (cy/yr)	Shoreline Length (ft)	Percent of Regional Shoreline (%)	Weighted BEG Shoreline Change Rate (ft/yr)	Volume Change Rate (cy/yr)
McFaddin	28,121	12.5	1.66	22,769	195,159	87.5	-14.22	-1,357,284
Bolivar	19,986	21.7	9.39	93,501	72,111	78.3	-5.20	-186,873
Galveston	28,282	49.2	3.27	49,211	28,510	50.8	-2.86	-43,290
Jamaica Beach	3,438	3.3	2.36	5,209	95,390	96.7	-4.26	-261,049
Surfside Beach	10,774	13.7	0.92	8,336	65,623	86.3	-3.65	-200,467
Quintana	0	0.0	-	-	32,836	100.0	-12.65	-311,725
Sargent Beach	28,729	28.3	27.75	580,810	72,690	71.7	-17.31	-916,367
East Matagorda	16,048	13.4	2.58	32,111	102,906	86.6	-9.39	-750,753
Matagorda Peninsula	51,331	34.6	12.41	517,275	95,883	65.4	-3.10	-241,242
Matagorda Island	67,540	35.5	7.34	404,941	122,121	64.5	-8.58	-855,352
San Jose Island	17,243	16.5	1.57	22,043	87,491	83.5	-4.61	-329,144
Mustang Island	21,616	22.2	1.11	20,660	73,623	77.8	-3.35	-213,114
Padre Island	68,321	17.0	0.73	45,351	327,236	83.0	-3.24	-961,801
South Padre Island	35,459	15.7	2.98	102,229	188,184	84.3	-9.95	-1,808,236

5.4.2 Discussion of Findings

Depth of Closure

The DOC results provided a set of regional estimates for the Texas coastline that tend to vary widely across the analyzed regions, ranging from -8.57 ft to -20.17 ft NAVD88 (-8.42 ft to -19.59 ft MLW). These estimates are based on over 30 years of wave data from buoys located along the Texas coast. One of the benefits of these data are that the length of record and buoy coverage along the Texas coast provides DOC values based on relatively homogeneous input parameter. This allows for an analogous comparison of DOC values from one region to another.

DOC values will vary based on the chosen equation, the location/depth of the buoy data, and length of the historic record. A longer historic record could account for more storms and increase the input wave condition, resulting in a deeper DOC. In other studies, there may be variations in the DOC results based on the type of calculation and record used. There is not one exact value of DOC for a particular location as DOC locations can vary over time due to changes in the localized wave and current regime.

More site-specific DOC values can be referenced in recent sediment budget reports developed by GLO for Region 1 (Bolivar, Galveston, Jamaica Beach, Surfside Beach, Quintana, and a portion of Sargent Beach regions) and Region 4 (South Padre and a portion of Padre regions), which used a littoral drift DOC ranging between 12 and 19 ft MLLW and 28.5 and 35.4 ft MLLW, respectively. The Region 1 study provided a full sediment budget analysis based on 2D wave and flow modeling, longshore transport modeling, and storm simulations for extreme events. These analyses are significantly more complex than the DOC and profile estimates completed for this task and could provide a more detailed localized representation of sediment needs for specific study areas. A similar analysis was completed for Region 4, but the primary focus of the Region 4 report was sediment transport analysis during extreme storm events.

As the above data sources generally produce deeper DOC values than the DOC estimates produced in this study, considering these DOC values as a range can also be helpful for TCRMP planning purposes. For example, in the event that a nourishment is prioritized as a Tier 1 project, designing for sand placement in areas landward (or shallower) than the range of DOC values will help to ensure that the site is maximizing the benefit of those sediment deposits.

Equilibrium Profile

There is a large variation in profile geometry across the Texas coast. When evaluating and prioritizing projects for the TCRMP, understanding the regional variations in profiles and DOC can help stakeholders assess the sediment needs that will vary based on a particular project location. These profiles viewed relative to the DOC provide information on the range of where sediment transport could be expected. Generally, northern portions of the Texas coast have a shallower DOC due to smaller localized wave conditions, whereas southern portions of the Texas coast have deeper DOC values based on larger wave conditions. The depth and distance from the shoreline of these DOC values can influence the distribution of sand from a nourishment project. In some cases, the amount of sand needed for nourishment could be impacted by how far along the profile the sand needs to be distributed to create an equilibrium profile after nourishment. For example, **Table 5-11** shows a simple geometric estimate of how much volume of sand would be needed to shift an equilibrium profile horizontally by 1 foot. These results show that, generally, about 1 CY of sand is needed per 1-foot horizontal change in shoreline position in South Padre. By comparison, McFaddin would need about half of that sand volume to accomplish a 1-foot horizontal change in shoreline position. Understanding the effects of different profile geometries and DOC extents on a particular region can assist TCRMP planners to better identify the cost and benefits of certain resilience projects and refine localized shoreline protection plans.

Like the DOC values, equilibrium profiles are not exact and change over time based on the wave and current climate and often vary seasonally. DOC estimates and equilibrium profiles can be refined using long-term monitoring of survey datasets and more complex modeling analyses.

Table 5-11. Regional effects of 1-foot shift in shoreline on volume

Region	1-foot Equilibrium Profile Volume Change (cubic ft/linear foot/ft)	1-foot Equilibrium Profile Volume Change (cubic ft/linear foot/ft)
McFaddin	13.21	0.49
Bolivar	13.45	0.50
Galveston	14.36	0.53
Jamaica Beach	17.35	0.64
Surfside Beach	22.61	0.84
Quintana	20.27	0.75
Sargent Beach	19.67	0.73
East Matagorda	20.97	0.78
Matagorda	21.93	0.81
Matagorda Island	22.05	0.82
San Jose Island	22.03	0.82
Mustang Island	23.33	0.86
Padre Island	24.48	0.91
South Padre Island	26.08	0.97

Nourishment

The influence of nourishment on the regional sediment needs appears to be clear in some areas and less clear in others. For example, according to the current data the Galveston area has a shoreline that is gaining sand volume; however, we know this area has required nearly 4 million CY of sediment contributions from numerous nourishment projects over the years to sustain the current shoreline condition (see **Table 5-8**). Similarly, the results for the Bolivar region indicate that the nourishment rate reduces the volume change rate by more than 50%. Conversely, the results for South Padre Island, where nearly 5 million CY of nourishment has been applied to the study area (excluding nearshore berm placements), the impact of nourishment appears to be minimal. This perception of the impact from nourishment is obscured by two factors and should be considered when evaluating the impact of nourishment in these areas:

- **Some regional study areas are much larger than nourishment areas:** For example, South Padre Island accounts for over 42 miles of shoreline, but the nourishment footprints typically range from ¼ – 3 miles of shoreline, with most projects accounting for less than ½ mile of shoreline. The application of nourishment volumes to a proportionally smaller shoreline length compared to the regional length can cause annual nourishment volumes to appear smaller compared to total regional volumetric changes. This can impact the perception of the benefits of nourishment contributions. In cases where nourishment volumes are more impactful to the overall volumetric results, such as the Galveston or Bolivar regions, the nourished shoreline lengths are relatively larger in comparison to the total regional shoreline, but the nourishments still only account for approximately 3–35% of the shoreline in these areas. It is likely that splitting some regions into sub-regions to isolate nourished areas would provide a more detailed understanding of how these nourishments benefit localized areas.

- **The annualized nourishment volumes are based on the duration of the UT-BEG shoreline change rates (1950's – 2019):** Because the UT-BEG shoreline change rates account for a long-term record of shoreline change, this same time range was applied to create an annual estimate of nourishment. This is reasonable for comparison purposes, but TCRMP stakeholders should understand that regular nourishment and beach management practices were not in place for a significant portion of this timeline. Many of the regional nourishment records do not begin until the late 1990's or early 2000's. If one were to re-calculate an annualized nourishment volume based on a more current era of nourishment projects (i.e., 1990 to 2019), the annual nourishment volumes would approximately triple the values reported in **Table 5-9**. This adjustment would change the volume change rates for several regions, and in some cases, significantly impacts the adjusted shoreline change rates (right column of **Table 5-9**). Shoreline change rates would increase by 0–20% for most cases but would be more than 100% increase for Bolivar and Galveston regions.

Based on the above findings, the total nourishment values from **Table 5-8** should be considered by TCRMP as a useful record of nourishment volumes applied to each region. The results in **Table 5-9** should only be considered from a regional perspective, without focusing on the impacts of nourishment to a particular localized project area. Future efforts could involve a more detailed analysis of nourishment areas vs. areas without construction within regions of interest, to better analyze the impact of the nourishments to those areas. More localized information would likely show a much higher benefit of nourishments in accounting for annual volume changes. Comparison of nourishment results to a more recent time series of shoreline change rates, such as the 2000-2019 timeline of shoreline change rates, could also provide some more detailed information regarding how some of these areas are responding to nourishment.

Volume

Volume change rates appear to vary significantly within areas of some regions. Viewing the total volume changes rates for a region (**Table 5-9**) as homogenous could underpredict volume changes in some localized areas. One pronounced case is Sargent Beach: along the northeastern extent of the region, the shoreline is experiencing shoreline transgression of over 50 ft per year in some areas (see **Figure 5-11**). However, the southwestern extent of the region is characterized by longer expanses of 10 to 30 ft of shoreline retreat per year, contributing to a net volume change rate of -0.34 million cy/yr. The results in **Table 5-10** show that Sargent Beach gains approximately 0.58 million cy/yr in the areas of shoreline accretion but loses approximately 0.92 million cy/yr in areas of shoreline retreat.

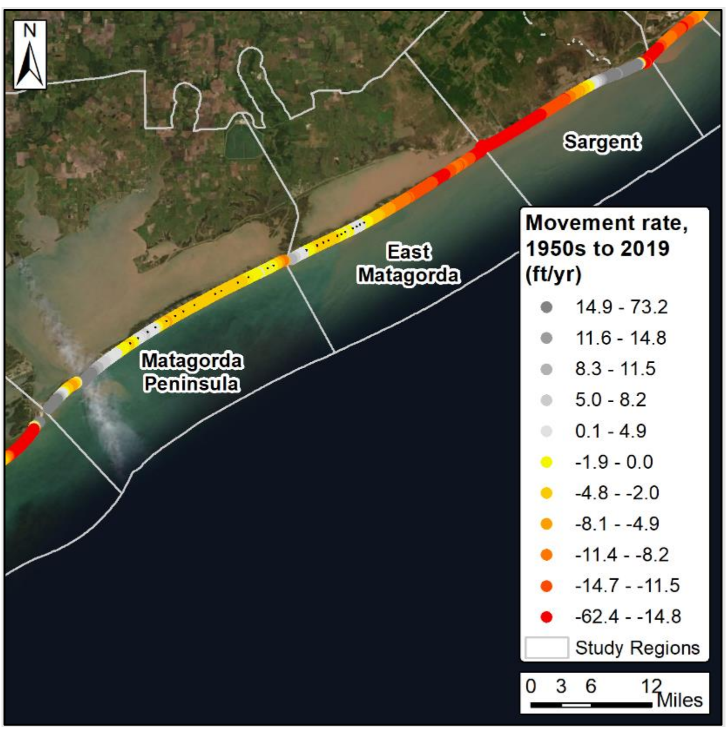


Figure 5-11. UT-BEG Shoreline Change Rates showing various shifts in accretion (gray) and erosion (color) within some regions

For use in TCRMP, understanding these variabilities in volume change within the regions will help to prioritize projects and understand what areas may need higher priority when undertaking regional sediment management.

Recommendations

The information in the *Sediment Estimates for the Texas Coast* provides a large-scale regional comparison of sediment volume change across the Texas coast for use in the TCRMP. Many of the findings from this data support resilience planning efforts by acting as a baseline for a regional sediment management plan and understanding what regions may require more sediment to sustain beach and dune systems.

The DOC and equilibrium profile information should communicate how each shoreline system is different and will respond differently to storm events and nourishment events. These values will also help with understanding of where sand placement is appropriate and how these sediment resources will result in different magnitudes of shoreline change based on the properties of these profile conditions.

The volumes and information from this report and the UT-BEG shoreline change rates could be leveraged to support identifying erosion hotspots or classifying areas in need of prioritized shoreline protection. Future efforts to compartmentalize volume changes in sub-regions could assist with more detailed evaluation of the effects of nourishments within the specific construction footprint. Sub-regions could also help to refine volume change results based on areas of interest (such as developed areas) or areas that are identified for monitoring but may be a lower tier of priority with respect to resilience project planning (such as undeveloped areas or areas identified for managed retreat).

Some regions are shown to have highly variable sediment needs within the region itself, as observed in Sargent Beach. As a recommendation for future study, some of these areas should be evaluated in higher detail to understand how to specifically manage erosion hotspots and areas of sediment accretion. In some cases, a management plan could include removal of sand from accretion areas and depositing on high-erosion areas, as is done in Galveston.

Nourishment contributions have a significant impact on volume change in some regions. For example, Galveston has a relatively mild shoreline erosion rate based on the UT-BEG shoreline change rates. This shoreline change rate is higher when one accounts for the annualized volume of nourishment contribution. In other cases where nourishments contributions appear to be small compared to total volume change rates, stakeholders should understand that these analyses are region-wide and much larger than the scale of nourishment projects. Based on changes to nourishment results expected for more localized volume change rates and a shorter duration for annualized nourishment rates, the impact of nourishment on smaller-scale study areas would be expected to be much larger. Observed alteration in shoreline change rates due to long-term execution of nourishment projects emphasizes the cyclical nature of nourishment needs. Continuous funding of nourishment projects is necessary to maintain shorelines and mitigate long-term volume loss in some areas.

Additionally, availability of funding for monitoring these regions is important for the success of any management programs and for validation of sediment needs. Monitoring programs are necessary to ensure that the projects being completed are having their desired effect and that funds are not spent on efforts that are not producing necessary positive results. Data-driven approaches for needs assessment and planning will be invaluable to target areas that would require complex management plans.

There are a number of sediment change analyses that may provide a higher-resolution evaluation of sediment needs and sediment change for localized areas. The results from this analysis are to support a statewide perspective of open coast sediment needs and should be used for regional comparisons to understand the variation in sediment needs from one region to the next. As rates of SLR increase over time, regional sediment management will become more important for the stability of the natural environments and will help to mitigate risks and negative outcomes on the economy. The loss of dune and beach resources along the Texas coast have potentially severe consequences regarding diminished storm wave and surge protection, damage to critical infrastructure and economically/environmentally valuable habitat, and loss of socially valuable resources.

Data-driven efforts to identify appropriate areas for resilience projects are key to determining appropriate needs for future funding and projects. Coastlines are naturally complex, dynamic environments that change over time and will require monitoring and data collection and analysis to ensure that projects are having the desired outcomes. Projects like nourishment can have significant effects on shoreline change rates, which ultimately dictate the stability and usability of a coastal area for recreational, conservational, or economic purposes. This means that shoreline change mitigation projects, whether nourishment or other stabilization projects, and monitoring will likely require dedicated, continuous funding to ensure success. Significant shoreline loss will likely result in higher storm damage risks, impacts to infrastructure, loss of habitat and recreation areas, and an overall negative impact on the economy.

Sediment Estimate Report Conclusions

Results showed that some of the larger annual volume change rates occur at the northern and southern extents of the Texas shoreline along the Bolivar/McFaddin regions and the Padre Island/South Padre Island regions. This was expected, as these areas tended to have larger shoreline change (in this case, loss) rates. These more vulnerable areas also correspond to regular and significant arrays of historic nourishment projects. Conversely, the Matagorda Peninsula region is the only region that had a net gain in annual volume change.

Observing the volume change rates can be useful for a high-level perspective of sediment estimates but should be assessed with consideration to the sizes of each region and the variations of shoreline change rates within each region. For example, Quintana shows a below average regional volume change rate, 0.3 million cy/yr (0.23 million m^3/yr), but is the smallest region examined in this study and has the second highest weighted shoreline change rate. Observing the volume change rate for this region on its own would not highlight the overall vulnerability of the area.

The Sargent Beach region is another area where the volume change rate should be reviewed with respect to the shoreline change rates within the region. Along the northeastern extent of the region, the shoreline is experiencing some shoreline advance of over 50 ft (15.2 m) per year in some areas. The southwestern extent of the region, however, is characterized by longer expanses of 10 to 30 ft (3 to 9 m) of shoreline retreat per year, contributing to a net volume change rate of -0.34 million cy/yr (-0.26 million m^3/yr). **Table 5-10** results show that Sargent Beach gains approximately 0.58 million cy/yr (0.44 million m^3/yr) in the areas of shoreline advance but loses approximately 0.92 million cy/yr (0.7 million $m^{3/}$yr) in areas of shoreline retreat. Because the region has such a wide range of shoreline change, a balanced regional volume change rate (0 cy/yr) could still potentially result in large-scale erosion in one portion of the region and accretion in another portion of the region. In future analyses, it could be useful to re-delineate some regions to separate areas not only by natural breaks in the shoreline, but also by areas of erosion and accretion, to better illustrate the volume change rates of certain hotspots along the Texas coast.

Depending on the conditions and history of each region, the more useful volume change rate data could correspond to the **Table 5-10** data (considering accretion and erosion areas) or the **Table 5-9** data (considering past nourishment contributions). For example, Sargent Beach as previously discussed, shows a large variation in shoreline change rate, but has an insignificant level of historic nourishment influence. Therefore, the data from **Table 5-10** would be of higher value for the Sargent Beach region. Some regions, such as the Bolivar Peninsula, Galveston, and South Padre, have both nourishment influence and varying shoreline change rates, and both results tables could be of value. In these cases, the areas of accretion and erosion could be subject to influence from historic nourishment, so a more detailed analysis could be beneficial.

Evaluating the information for the Galveston Region more closely could provide more insight on a complex region. In **Table 5-9**, the Galveston Region is showing a net increase in volume of nearly 6,000 cy/yr, when disregarding nourishment. In **Table 5-10**, however, the data shows that there are areas within the Galveston Region that are accreting and eroding, which is not clear when viewing the net volume results. Still disregarding nourishment data, Galveston areas are losing and gaining approximately 43,000 cy/yr and 49,000 cy/yr respectively, depending on the localized shoreline change at particular locations. Finally, in **Table 5-9**, the Galveston Region shows notable total volume loss of approximately 56,000 cy/yr when considering the nourishment record for this area. In all of the values, the influence of the hardened structures in the Galveston Region is not clear, although it is expected that the robust groin system and seawalls have an impact on the sediment budget and erosion rates for certain areas. This is apparent when reviewing the shoreline change rates in the area of the groin system, compared to the neighboring areas. The shoreline change rates in the location of the Galveston groin system appear relatively mild with less than 2 ft/yr of shoreline change. Areas to the west of the groin system have higher shoreline change rates of 2-3.5 ft/yr of erosion, increasing to 5-10 ft/yr of erosion in areas of the Jamaica Beach Region continuing west. As the longshore sediment transport generally travels from east to west, the higher erosion west of the groin field could present another example of the downdrift erosion impacts of groin fields.

Adjusting volume change rates to account for nourishment required several assumptions that could impact the accuracy of the results. For example, there is no differentiation between beach nourishment versus nearshore berm nourishment in this study. Dune restoration volumes, although likely falling outside of the profile envelope used for volume calculation, were not removed from the nourishment contributions due to lack of detailed information. Also, there could have been some nourishment cases that impacted more than one region.

Other than nourishment influence, this study did not explore the influences of sediment transport from one region to the next. Most likely there is not a longshore balance of sediment volume from one region to another. Understanding sediment transport across regions (including neighboring shorelines of Mexico and Louisiana) as well as influence of inland sediment contributions through inlets could add value to the current volume change rates provided in this study.

Also, comparison of volume change rates from different time periods of UT-BEG shoreline change rate data could provide additional information regarding more current or long-term shoreline changes. The start and end dates used for shoreline change rates can make a significant difference in the results. A recent USACE-developed Coastal Texas Protection and Restoration study produced a regional volume change rate assessment for sections of South Padre Island using two sets of shoreline change rates: 1937-1995 and 1995-2015. This report was referenced to validate the methodology in this current study. The current analysis and the USACE study applied similar methodologies with respect to calculating volume change and adjusting for nourishment, with slight differences in the DOC that was applied and consideration of nearshore berm nourishment placement. The results of the report showed a significant difference in average regional shoreline change and corresponding volumes depending on the timespan of shoreline change rates applied to each area. This same pattern could be observed in the current UT-BEG shoreline change rate dataset, as the differences between the 1930's-2019, 1950's-2019, and 2000-2019 datasets can be pronounced in certain areas along the Texas coast. Further evaluation of the 2000-2019 UT-BEG Shoreline Change Rates could provide additional understanding of the increased nourishments of the modern coastal management era and the impact to sediment needs in some regions.

The intent of this study was to provide a high-level perspective of sediment needs along the Texas coast for use in beach management. Use of this data should come with an understanding of the assumptions made within the study and how those decisions could contribute to uncertainty in the results. The sensitivity analysis in this study identified significant variation in the volume results based on the inland or offshore extent of volume calculations, showing approximately 5% change in volume measured per 1-foot (0.3-m) vertical change in the extents of the profile measured (see Section 2.2.1 in the appended full report). Users of this dataset must recognize that the DOC (used as the offshore extent of volume measurement) could vary by several feet from one year to another based on the severity of storms that impact an area and could make a significant difference to the overall volume change rates of each region. Data in Appendix B of the *Sediment Estimates for the Texas Coast* report (**Appendix G**) was included to illustrate the types of variation in DOC data.

The findings in the report would be beneficial for beach management efforts and provide valuable background data for localized economic or environmental impact studies. Additional monitoring provided in beach management plans could also capture performance details for nourishments and episodic erosion response of localized areas.

In future efforts, the results of this study should be calibrated as more information becomes available. Previous, smaller-scale volume estimates have been conducted in local areas such as South Padre and Galveston, however the existing studies reviewed used different ranges of shoreline change rate data, making comparison difficult. Shoreline change polyline data, regional delineations, and survey datasets were provided in the full report so that the data produced in this study can be leveraged and updated for shoreline management needs.

5.5 Ecosystem Services and Hazard Mitigation

This section supports the refinement and implementation of the TCRMP and provides a high-level summary of the scope of the *Hazard Mitigation Funding Opportunity Approach for Coastal Resilience Projects with Ecosystem*

Services Methodology. This section serves to outline the benefits of incorporating ecosystem services and coastal resilience components into traditional hazard mitigation projects as part of traditional Benefit Cost Analyses (BCAs) developed for federal grant opportunities.[1] This collaborative effort was developed by the GLO Planning Team and Ecosystem Services for Hazard Mitigation TWG. The TWG is composed of carefully selected experts from public agencies, private companies, and non-governmental organizations to work with the Planning Team to: (1) develop a framework to assist the GLO in understanding existing funding structures, and (2) create an approach to evaluate the natural capital benefits to implement infrastructure projects that incorporate ecosystem services.

The framework shown in **Figure 5-12** summarizes the overall process.

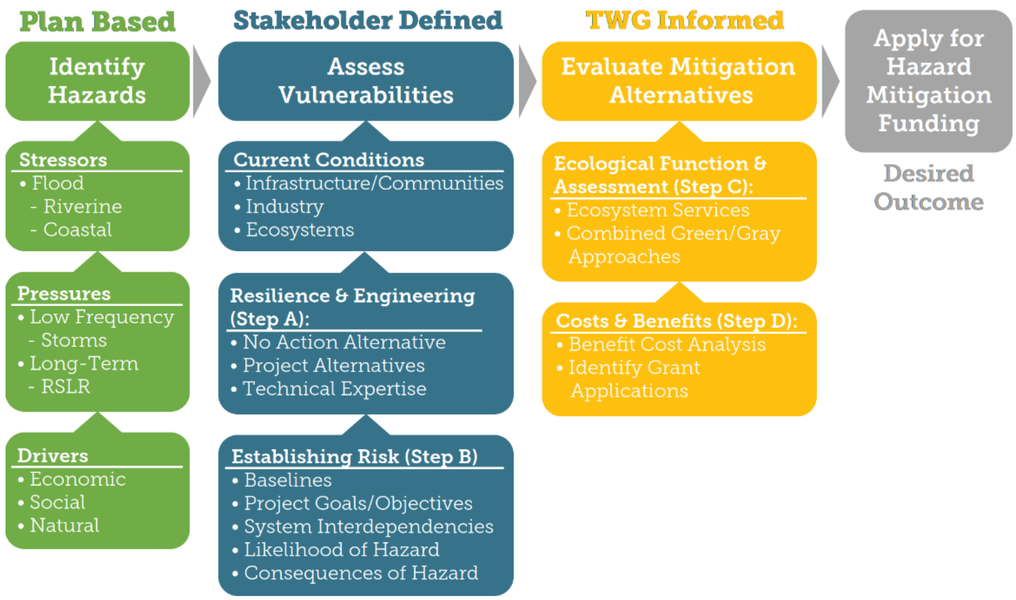


Figure 5-12. Ecosystem Services for Hazard Mitigation Funding Framework

The organization of this section is as follows:

- Introduction
- TCRMP 2018 Ecosystem Services Technical Memorandum
- Literature Review
- Hazard Mitigation Funding Approach (Steps A–D)
- Project Step-Through Example (separate document)

5.5.1 Introduction

The goal of the *Hazard Mitigation Funding Opportunity Approach for Coastal Resilience Projects with Ecosystem Services Methodology* document (hereafter referred to as the main document), is to present a balanced approach to hazard mitigation funding that better integrates NbS and coastal resilience components to support project proponents in determining whether a project may be appropriate for hazard mitigation funding opportunities. To reference the full report/methodology, see **Appendix H** or use the link provided above. An executive summary is also available on the TCRMP website, www.glo.texas.gov/crmp.

By including ecosystem service concepts into conventional project planning and taking a more comprehensive approach to evaluate project benefits, the aim is to broaden the scope and technical reach of traditional hazard

[1] Different funding opportunities may have different requirements for their BCAs, which should be reviewed in further detail by project proponents utilizing this approach.

mitigation methods. In turn, this approach is aimed to improve the net quality of coastal hazard mitigation projects funded and designed into the future.

> **Potential Benefits of this Methodology:**
>
> - Increase the role that nature-based solutions play in project decision-making to approach hazard mitigation projects comprehensively, considering both ecological and structural components.
> - A more streamlined approach to account for, and secure, project funding for projects that include ecosystem services and nature-based components.
> - Better integration of the benefits of ecosystem services and coastal resiliency into traditional hazard mitigation projects.

This methodology:

- Provides an assessment to screen projects that are potentially appropriate for hazard mitigation funding opportunities,
- Identifies and defines potential areas of risk along the Texas coast where nature-based hazard mitigation projects might be most beneficial,
- Describes the benefits of the ecological components of projects through characterization of their main ecosystem service functions, and
- Identifies potential target hazard mitigation funding opportunities for selected projects.

The remainder of this document frames the methodology that was developed by the Planning Team in conjunction with the TWG.

5.5.2 The TWG

The TWG is composed of carefully selected experts from public agencies, private companies, and non-governmental organizations to work with the Planning Team to develop a framework to assist the GLO in understanding existing funding structure and creating an approach to evaluate the natural capital benefits to implementing infrastructure projects that incorporate ecosystem services (**Figure 5-13**). These benefits are associated with the ecological components of projects seeking federal grant funding, which typically require a planning-level BCA as part of the submitted application. Presently, there are limited metrics available to include these benefits into the required BCAs.

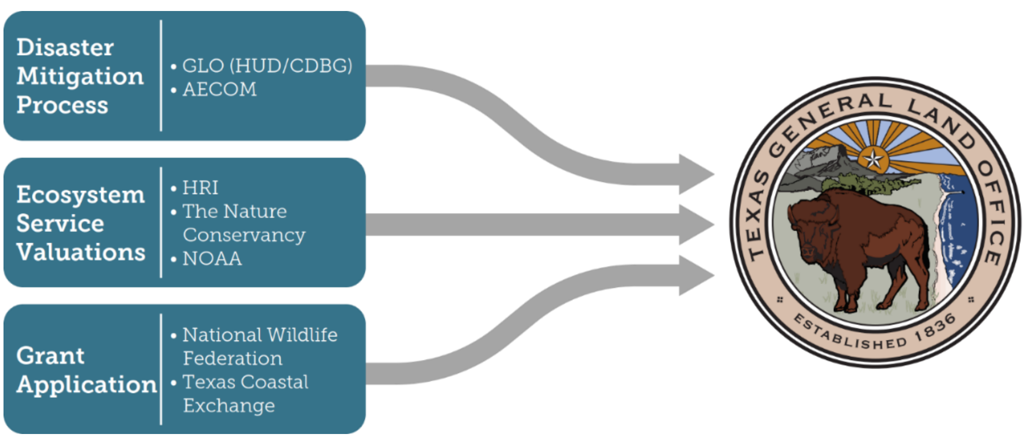


Figure 5-13. Primary Roles and Technical Expertise of TWG Participants[2]

5.5.3 Ecosystem Services Technical Memorandum

The *2018 TCRMP Ecosystem Services Technical Memorandum* (hereafter, memorandum) was developed for the 2019 TCRMP and highlighted economic valuations of ecosystem services for the Texas coast at the ecosystem (habitat type) level. The memorandum was used as the basis of this methodology and is included in full within the broader methodology document (pages 2-1 to 2-26 of the main document). More specifically, the memorandum enhanced and built upon relevant literature and databases while considering regional and/or sub-regional

[2] HUD: U.S. Department of Housing and Urban Development

characteristics that might influence how ecosystem services are represented at specific locations along the Texas coast. The memorandum can also be found in the 2019 TCRMP Technical Report.

Ecosystems and their associated services have economic values for society because people derive utility from their actual or potential uses, as well as from motivations not connected with use (such as altruism, bequests, and stewardship). Assigning an economic value to ecosystem services is challenging – conventional economic valuation traditionally considers provisioning services that are considered to have a market value (i.e., the products that can be harvested and sourced from an ecosystem, such as timber or food). Yet, ecosystems provide many other services benefitting humans either directly or indirectly, such as regulating, cultural, and supporting services.

To further explicate how they are monetized for specific Texas coastal habitats, ecosystem service benefits can be categorized into four broad service groups (definitions can be found on page 2-2 of the main document):

- **Provisioning services** include food, raw materials, and medicinal resources provided by ecosystems that can be used by people.
- **Regulating services** are provided by ecosystems that act as regulators, such as regulating air quality, water quality, and heat, moderating extreme events, preventing erosion, and acting as biological control.
- **Supporting services** are provided by the habitats that enable flora and fauna to survive, and include supports such as food, water, and shelter. Supporting services may also include the maintenance of biogenetic diversity.
- **Cultural services** include the recreational value of ecosystems, such as the aesthetics, tourism, and spiritual experiences provided by ecosystems.

5.5.4 Summary of Methods

A benefit transfer approach using meta-analyses on a national or global scale was applied to select coastal habitats in an attempt to refine the ecosystem service valuations from the aforementioned memorandum, except when studies specific to the Texas or Gulf Coast were available. Since there are a limited number of ecosystem services studies conducted for Texas and neighboring states, average national/global values were used to estimate the values of specific ecosystem services. The estimated benefits transferred from other studies were then adapted to the Texas coast and adjusted for inflation to 2018 dollars.[3]

The value of ecosystem services provided by habitats is highly contextual and unique to each habitat which can make valuation difficult when comparing across different environmental conditions and landscapes. Ecosystem services from seven target habitat types (described in detail on pages 2-3 to 2-26 of the main document) were evaluated along the Texas coast, and include:

- Oyster Reefs
- Coastal Wetlands
- Coastal Bottomland Forests
- Mangroves
- Coastal Prairies
- Beaches and Dunes
- Seagrass

These habitat types were evaluated based on the four above-mentioned ecosystem services categories and best available scientific data.

[3] Although some habitats may be difficult to distinguish, it is important to designate each acre (or fraction of an acre) as a specific habitat type to prevent double-counting benefits.

5.5.5 Summary of Results

The seven habitats were valued for their respective ecosystem services in coastal Texas and a high-level discussion of the findings are provided below (**Table 5-12**). Most habitats are likely underestimated in terms of the ecosystem services they provide. They represent conservative values intended as high-level estimates and do not necessarily encapsulate the full range of ecosystem services for the Texas coast. It is expected that there is a high level of uncertainty associated with these estimates due to the limited availability of data, extrapolating information from preexisting studies, variability of habitats across the landscape, etc.

Oyster Reefs: Oyster reefs (pages 2-3 to 2-6 of the main document) provide provisioning services and nutrient control, unless highly degraded. In addition, the health and location of oyster reefs should be considered when valuing its regulating (erosion control), supporting (providing habitat), and cultural services (recreational fishing).

Coastal Wetlands: The monetized benefit values reported for coastal wetlands apply to healthy habitats, with the exception of storm protection services, which applies to wetlands located near flood prone infrastructure. Additional information regarding coastal wetlands can be found on pages 2-6 to 2-9 of the main document.

Coastal Bottomland Forests: Ecosystem services for Texas coastal bottomland forests (pages 2-9 to 2-11 of the main document) include regulating services, in the form of nutrient control, and water regulation, depending if the habitat is situated in an urban or rural area. Supporting services vary greatly due to the abundance of rare species associated with this habitat type.

Mangroves: The values monetized for mangroves were based on meta-analyses and apply to healthy mangroves, with the exception of storm protection services, which only apply to mangroves located near infrastructure at risk for flood damage. Mangroves also provide supporting (nutrient cycling, food production, habitat, and biodiversity) and cultural services (recreation and eco-tourism). More information can be found on pages 2-11 to 2-14 of the main document.

Coastal Prairies: The ecosystem service values that were monetized for coastal prairies were based on meta-analyses or studies conducted in Texas and neighboring states with similar prairie habitats. Coastal prairies occupy less than 1 percent of the Texas coastal region but are known to supply provisioning services, (grazing land and hunting). For more information regarding coastal prairies, see pages 2-14 to 2-16 of the main document.

Beaches and Dunes: Beaches and dunes (pages 2-16 to 2-18 of the main document) are associated with cultural services (recreation and tourism) and also provide regulating services through erosion control and protection from coastal storms.

Seagrass: Seagrass habitats are one of the most productive ecosystems in coastal Texas and support all four categories of ecosystem services. Additional information can be found on pages 2-18 to 2-21 of the main document. Meta-analyses were used to value seagrass ecosystems, given that current economic valuations are very limited and incomplete, and resulted in grossly undervalued seagrass beds.

Table 5-12. Ecosystem Services Summary Table

Habitat Type	Average Annual Value per Hectare per Year
Oyster Reefs	$114,300 - $224,400
Coastal Wetlands	$37,200 - $53,800
Coastal Bottomland Forests	$28,900 - $39,700
Mangroves	$225,500 - $231,900
Coastal Prairies	$15,500
Beaches	$47,900 - $131,000

Habitat Type	Average Annual Value per Hectare per Year
Dunes	$13,000 - $96,100
Seagrass	$64,900

Note: All values rounded to the nearest hundred and based on 2018 dollars.

5.5.6 Literature Review

A literature review of available data relevant to the Texas coast was performed to (1) build upon the aforementioned 2018 memorandum, and (2) assess the extent of research conducted on ecosystem services, their benefits, techniques applied to evaluate them, and online tools available for valuing ecosystem services. An overview of the approach and methods to value ecosystem services are discussed herein. To view the entire Literature Review, see pages 3-1 to 3-32 of the main document.

5.5.7 Approach to Value Ecosystem Services

The following factors should be considered when designing a valuable ecosystem valuation exercise:

- Define the scope of the analysis and consider which ecosystem services will be included or excluded, by choice or necessity, in the valuation process.
- Define the geographic extent of the relevant ecosystems for the valuation process.
- Define the relevant stakeholders – identifying and including relevant stakeholders in the valuation analysis will improve the valuation estimate (National Research Council, 2005); (Pascual et al., 2010).

It is important to remember that no valuation technique is perfect. For any valuation effort, the requirements of the analysis will be influenced by the resources and data available, and uncertainty will always be a concern (Costanza et al., 2017).

5.5.8 Methods of Economic Valuation of Ecosystem Services

To gain one step toward valuing ecosystems services along the Texas coastline, the Literature Review dives deeper into the Total Economic Value (TEV) framework, preference-based economic valuation, and other methods currently in practice. Below are high-level discussions of each topic area discussed in detail in the full methodology.

TEV Framework

The TEV framework (explained in greater detail on pages 3-8 to 3-10 of the main document) assesses both market and non-market values of ecosystem services (Ledoux & Turner, 2002). TEV is a concept in BCAs where humans derive a value from having ecosystem services as compared to not having those services. The TEV framework aggregates the values of all services provided by a habitat that are generated now, and in the future (Pascual et al., 2010).

Preference-Based Valuation

Preference-based approaches (pages 3-10 to 3-11 of the main document) are widely accepted for valuing ecosystem services and rely on observing human behavior and estimating value from individual choices (Pascual et al., 2010). The primary objectives of preference-based valuation are to determine stakeholder preference, how much stakeholders are willing to pay for a service, and to what degree they would consider themselves to be better or worse off due to any changes in the provision of a service (Wood et al., 2010).

Conventional preference-based economic valuation includes two primary methods for estimating value and requires significant time and resources to gather pertinent data:

a. *Revealed Preference* methods are based on observed human behavior in a real-world setting. The method analyzes human choices and deduces a value from these observed choices.

b. *Stated Preference* methods rely on analyzing individual responses to carefully designed survey questions. The method includes using contingent valuation and choice experiments.

Benefit Transfer

When revealed and stated preference methods are not possible, the benefit transfer method is an additional option, but has greater error rates (more information on this approach can be found on pages 3-11 to 3-12 of the main document). Benefit transfer uses research results from primary valuation studies at one site and transfers the results to other, similar sites (Olander et al., 2015). It is also a means to aggregate calculated values to larger spatial scales and contexts (Costanza et al., 2017).

Use of Proxies

For some ecosystem services that are difficult to quantify, such as regulating or supporting services, proxy measures have been useful to estimate economic values (more information on pages 3-12 to 3-13 of the main document) (Costanza et al., 2017). For example, Net Primary Productivity (NPP) – the rate energy is stored as biomass by primary producers for other consumers in the trophic food web – provides a good proxy for ecosystem services (Costanza et al., 1998). Additionally, oyster reefs can be substituted as a proxy for shoreline protection when compared to protection using traditional gray infrastructure (Henderson & O'Neil, 2003).

Biophysical Valuation

Biophysical valuation (page 3-13 of the main document) refers to the 'cost of production' approach, which considers the sum of the cost of resources that goes into producing a good or service (i.e., labor, energy, or material inputs) to maintain a specified ecological state (Pascual et al., 2010). This approach considers the physical costs of maintaining a particular ecological state, and therefore is more useful for valuing natural capital stocks that have a biophysical form than for valuing indirect services like storm protection. Biophysical valuation relies heavily on implicit assumptions (i.e., ecosystem services with direct biophysical expression irrespective of the value for humans, or cultural services provided) and, therefore, is not a common method for valuing ecosystem services.

5.5.9 Identifying Nature-based Projects for Hazard Mitigation Funding

The approach outline provided on pages 4-1 to 4-4 of the main document gives a description of each step in the process to identify prospective projects that could be used to apply for hazard mitigation grant funding. The steps included in the approach (Steps A to D) are meant to guide project proponents through selecting a nature-based project that meets minimum criteria to be eligible for funding (Step A); meets certain risk thresholds for SLR, flooding, and wave effects (Step B); provides ecosystem services (Step C); and can be tailored for one or more hazard mitigation funding grant opportunities (Step D). These steps are described, in brief, below.

Step A - Project Assessment

During Step A (pages 5-1 to 5-2 of the main document), projects are systematically screened to determine whether each project would be appropriate for hazard mitigation funding under federal and/or other grant funding opportunities. Projects can be determined to be potentially appropriate while including ecosystem service benefits by answering several simple questions.

Step B - Risk Index

During Step B (pages 6-1 to 6-8 of the main document), sites that are vulnerable to coastal hazards will be identified. For a project to be considered more appropriate for hazard mitigation funding opportunities, the project site would need to have developed areas that are vulnerable to hazards that would be mitigated under the funding source (e.g., flooding in the case of a FEMA Flood Mitigation Assistance (FMA) grant). The risk index may be used to help a project proponent (1) select a location for a proposed project that would likely be appropriate for hazard mitigation funding, or (2) decide if a pre-determined project location is a good candidate for a hazard mitigation project.

Risk index maps are included for each hazard and allow project proponents to determine the level of risk at each proposed project site:

- Landcover change due to future SLR projections (Figures 6-4 to 6-7 in the main document).

- Inundation due to 1% annual chance storm (100-year storm) FEMA National Flood Hazard maps (Figures 6-8 to 6-11 in the main document).
- Wave exposure (Figures 6-12 to 6-15 in the main document).

Step C - Value of Ecosystem Services

Step C (pages 7-1 to 7-50 of the main document) will aid a project proponent in describing the benefits of the ecological components of the proposed project. This will be done by characterizing the project by its main ecosystem service functions, such as habitat, biodiversity (species richness), primary productivity, provisioning services, and carbon sequestration. When data is available, quantified benefits may be transferred to the project based on regionally specific monetary valuations of the benefits of ecosystem services. Any benefits that cannot be determined quantitatively can be discussed qualitatively in a grant funding application.

Step D – Synthesis of Results and Hazard Mitigation Application

After completing the preceding steps, Step D (pages 8-1 to 8-7 of the main document) provides a synthesis of the information determined in Steps A to C. The template table below is provided to record and evaluate the results of each step and can be used to organize the relevant hazard mitigation application information (more detailed information on how to use the table can be found on page 8-4 in the main methodology document).

Step D also includes a list of potential hazard mitigation funding opportunities (pages 8-5 to 8-7 of the main document) that have been identified to help a project proponent determine potential opportunities that may be available for funding applications for the selected project.

5.5.10 Project Example Step-Through

The project step-through is a separate document meant to serve as a guide for project proponents to walk through the intricacies of determining the responses to Steps A to C for a specific project example. Based on the TCRMP Tier 1 list of opportunities that currently lack funding, the project selected to act as a guide for this step-through example is **Ocean Drive Living Shoreline (Project ID R2-7)**.

Project Description

This project is in Calhoun County, Texas (Region 2) near Indianola Beach, adjacent to the ANWR. As of the 2019 TCRMP, the project is in the conceptual phase without secured funding. The major stakeholder is Calhoun County, and the overarching project goals are to create and restore habitat, stabilize the shoreline, and enhance community infrastructure. The resiliency strategies that this project targets include both ecological benefits – wetland planning, restoration, and monitoring – and societal benefits – enhancing land-based transit systems.

Ocean Drive is a coastal roadway that connects several coastal communities on the western side of Matagorda Bay. This project would add a living shoreline-type stabilization using breakwaters along Ocean Drive near Indianola, heading north, to control shoreline erosion while potentially building back eroded nearshore habitat. The shoreline in this area has seen an increase in bay shoreline erosion, and Ocean Drive is experiencing more frequent flooding, which is expected to continue to worsen under future SLR predictions. Magnolia Beach, off the northern end of Ocean Drive, is a popular Recreational Vehicle (RV) and camping area that is experiencing significant beach erosion. This project would serve as a long-term solution to preserve the various restoration projects that have been attempted in the past, such as beach nourishments and wetland restorations. Protecting the shoreline also would help reduce the risk of Ocean Drive from being inundated during high tides or large rainfall events. This is critical since Ocean Drive is an evacuation route for the nearby community.

Ecosystem Services Scoring Table

The Ecosystem Services Scoring Table (below) provides an example evaluation of the Ocean Drive Living Shoreline project. **Appendix H** includes a clean copy of the scoring table and an electronic editable version can be downloaded from the TCRMP website.

Project Name	Ocean Drive Living Shoreline	*Regulating Services Score*	14
Project ID (2019 TCRMP)	R2-7	*Co-Benefits Score*	8.5
		Total Ecosystem Services Score	22.5
Project Description	Ocean Drive is a coastal roadway that connects several coastal communities on the western side of Matagorda Bay. This project would add a living shoreline-type stabilization using breakwaters along Ocean Drive near Indianola, heading north, to control shoreline erosion while potentially building back eroded nearshore habitat.		

Step A		Step B					
General Project Assessment	Y/N	Risk index score (check one column per row)					
Does the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)?	Y	Hazard	Low	Low-Medium	Medium	Medium-High	High
Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)?	Y	Land Loss Risk Index			X		
Is the project in need of funding? (partially funded or not funded)	Y	Flood Risk Index		X			
Is the project in an early planning phase? (conceptual, preliminary design, permitting, final design, shovel ready)	Y	Wave Action Index			X		
If a "yes" response is achieved for each question, proceed to Step B.	PROCEED	If the project achieves a medium to high score for at least one hazard, proceed to Step C.					PROCEED

Ecosystem Service Matrix Benefits

Regulating Services					
Project Alignment Questions	Y/N	Score	*Regulating Service Scores*	High, Medium, Low	Score
Is project considered a pre- or post- 'hazard mitigation' project (targeting hazards such as flood mitigation, coastal storm surge protection, erosion control, shoreline stabilization)?	Y	2	Storm Surge Protection/Flooding Protection	medium	3
Is the proposed project located in a vulnerable coastal zone as assessed by the 'ecological vulnerability index' or 'risk score'?	Y	2	Erosion Control/Shoreline Stabilization	high	5
Does the project incorporate relevant NbS features derived from Texas coastal habitats to address an expected hazard (e.g., using coastal wetland features to provide storm surge protection)?	Y	2			
			Total Regulating Services Score		14

Co-Benefits Score					
Supporting Services	High, Medium, Low	Score	*Regulating Co-Benefit*	High, Medium, Low	Score
Habitat provision	medium	1	Carbon sequestration	medium	1
Species richness	high	1.5	*Cultural Services*		
Listed species	medium	1	Eco-tourism	low	0.5
Critical habitat	low	0.5	Recreation	medium	1
Primary production	medium	1	*Provisioning Services*		
			Fisheries/Timber/Grazing	medium	1
			Total Co-Benefits Score		8.5

Notes
Further qualitative information that could be discussed in the application may include that the Ocean Drive project would improve access as a critical evacuation route for nearby communities in addition to popular recreation and camping areas at Magnolia Beach.

Detailed descriptions for how each score was determined are provided below.

Step A – Project Assessment

General questions to consider to better understand if the Ocean Drive Living Shoreline project may be applicable for hazard mitigation funding and opportunities:

- Does the project reduce loss of life and property by minimizing natural disaster impacts (e.g., coastal or riverine flooding)? Yes.

- Does the project enhance, create, or support ecosystems through avoided damages (i.e., is the project a nature-based solution)? Yes.
- Is the project in need of funding? (partially funded or not funded) Yes, and not currently funded.
- Is the project in an early planning phase? (conceptual, preliminary design, permitting, final design, shovel ready) Yes, and in the conceptual phase.

Since “yes” was achieved for each question, proceed to Step B.

Step B – Coastal Vulnerabilities for Ocean Drive based on the Risk Index Maps

The scores pertaining to each coastal hazard above (land loss, flood risk, and wave action) for the Ocean Drive Living Shoreline project are outlined below based on the Region 2 risk index maps (Figures 6-5, 6-9, and 6-13, respectively, in the main document).

- **Land Loss Risk Index** – Medium ***(Figure 5-14)***
- **Flood Risk Index** – Low-Medium ***(Figure 5-15)***
- **Wave Action Risk Index** – Medium ***(Figure 5-16)***

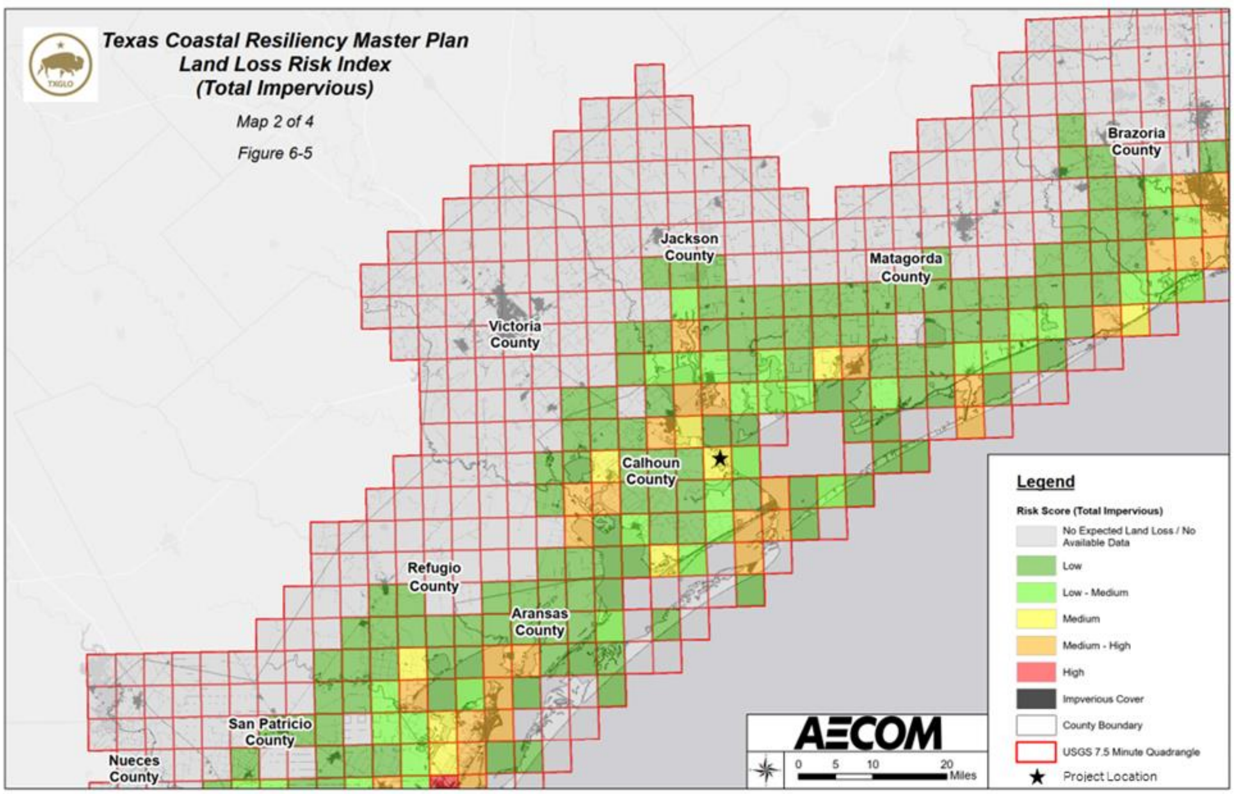


Figure 5-14. Land Loss Risk Index for Region 2

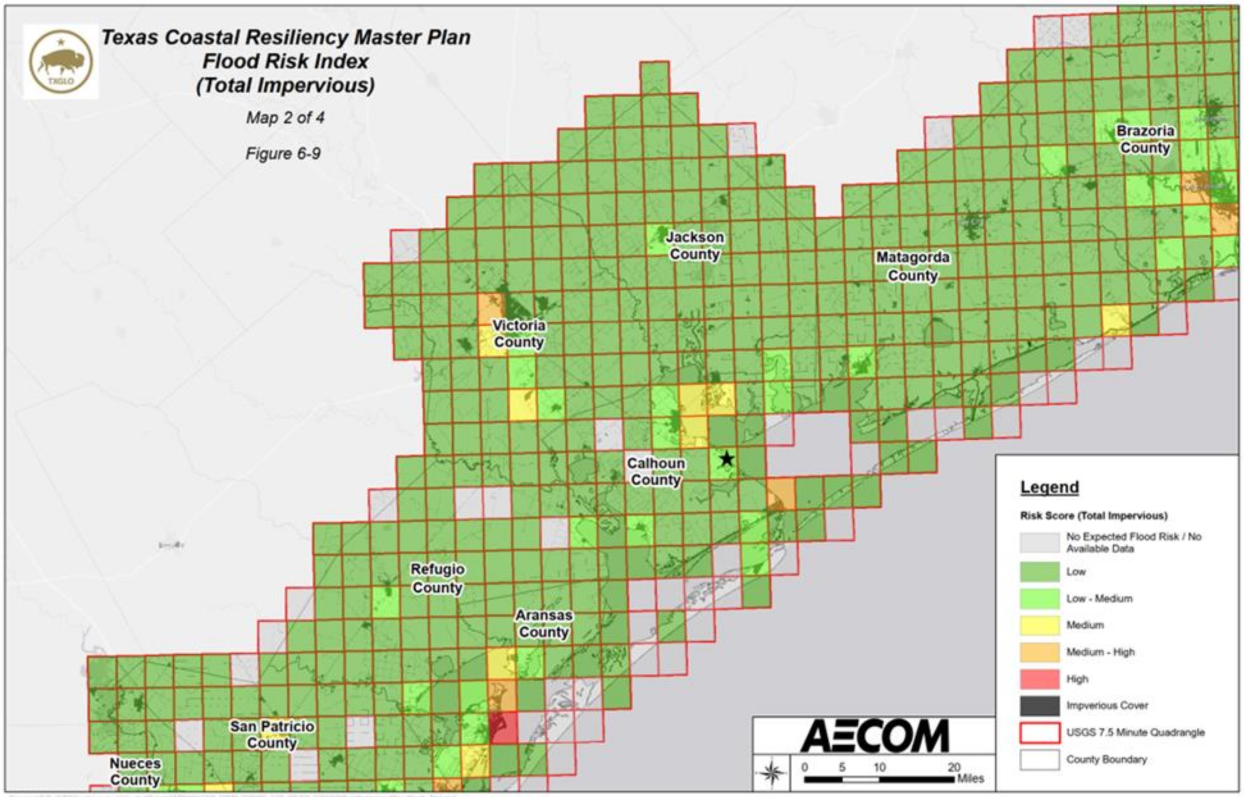


Figure 5-15. Flood Risk Index for Region 2

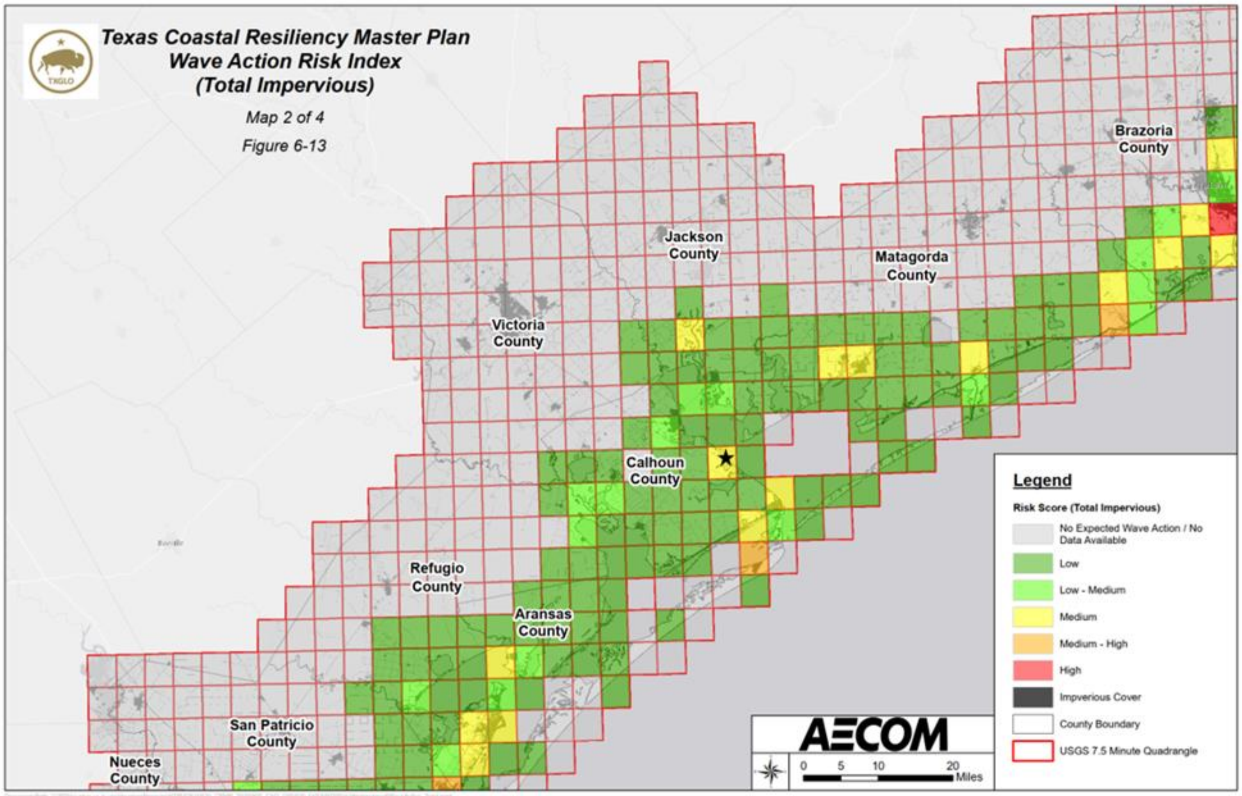


Figure 5-16. Wave Action Risk Index for Region 2

Since this project achieved a medium score for both land loss and wave action risk, proceed to Step C.

Step C – Value of Ecosystem Services

Scoring for Step C is explained below. The ecosystem services scores selected for the Ocean Drive Living Shoreline project are shown in **Table 5-13**.

Project Alignment Questions

To begin scoring regulating services, a series of questions will be answered. Each question is scored as a binary score of yes (score 2) and no (score 0). The questions include:

1. Is the project considered a pre- or post- 'hazard mitigation' project (targeting hazards such as flood mitigation, coastal storm surge protection, erosion control, shoreline stabilization)?

   The project aims to restore habitat to armor the coastline for flood mitigation and provide shoreline stabilization, indicating it would be applicable for pre-disaster funding **(2 points)**.

2. Is the proposed project located in a vulnerable coastal zone as assessed by the 'ecological vulnerability index' or 'risk score'?

   Yes, the project received medium risk index scores for both land loss and wave action in Step B **(2 points)**.

3. Does the project incorporate relevant NbS features derived from Texas coastal habitats to address an expected hazard (e.g., using coastal wetland features to provide storm surge protection)?

   Ocean Drive incorporates wetland planning, restoration, and monitoring into the project design as relevant nature-based designs to address coastal flooding hazards **(2 points)**.

Ecosystem Service Scores

Table 5-13. Ecosystem Service Scores by Service Category (shading indicates co-benefits)

Ecosystem Service Category	Ecosystem Service	Score	Points Awarded	Explanation
Regulating Services	Storm Surge and Flooding Protection	Medium	3 points	Scored a medium (3 points) due to the indirect benefits it would have on shoreline stabilization.
	Erosion Control and Shoreline Stabilization	High	5 points	Scored high (5 points) as it is the main objective of the project – the shoreline in this region has seen an increase in bay shoreline erosion and Ocean Drive is experiencing more frequent flooding, expected to worsen under future SLR predictions.
	Co-Benefit: Carbon Sequestration	Medium	1 point	Scored a medium (1 point) due to the wetland restoration planned to promote shoreline stabilization and reduce flooding impacts.
Supporting Services	Habitat Provisioning	Medium	1 point	Scored a medium (1 point), due to the presence of approximately 10 ac of beach habitat in the project area.
	Species Richness	High	1.5 points	Scored high (1.5 points) due the presence of beach habitat which can support approximately 650 different species.
Supporting Services (cont.)	Listed Species	Medium	1 point	There are six potential listed species that could utilize the beach habitats the living shoreline would protect. For this reason, the project is moderately ranked (1 point).
	Critical Habitat	Low	0.5 points	Beaches are considered critical habitat for the listed piping plover species, so this project receives a “yes” for critical habitat present (0.5 points).
	Primary Production	Medium	1 point	The average NPP for a beach habitat is approximately 6,491 lbs. acre/year, which scores medium (1 point).
Cultural Services	Eco-tourism	Low	0.5 points	Scored low (0.5 points) since tourism was not called out in the project description.
	Recreation	Medium	1 point	Scored a medium (1 point) since Magnolia Beach, off the northern end of Ocean Drive, is a popular RV and camping area and is experiencing significant beach erosion and is impacted by flood risk.
Provisioning Services	Fisheries / Timber / Grazing	Medium	1 point	Scored a medium (1 point) for the recreational fishing that is located near the project vicinity.

Note: Co-benefits are indicated as shaded rows for each Ecosystem Service Category.

The total Ecosystem Services score for Ocean Drive (including the 6 points for project alignment scores, the 8 points for ecosystem regulating services, and the 8.5 points for co-benefits) sums to 22.5, which signifies that the project would offer significant ecosystem service benefits for hazard mitigation. There is a potential to evaluate these further through a cost-benefit analysis. As the co-benefits tabulated for Ocean Drive sum to 8.5, the project is noted to offer significant co-benefits. These co-benefits could be discussed qualitatively in a project narrative writeup for the purposes of a hazard mitigation grant funding application.

Notes can be entered into the aforementioned Ecosystem Services Scoring Table to list benefits that should be discussed qualitatively in the subsequent hazard mitigation funding application. An example may include additional information relating to how this project would improve the roadway as a critical evacuation route for nearby communities. This project would also enhance co-benefits such as improving access to a popular recreation area at Magnolia Beach for camping.

Step D – Hazard Mitigation Application

Potential hazard mitigation funding sources applicable to the Ocean Drive Living Shoreline project are shown in **Table 5-14** (Table 8-4 in **Appendix H** provides more detailed information for additional hazard mitigation funding options).

Table 5-14. Potential Hazard Mitigation Funding Opportunities

Funding Entity	Funding Opportunity	Explanation
Environmental Protection Agency (EPA)	Wetland Program Development Grant	May be another option for Calhoun County to consider, as wetland creation and restoration is included in the project description.
Environmental Sustainability Research Program	National Science Foundation	This program would promote sustainable engineered systems for the Ocean Drive project that support human well-being and are compatible with sustaining natural (environmental) systems.
FEMA	FMA pre-disaster	The Ocean Drive project would reduce flood risk for surrounding communities that have experienced repetitive loss.
Federal Highway Administration (FHWA)	Nature Based Resilience for Coastal Highways	Ocean Drive not only provides access but serves as a critical evacuation route for nearby communities, making it eligible for this grant opportunity.
NFWF/NOAA	National Coastal Resilience Fund	This grant would directly apply to Ocean Drive as it aims to create and restore habitats and stabilize shoreline to prevent future hazards from occurring for neighbouring communities.
NFWF	Gulf Coast Conservation Grants Program	This grant would help support priority land conservation needs in Calhoun County, Gulf Coast.
GLO	CEPRA	This reimbursement program would help to fund Ocean Drive as a project and study to reduce coastal erosion.
TWDB	Flood Infrastructure Fund	This fund provides financial assistance in the form of loans and/or grants for flood control and mitigation projects, which directly applies to Ocean Drive.
USACE	Continuing Authorities Program	This grant opportunity provides mitigation funds for counties to implement both flood and erosion control through ecosystem restoration and shoreline stabilization, which is directly applicable to the Ocean Drive Living Shoreline project.
U.S. Department of Housing and Urban Development (HUD)/GLO	CDBG-MIT	This grant would apply to Ocean Drive as it relates to disaster mitigation and risk reduction in impacted areas.
USFWS	National Coastal Wetlands Conservation Grant	This funding opportunity would help protect, restore and enhance coastal wetlands located in the project vicinity.

5.5.11 Conclusion

This section serves to describe the *Hazard Mitigation Funding Opportunity Approach for Coastal Resilience Projects with Ecosystem Services Methodology* and is intended to clarify and streamline the approach process for project proponents looking to apply for and secure hazard mitigation funding for nature-based resiliency projects in coastal Texas. Specifically, the methodology document aims to support project proponents in determining the appropriateness of a particular project as a NbS for hazard mitigation funding, the level of exposure to particular hazards that could be at the project site, and the ecosystem service benefits that could result after project implementation.

5.6 Unauthorized Discharges and Sanitary Sewer Overflows in the Coastal Zone

This section examines unauthorized discharge (UD) and sanitary sewer overflow (SSO) incidents occurring in wastewater collection, transmission, and treatment systems in the Texas Coastal Zone Boundary (CZB) between July 2012 to April 2022. Depending on the designation, UD or SSO incidents release untreated or partially treated wastewater into Texas waters at a WWTP or somewhere within the wastewater collection and transmission system (WCTS) and are required by federal law to be reported, regardless of incident size. Within this memo, UD/SSO incident data reported by permitted facilities in the CZB were processed to reveal commonly reported causes of incidents, geographic areas most impacted by UDs/SSOs, and estimated UD/SSO discharge volumes and incident frequencies. This section also assesses the potential impacts of future expected SLR on future performance of permitted facilities.

The data available for this analysis included 4,864 UD/SSO incidents over the period of record. The incidents were reported by staff from 86 of the 154 WWTPs in the dataset (roughly 56%). The most commonly reported causes of UD/SSO incidents were infiltration/inflow, accounting for nearly 25% of the dataset, and line blockages (both grease and non-grease), accounting for almost 15% and 21% of the dataset, respectively. The geographic areas of the Texas coast that are most impacted by UD/SSO incidents include Harris County and Galveston Bay, accounting for 74.7% and 82.6%, respectively, of cumulative reported discharge, followed by Nueces County and Corpus Christi Bay, accounting for 7.48% and 9.5%, respectively. The most frequently reported incident volume is between 0.1 and 1,000 gallons (44.1% of incidents reported). Incidents of 100,000 to 1,000,000 gallons in size are attributed to the majority of total UD/SSO volume produced, accounting for over 32 million gallons, or 48.6% of the total UD/SSO volume reported within the period of record. Six existing WWTPs are at risk of inundation assuming a future SLR of 3 ft scenario.

Analyzing the top occurrences of UD/SSO incidents by number of incidents, total cumulative volume, and total single-incident volume did not yield any clear trends or correlation for why a particular WWTP reported greater numbers of incidents or larger volumes of discharge resulting from one or more incidents. The relationship between frequency and volume of reported UD/SSO incidents to existing urban/impervious cover, seasonal rainfall, and population were also explored to reveal possible trends and correlations driving UD/SSO occurrences. There are known data gaps in the dataset that were not able to be addressed under the scope of this analysis, and so the findings presented herein are preliminary, although useful for an initial look at the potential impacts of UDs/SSOs in the Texas CZB. Further discussion is available within this section.

The data for the analysis also included a spatial dataset containing 62,645 permitted on-site sewage facilities (OSSFs) as of April 2022 to collect domestic wastewater where centralized public or private wastewater collection is unavailable. The age of individual OSSFs is reported for only one third of the dataset. No OSSF incident data was available for the analysis; the analysis was therefore limited to a geospatial and SLR analysis to determine where potential risk for incidents may be present based on OSSF relative spatial density and/or future SLR. Within the Texas CZB, approximately 34% of permitted OSSFs are in urbanized areas, while the remaining 66% are in non-urbanized areas. Approximately 12% of coastal OSSFs are on peninsulas and barrier islands. Areas of high relative density for OSSFs include Bolivar Peninsula, Baytown, and Rockport. Over 2,200 OSSFs (3.6% of the dataset) would be inundated by 3 ft of SLR; many of the potentially inundated systems are on barrier islands and peninsulas.

The section includes recommendations to improve best practices for UD/SSO and OSSF management in coastal Texas. More incident reporting is needed for UD/SSO incidents to obtain more accurate and consistent reporting. Reporting practices should be investigated further to understand the shortcomings leading to inconsistent or missing UD/SSO data and recommend best practices for improvement. Future data collection would benefit from differentiation between an SSO and an UD occurring at a WWTP. Addressing issues to reduce UD/SSO volumes and frequencies of occurrence should take place at a site-level, focusing on problematic WCTS in the most impacted bay systems. Approvals for future permitted facilities, both WWTPs or OSSFs, should consider the location of the facility regarding potential future SLR so that greater resiliency of the permitted facility is achieved. Long term, adaptive management is recommended to preemptively address the CZB's rapidly increasing population that is further expected to exacerbate drivers of UD/SSO incidents.

5.6.1 Introduction and Background

An UD is any discharge of wastewater into or adjacent to any water in the state at a location not permitted as an outfall. SSO incidents are a type of reported unauthorized discharges of untreated or partially treated wastewater from a collection system or its components before reaching its associated treatment facility, typically a WWTP. The WWTP and its collection system will be referred to as the WCTS for the purposes of this analysis. The objective of this section is to characterize available data pertaining to reported UD and SSO incidents in the Texas Coastal Zone. Data analysis done in support of this objective aims to provide a better understanding of existing wastewater treatment system performance in Texas coastal counties. It will also help to identify possible factors affecting existing domestic WCTSs that influence the occurrence, frequency, and volume of UDs and, in particular, SSOs.

This section discusses the analysis of existing OSSFs, commonly known as septic systems, in the Texas CZB to determine where there may be risks of future UDs/SSOs due to coastal processes and future conditions, such as anticipated SLR.

This analysis aims to determine:

- Where WWTPs and OSSFs are spatially located along the coast,
- Which counties and bay systems have histories of UD/SSO incidents,
- If individual WCTSs have a history of UD/SSO incidents,
- The most reported events leading to UDs/SSOs (e.g., Infiltration and Inflow, Power Outage, Act of God, etc.),
- The locations of WWTPs and OSSFs that are at risk of future incidents due to SLR, and
- How UD/SSO incidents align with TCEQ Impaired Waterbody data.

The findings from this memo will help identify Texas coastal areas at risk of poor water quality due to UDs/SSOs, as well as reported WCTS trends that may require resources to improve coastal water quality and better protect public health. However, it is important to understand there are many factors affecting water quality. While the effects of environmental contamination from UDs/SSOs contribute negatively to water quality, UDs/SSOs are not the only sources of contamination, and their direct relationship to measured water quality is not determined (EPA, 2022b). There are innumerable sources of point source and non-point source pollutants that collectively impact water quality along the Texas coast.

Wastewater Treatment Overview

Sanitary sewers are not designed to collect large volumes of stormwater in addition to wastewater. When stormwater enters sewers (for instance, through *infiltration* that occurs when groundwater seeps into sewer pipes or *inflow* that occurs when stormwater flows directly into sanitary sewers through drains and other connectors) or maintenance issues occur, collection capacities of these systems are overwhelmed. This can cause unauthorized discharges of untreated or partially treated wastewater into water bodies and public areas. Exposure to unauthorized discharge incidents is a threat to public health and a cause of property damage. Across the United States, 34 billion gallons of wastewater are processed daily, coming to 12.5 trillion gallons over the course of a year (EPA, 2022a). An estimated 23,000 to 75,000 SSO events occur each year within the United States, according to the EPA (EPA, 2022c).

Permitted wastewater treatment facilities are holders of a water quality permit issued by the TCEQ or the EPA, and may be a municipality, municipal water district, private individual, or company. A permitted facility is required to notify the TCEQ of any UD/SSO incident within 24 hours of when the incident is discovered, regardless of incident volume. For large volume incidents or discharges that will adversely affect a public or private source of drinking water, the permit holder may be required to inform the general public, as well. Permits from the TCEQ require the permitted facility to begin engineering and financial planning for upgrades whenever the facility experiences 75% of the permitted daily average or annual flow for three consecutive months. Once the permitted facility meets or exceeds 90% of the permitted daily average or annual flow, the permit holder is obligated to obtain authorization for construction of the planned upgrades. Unfortunately, in Texas, there is a shortfall of more than $200 million in federal and state funding for WTCS expansion and improvements (ASCE, 2021).

The UD/SSO dataset used for this analysis ranged from July 2012 – April 2022 and included 154 WWTPs. Over that timeframe, a total of 4,864 UD/SSO incidents were reported by personnel from 86 WWTPs in the CZB. WWTP personnel individually report UD/SSO incidents, and reported discharges are typically estimates rather than measured volumes.

Onsite Sewage Facilities (Septic Systems) Overview

Those who do not have centralized public or private domestic wastewater treatment access process their waste via household OSSFs, or septic tanks. Twenty percent of new construction homes in Texas are being built with septic systems and similarly account for 20% of new wastewater treatment capacity in Texas according to the Texas Section of the American Society of Civil Engineers (ASCE)'s 2021 Texas Infrastructure Report Card (ASCE, 2021). As of 2020, there are over 2.2 million septic systems operating in Texas, including coastal and inland areas (Texas Water Quality and Septic Systems, 2020).

OSSFs in Texas are required to be permitted by the TCEQ by local permitting authorities and must possess this permit for initial construction, installation, repair, extension, or other alteration (TCEQ, 2022b). Maintenance requirements on the landowner are typically unspecified by local permitting authorities; exceptions to this case sometimes require a 1- to 2-year inspection period for the OSSF system immediately following its installation. The EPA states that an estimated 10-20% of all septic systems fail because of aging infrastructure, poor design, and too much wastewater generated by the users (EPA, 2022a). Flooding can also contribute to the failure of OSSFs, resulting in a discharge of waste previously contained within the OSSF. Malfunctions caused by stormwater inundation, equipment failures, or other circumstances are not systematically reported or recorded. The number of OSSF malfunctions within Texas may increase due to increased future flooding or changing coastal conditions (Miami-Dade County Department of Regulatory and Economic Resources, 2018).

OSSF data in this analysis included the locations of 62,645 permitted OSSFs in the CZB as of April 2022. No OSSF malfunction or discharge data was available from the available dataset.

Available Data

The shapefiles shown in **Table 5-15** used for the purposes of this analysis include:

Table 5-15. Data used in SSO analysis

Filename	Source	Date	Description
TCEQ_Segment_Impairment_2022.shp	TCEQ, ArcGIS Online	2022	Shapefile showing bodies/segments of water declared impaired by the TCEQ
SSO_Incidents_WWTP.shp	TCEQ	2022	Shapefile showing individual UDs/SSOs in the CZB
_2021_InventoryCZ_All_4-13-2022.shp	GLO	13 April 2022	Shapefile containing a list of OSSFs in the CZB
CZB.shp	GLO	2022	Shapefile outlining the Texas Coastal Zone Boundary
WWTPs_CZB.shp	GLO	04 April 2020	Shapefile listing the WWTPs in the CZB

Filename	Source	Date	Description
TX_Central_slr_3ft.shp **TX_North1_slr_3ft.shp** **TX_North2_slr_3ft.shp** **TX_South1_slr_ 3ft.shp** **TX_South2_slr_3ft.shp**	NOAA	2020	Shapefiles showing the area inundated by a 3ft SLR scenario
Urbanized_Area.shp	TxDOT	2022	Shapefile showing dense urban areas in Texas
PRISM_tx_v1.shp	PRISM Climate Group, Oregon State Univ.	2012-2021	Shapefile showing average annual precipitation (inches) in Texas
Precip.xlsx	Texas Water Development Board (TWDB)	1981-2022	Daily record of precipitation per county within the CZB

Data Limitations

There are several limitations for the above datasets that are noted below. These considerations were not able to be assessed further for the purposes of this analysis. Future work is needed to address these data gaps to obtain a more comprehensive analysis of domestic waste treatment in coastal Texas.

UD/SSO Data

- **Dataset Including both UD and SSO data:** The UD/SSO dataset includes unauthorized discharges as well as sanitary sewer overflows, which are a subset of unauthorized discharges. There is not clear reporting within the dataset to differentiate which entries are SSOs that take place within the collection systems from other UDs that occur at the WWTP. Because of this, it is difficult to identify with certainty which data points are most properly designated as UDs, and which data points are most properly designated as SSOs. To generalize the dataset, the analysis makes the following assumption given designations for individual incidents:
  - SSO data: Source of incident was labeled as an individual address, cross street, or was labeled as “sewage,” “manhole,” or “collection system”
  - UD data: Source of incident was labeled as “WWTP,” was assigned a reference number indicating the associated WWTP, or was otherwise indicated as “Plant”

  Using those designations, approximately 95% of the reported incidents are assumed to be SSOs. Approximately 5% of the reported incidents are assumed to be other UDs.

  SSO Incidents: 4,622 (approx. 95%)
  UD Incidents: 242 (approx. 5%)

  SSO Volume: 60,496,039 gal (approx. 91%)
  UD Volume: 5,883,038 gal (approx. 9%)

  However, these assumptions are given for reference only, and more refinement is needed in the future to validate these assumptions. Additionally, updated data collection techniques that require respondents to specify whether the reportable incident is a UD vs. SSO is recommended as a best practice.

- **Age of Collection System Infrastructure:** The UD/SSO data does not show the age of sewer and wastewater infrastructure within the collection systems associated with individual WWTPs, nor the age of the WWTPs themselves. These systems are responsible for collecting and transporting sewage and wastewater to WWTPs, and SSOs occur within the collection system as sewage is enroute to the WWTP. Information on the age of collection system infrastructure was not available within the dataset and is not readily or publicly available. According to the Texas Section of the ASCE, the decline of collection system infrastructure function is primarily due to system age (ASCE, 2021).

- **Geospatial location of UDs/SSOs:** Geospatial information for UD/SSO events is approximated by the location of the collection system’s corresponding WWTP. Specific data is available for most, but not all reported incidents. Specific geospatial data is reported as observed approximate locations based on references, such as addresses, local connection system infrastructure, or city/town names. These observed locations vary greatly in detail and description, making consistent and accurate geographic identification difficult. Resources were not available to identify the specific geographic location from the written observed location, so the readily available WWTP location was used to approximate the location of the UD/SSO within the WCTS.

- **Dataset Incompleteness:** A Quality Control review of the data indicated there may be an unknown number of additional permitted facilities not included in the UD/SSO dataset that have unrecorded, but reportable SSOs. The City of Bishop WWTP (WQ0010427001) and BCFS Driscoll Health and Human Services WWTP (WQ0014981002) were both formally sanctioned by the TCEQ for having known SSO incidents occurring within the dataset period of record; however, neither incident nor WWTP were included in the dataset. Given the limited sample size and no way to verify the completeness and accuracy of the data, the UD/SSO data may or may not be representative of all the WWTPs and all the UD/SSO incidents in the Texas CZB. The incompleteness of the dataset is a key limitation of the data.

OSSF Data

- **Age of OSSFs:** The age of individual OSSF systems was sometimes recorded within the dataset; however, approximately 67% of the 62,645 OSSFs in the data did not have a construction year associated with them. It is possible that the age of an OSSF could be a factor in whether SSOs occur from the facility; however, this was not able to be accurately assessed given the limited information.
- **Incident / Failure Information for OSSFs:** The data does not include any malfunction information for the OSSFs, so it is not possible to analyze the amount of discharge produced by OSSFs, nor the likelihood and type of incidents leading to malfunctions. The Texas Section of the ASCE indicates that the operations and maintenance (O&M) practices adopted by the household owners are the primary indicator of system performance (ASCE, 2021). Compliance with TCEQ operational guidance for OSSFs is ultimately dependent on local authorities to oversee OSSF operations.

Coastal Planning Regions

For this analysis, UD/SSO data were analyzed by county, major bay system, and region on the coast following the TCRMP's four coastal planning regions. The four coastal planning regions correspond closely to county boundaries, as shown in **Figure 4-3**, and are used interchangeably. SSOs and UDs were also cataloged by major bay system. Drainage areas corresponding to the major bay systems are shown in **Figure 5-17**.

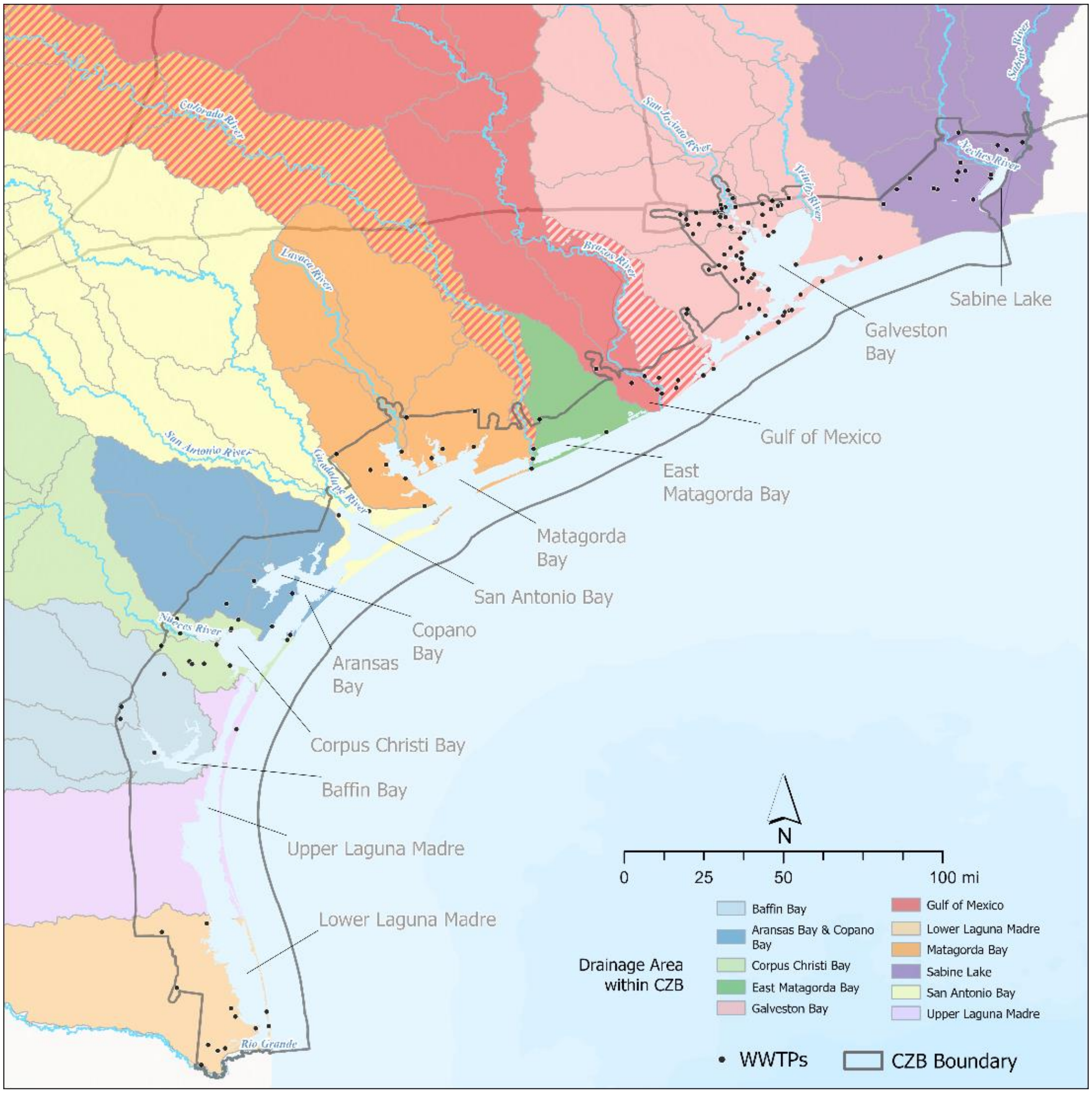


Figure 5-17. Drainage areas for bay systems reporting

Wastewater Treatment Plants and Sanitary Sewer Overflows in the Coastal Zone

Figure 5-18 provides a heat map overview of all the WWTPs located in the CZB, indicating whether the presence of plants is relatively sparse or dense compared to other locations along the coast.

Figure 5-19 shows the locations of individual WWTPs within the Texas CZB. The red dots indicate WCTS that have reported one or more recorded UD/SSO events, and the green dots indicate WWTPs that reported no UD/SSO events. From the 154 WWTPs included in this analysis, 86 (55.8%) reported one or more UD/SSO incidents. More detailed (tabular) information about the number of WWTPs and location/volume of UDs/SSOs by county and bay system are provided in later sections of this memo.

Figure 5-20 shows the WWTPs in portions of Harris, Chambers, Galveston, and Brazoria counties within the CZB, the area with the highest concentration of WWTPs on the Texas Gulf coast, in more detail. This area corresponds to Region 1 of the TCRMP. There is a distribution of WWTPs that reported UDs/SSOs and WWTPs that reported no

UDs/SSOs throughout the metroplex, with no apparent spatial pattern indicating why certain WCTS may produce or not produce UDs/SSOs.

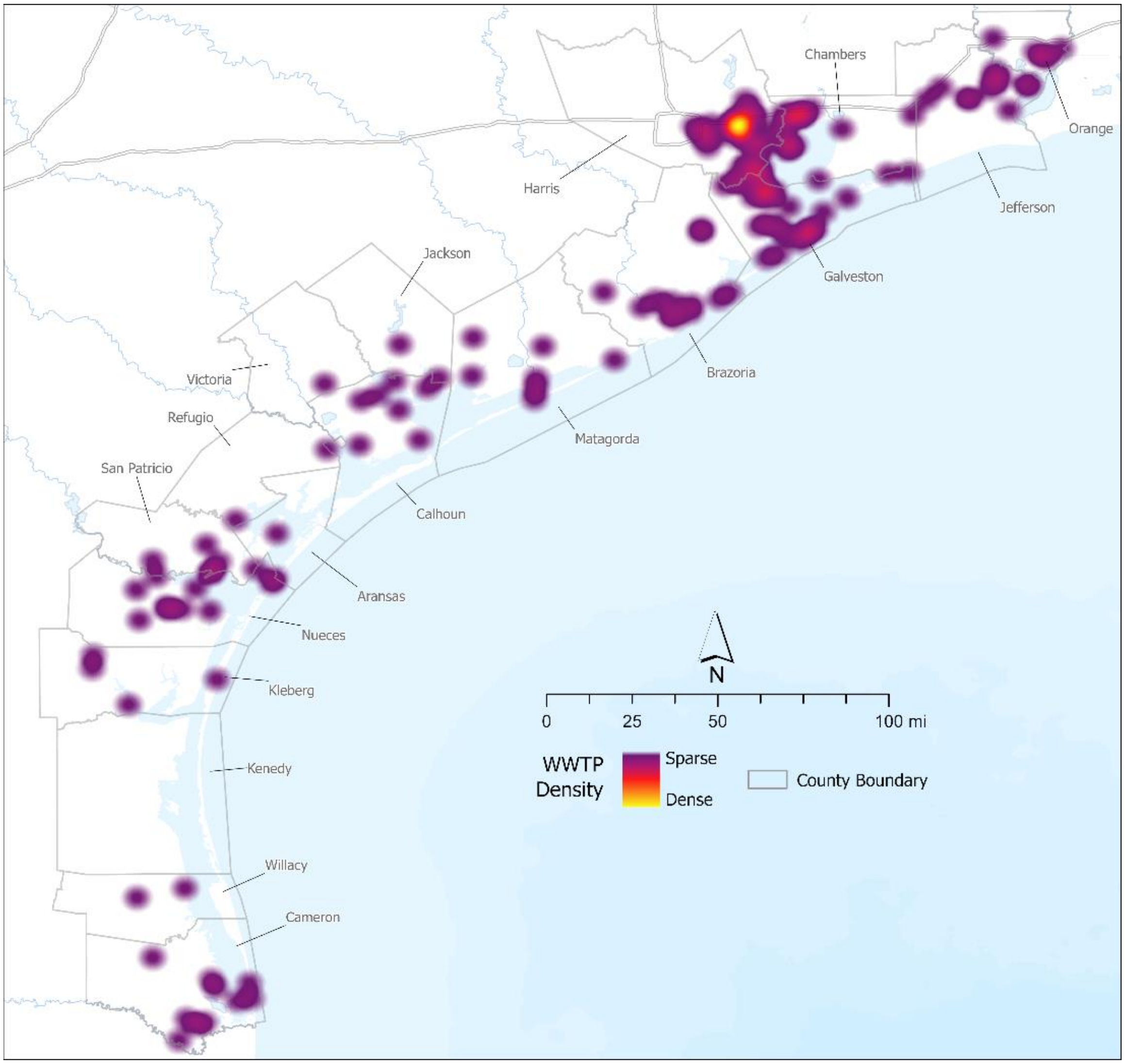


Figure 5-18. Distribution of all WWTPs in the Texas Coastal Counties, April 2022

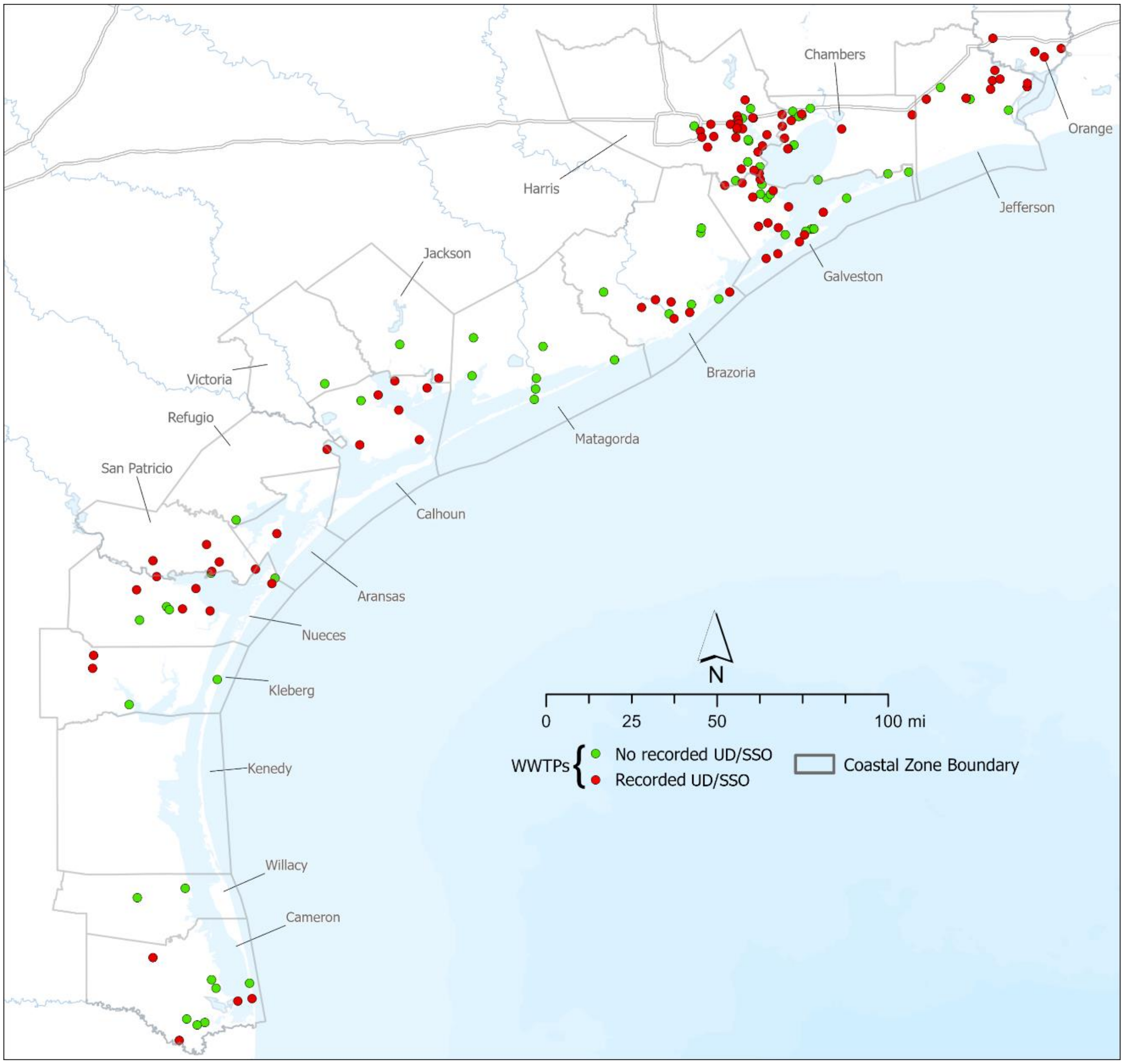


Figure 5-19. Locations of WWTPs with or without reported UDs/SSOs in the Texas Coastal Counties

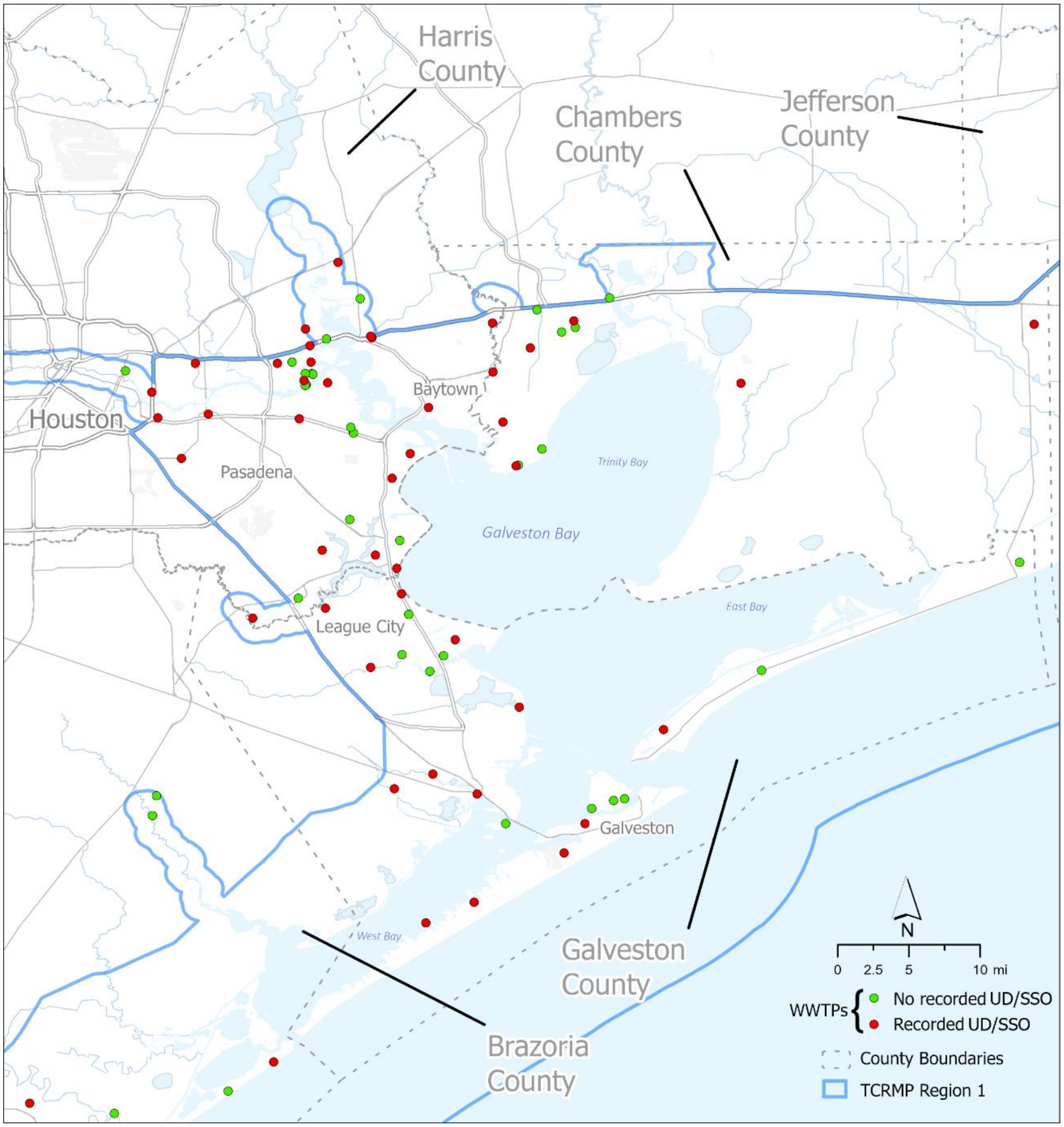


Figure 5-20. Locations of WWTPs in portions of Harris, Chambers, Galveston, and Brazoria counties in the CZB with or without reported UDs/SSOs

Despite WCTSs being distributed amongst numerous populated areas across Texas, the greatest total volume of UDs/SSOs appears to occur in one localized area. As shown in **Figure 5-21**, Harris County, along the north side of the Galveston Bay system, produces the majority (74.7%) of the overall volume of recorded UDs/SSOs within the dataset. All other metro areas having relatively high concentrations of WWTPs, shown previously in **Figure 5-19**, produce smaller total volumes of UDs/SSOs compared to Harris County.

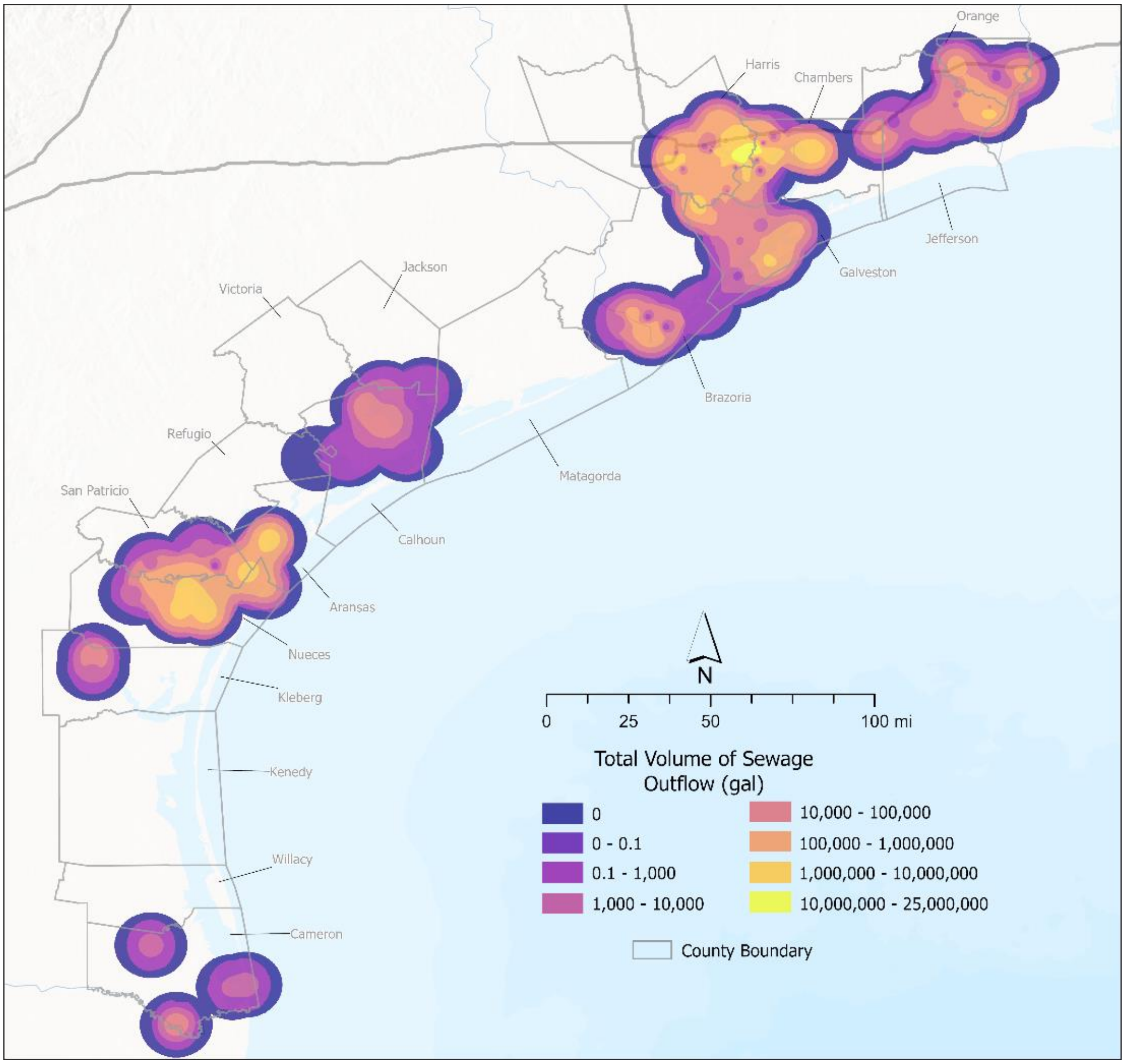


Figure 5-21. Total volume of reported UDs/SSOs produced from all WWTPs in the CZB

It is possible that the volume of UDs/SSOs reported in Harris County—which includes the City of Houston—is related to the larger population in that county relative to the rest of the state, aging infrastructure, large amounts of impervious cover, and many permitted facilities. In 2019, the City of Houston entered into a Consent Decree with the EPA requiring the City to conduct monitoring and enforcement activities aimed at improving the City's compliance with the Texas Pollutant Discharge Elimination System (TPDES) program due to its prior and persistent violations of the Clean Water Act (EPA, 2019).

Onsite Sewage Facilities in the Coastal Zone

OSSFs are distributed across the Texas coastal zone. In the CZB, a total 62,645 OSSFs are permitted and on record with the TCEQ. The distribution and density of these systems is shown in **Figure 5-22**; for privacy of individual households, individual OSSFs are not shown. Certain areas in the CZB have especially high concentration of OSSFs, such as Beaumont/Orange/Port Arthur, Baytown, Bolivar Peninsula, Freeport, and Rockport.

Approximately 21,140 (33.75%) OSSF systems are in urbanized areas, as depicted in **Figure 5-32** using urbanized area data developed by the TxDOT, while the remaining 41,505 (66.25%) are in non-urbanized areas. OSSFs are typically associated with rural or remote communities, and, while that is true for most systems, some of the highest OSSF-density areas in coastal Texas are in Rockport, Baytown, and the Bolivar Peninsula. These dense clusters appear to occur in developed communities that are not integrated with centralized public or private domestic wastewater treatment systems, requiring large numbers of households to rely on their own systems to process wastewater. There are also 7,576 OSSFs (approximately 12% of all the recorded OSSFs in the CZB) located on peninsulas and barrier islands, where centralized public or private domestic wastewater treatment systems are generally less present. OSSFs located on barrier islands and peninsulas are especially concentrated in the northern portions of the CZB corresponding to Region 1 of the TCRMP.

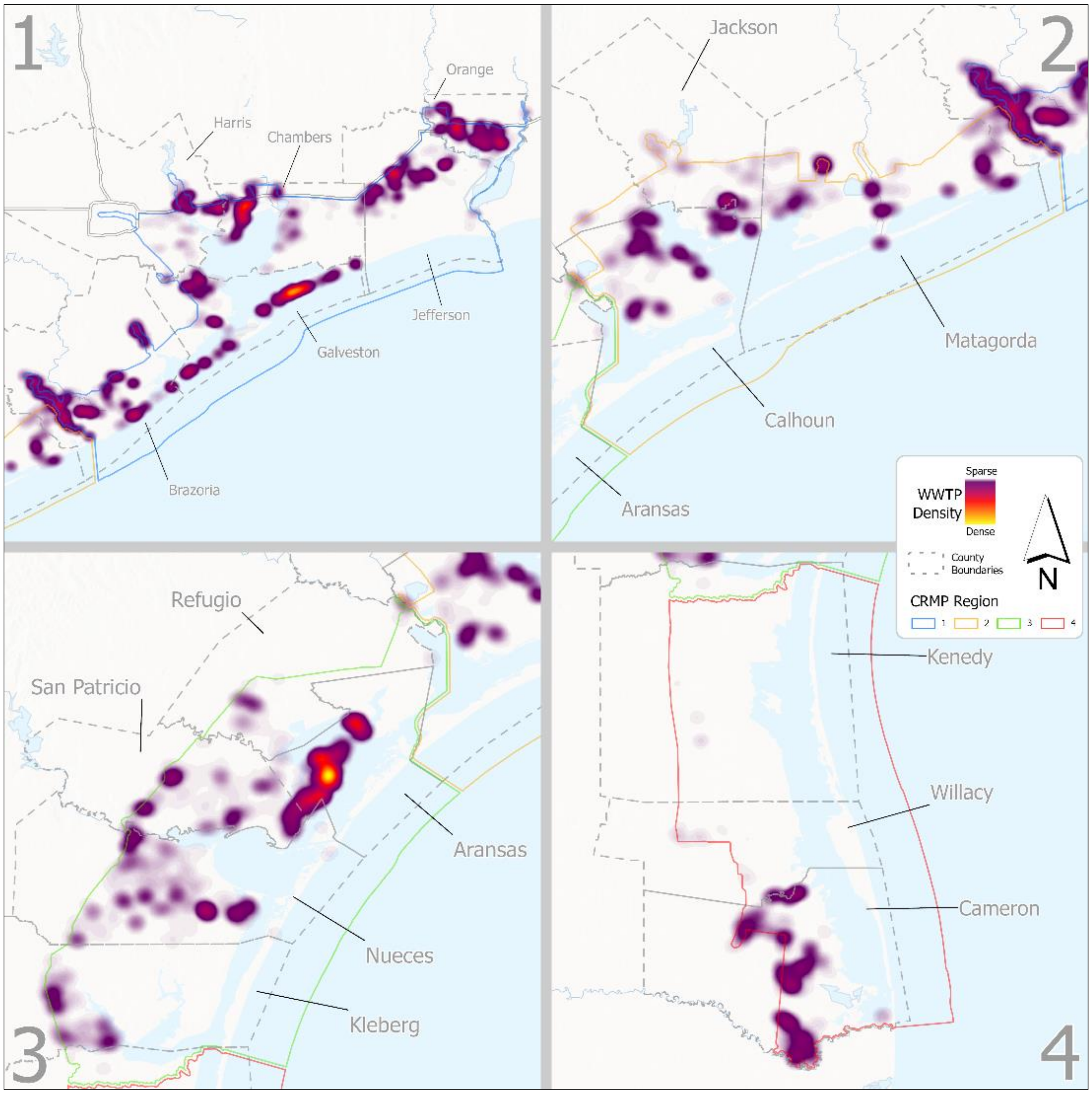


Figure 5-22. Density of OSSFs in the Texas CZB, April 2022

5.6.2 Data Analysis

Figure 5-18 to **Figure 5-21,** above, are important for understanding the general distribution of WWTPs, the locations of the WCTSs that reported UDs/SSOs versus those that did not, and the relative volumes of untreated or partially treated wastewater produced when UD/SSO incidents occurred from July 2012 – April 2022. To better understand any patterns that exist and to better inform coastal management, the data surrounding these UD/SSO events has been assessed and is presented below.

SSO Incidents by County and Bay System

Table 5-16 gives an overview of the WCTS and UDs/SSOs across the Texas CZB categorized by county (counties are shown by coastal region from north to south). This table includes the number of WWTPs located within the county, the number of WCTSs that reported UDs/SSOs per county within the dataset period of record, the total number of incidents, the total UD/SSO volume resulting from reported incidents in gallons, and the percent that each county contributed to the overall volume of reported incidents in the CZB. The majority of UDs/SSOs by total volume occurred in Harris County (74.7%), followed by Nueces County (7.5%) and Chambers County (4.9%). The percent that each coastal county contributed of the total reported UD/SSO volume during the dataset period of record is shown graphically in **Figure 5-23**.

Table 5-16. Reported UD/SSO Incidents by county

Region	County	No. WWTPs in CZB	No. WCTS with reported incidents (% of county)	No. Incidents	Cumulative UD/SSO Volume (Gal.)	% of Total Volume
1	**Orange**	5	4 (80.0%)	192	265,997	0.40%
	Jefferson	11	8 (72.7%)	387	2,277,592	3.43%
	Chambers	13	6 (46.2%)	60	3,218,767	4.85%
	Harris	39	24 (61.5%)	2,943	49,590,635	74.71%
	Galveston	23	13 (56.5%)	398	2,118,941	3.19%
	Brazoria	12	6 (50.0%)	127	837,491	1.26%
2	**Matagorda**	7	0 (0.00%)	0	0	0.00%
	Jackson	2	1 (50.0%)	5	49	0.00%
	Victoria	1	0 (0.00%)	0	0	0.00%
	Calhoun	7	6 (85.7%)	32	59,855	0.09%
3	**Refugio**	2	1 (50.0%)	1	0	0.00%
	Aransas	1	1 (100%)	30	1,603,825	2.42%
	San Patricio	6	5 (83.3%)	128	1,361,089	2.05%
	Nueces	10	6 (60.0%)	497	4,967,266	7.48%
	Kleberg	4	2 (50.0%)	22	44,800	0.07%
4	**Kenedy**	0	0 (0.00%)	0	0	0.00%
	Willacy	2	0 (0.00%)	0	0	0.00%
	Cameron	10	4 (40.0%)	42	32,770	0.05%
	Total	**154**	**86 (55.8%)**	**4,864**	**66,379,078**	**100.00%**

Source: TCEQ

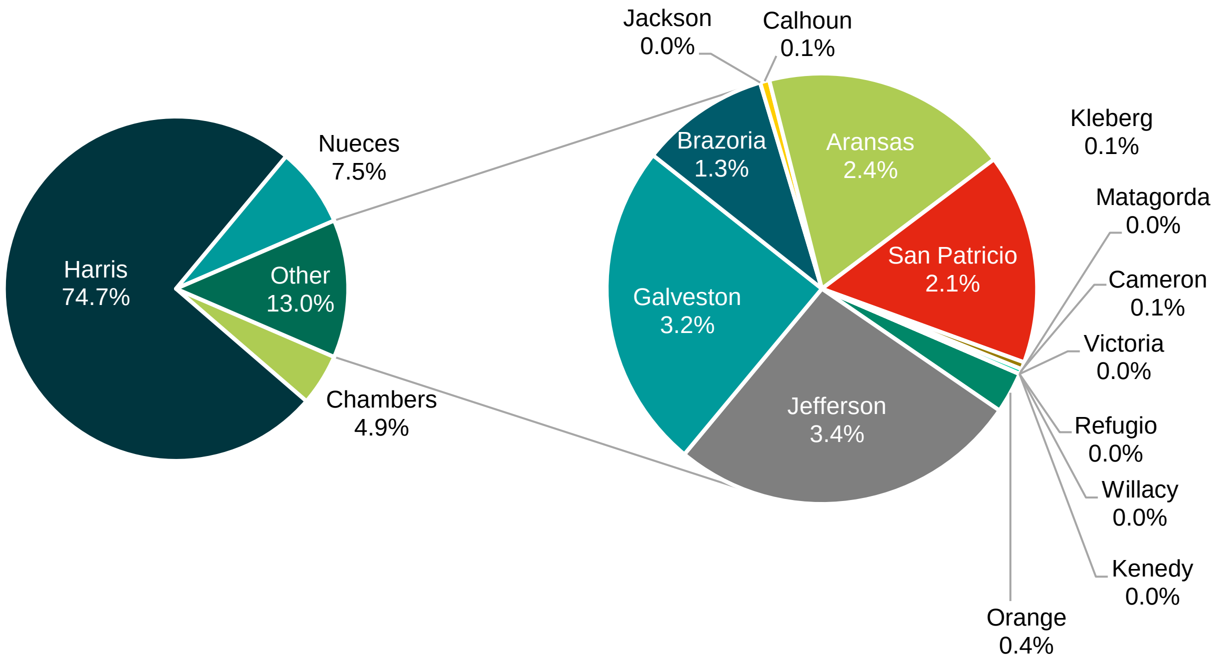


Figure 5-23. Percent contribution of total UD/SSO volume by county

Similar to the above county breakdown, an overview of WTCS and UD/SSOs are shown below by major bay system in **Table 5-17**. This analysis approximates which bay system that a UD/SSO would discharge to based on the watershed where the WCTS is located and estimates which major water bodies the discharges would impact. Bay systems receiving greater volumes of UDs/SSOs are expected to be subject to an increased risk of degraded water quality. The majority of UD/SSO incidents by volume impact the Galveston Bay system (82.6%), followed by the Corpus Christi Bay system (9.5%) and Sabine Lake System (4%). The data is presented by cumulative total discharge volume in descending order. The bay system entitled 'Gulf' indicates WCTS located in a watershed that outfalls directly into the Gulf of Mexico rather than into a receiving bay. The percent of total reported UD/SSO volume received by each major bay system is presented graphically in **Figure 5-24**.

Table 5-17. Reported UD/SSO incidents by bay system

Bay System	Region	No. WCTSs in CZB	No. WCTSs with Reported Incidents (% of Bay System)	No. Incidents	Cumulative UD/SSO Volume (Gal.)	% of Total Volume
Galveston Bay	1	76	42 (55.3%)	3,379	54,819,903	82.59%
Corpus Christi Bay	3	15	11 (73.3%)	625	6,328,355	9.53%
Sabine Lake	1	16	12 (75.0%)	601	2,652,029	4.00%
Aransas Bay	3	1	1 (100%)	30	1,603,825	2.41%
Gulf*	N/A	10	6 (60.0%)	127	837,491	1.26%
Matagorda Bay	2	11	6 (54.5%)	35	59,779	0.09%
Baffin Bay	3	3	2 (66.7%)	22	44,800	0.07%
Lower Laguna Madre	4	12	4 (33.3%)	42	32,770	0.05%

Bay System	Region	No. WCTSs in CZB	No. WCTSs with Reported Incidents (% of Bay System)	No. Incidents	Cumulative UD/SSO Volume (Gal.)	% of Total Volume
San Antonio Bay	2/3	2	2 (100%)	3	125	0.00%
Copano Bay	3	2	0 (0%)	0	0	0.00%
East Matagorda Bay	2	5	0 (0%)	0	0	0.00%
Upper Laguna Madre	4	2	0 (0%)	0	0	0.00%
Total		**154**	**86**	**4,864**	**66,379,078**	**100.00%**

*Includes UD/SSO incidents from WCTS located in watersheds that discharge directly into the Gulf of Mexico without an intercepting bay system.

Source: TCEQ

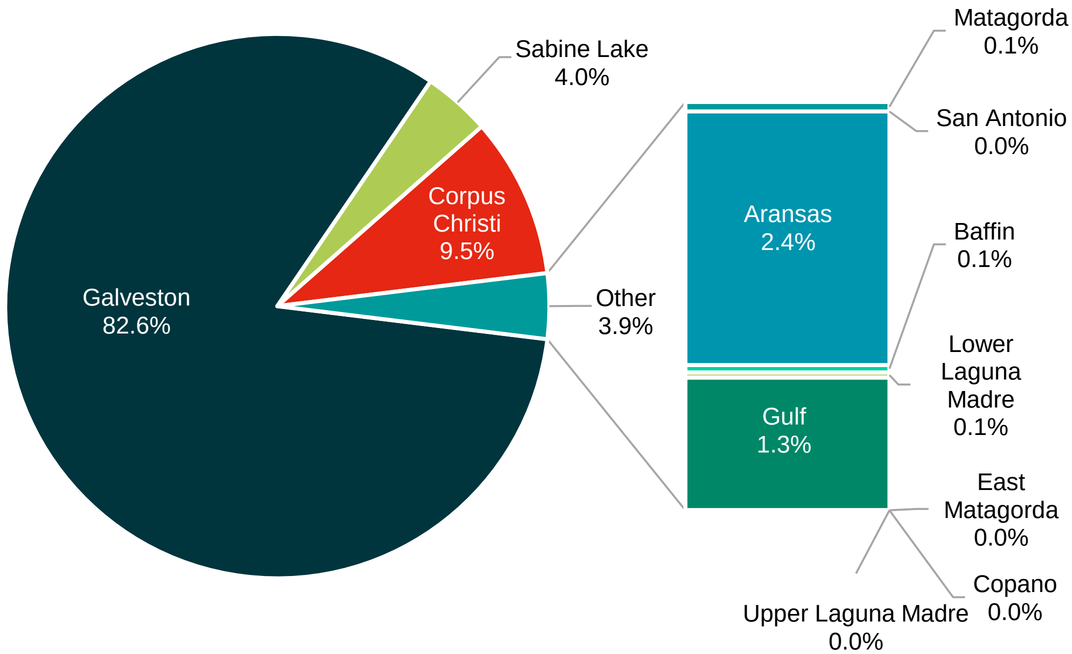


Figure 5-24. Percent of total UD/SSO volume reported by bay system

Reported Causes of UD/SSO Incidents

Table 5-18 shows reported causes of UD/SSO incidents from July 2012 – April 2022 for all recorded UD/SSO incidents, as well as for large and small UD/SSO events. The largest 500 incidents by volume (corresponding to incidents greater than 24,700 gallons) in the dataset were selected to represent large UD/SSO events, and the UD/SSO incidents with volumes of less than 50 gallons (n = 1,620) were selected to represent small UD/SSO events. A greater number of small volume incidents were selected to make up the small SSO dataset because the smallest 500 incidents were reported to have contained between zero and 0.1 gallon of wastewater (refer to **Table 5-22**, below). Extending the range of the small UDs/SSOs allows more non-zero discharges to be evaluated and create a more comprehensive dataset. Furthermore, the distribution of incident volume indicates there are few large volume incidents compared to small volume incidents. As such, there is more small incident data to be evaluated compared to the high-volume data due to the distribution of incident volumes.

The data in **Table 5-18** is presented by the percent occurrence of incidents by incident cause for all UDs/SSOs in descending order. Note that while only one primary cause is given per UD/SSO incident for reporting purposes, UDs/SSOs may be the result of a combination of multiple causes. No further information is available for UD/SSO causes labeled as “Other”. For all UD/SSO incidents, infiltration and inflow and line blockages are the most reported cause (24.9% and 21.1%). Infiltration and inflow (or I&I), which is related to large precipitation events, is the most frequently reported cause of large volume UD/SSO incidents (48.2%). Line Blockages (non-grease, followed by grease) are the most reported causes for small volume UD/SSO incidents (39.9% and 22.0%, respectively).

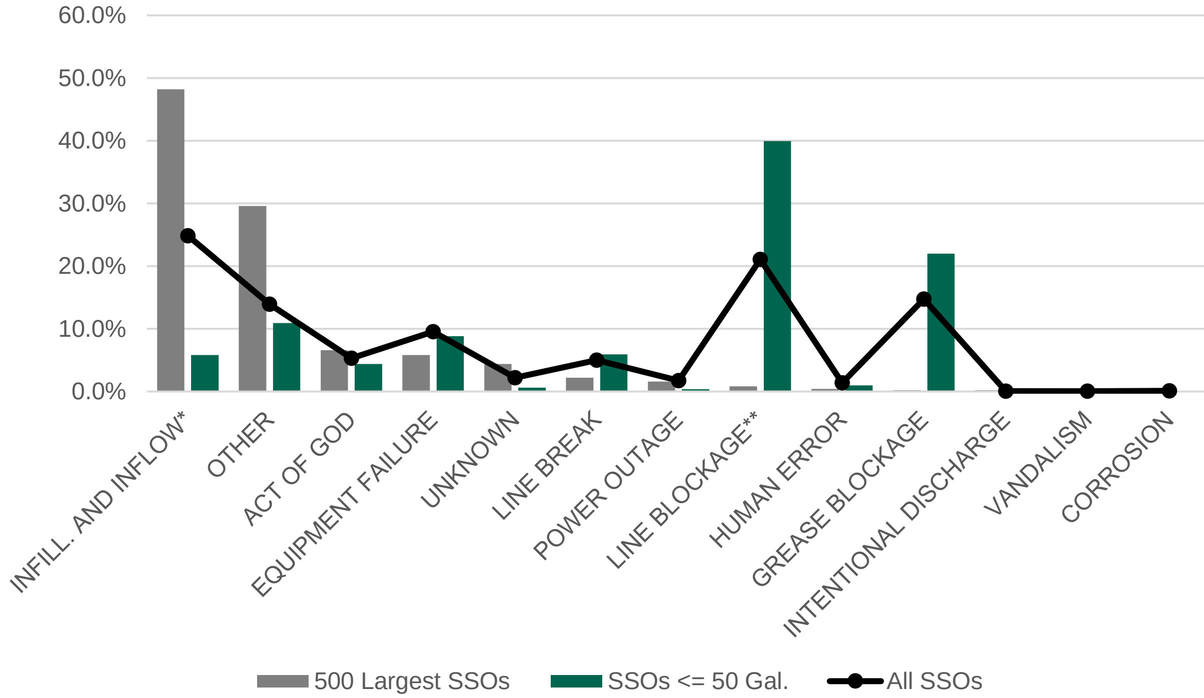
Figure 5-25, below, indicates visually the most reported causes of UD/SSO incidents for large and small volume incidents.

Table 5-18. Reported causes of UD/SSO incidents by incident volume

	All UD/SSO Incidents		500 Largest UD/SSO Incidents by Volume		Smallest UD/SSO Incidents by Volume (Less Than/Equal to 50 Gal.)	
Cause	**Number of SSOs**	**Percent Occurrent**	**Number of SSOs**	**Percent Occurrence**	**Number of SSOs**	**Percent Occurrence**
Infiltration and Inflow	**1,207**	**24.9%**	**241**	**48.2%**	94	5.8%
Line Blockage (Non-Grease)	1,024	21.1%	4	0.8%	**647**	**39.9%**
Grease Blockage	717	14.8%	1	0.2%	356	22.0%
Other*	667	14.0%	148	29.6%	177	11.0%
Equipment Failure	463	9.5%	29	5.8%	143	8.8%
Act of God	259	5.3%	33	6.6%	71	4.4%
Line Break	242	5.0%	11	2.2%	96	5.9%
Unknown	106	2.2%	22	4.4%	10	0.6%
Power Outage	85	1.8%	8	1.6%	6	0.3%
Human Error	66	1.4%	2	0.4%	16	1.0%
Vandalism	4	< 0.1%	0	0%	0	0%
Intentional Discharge	3	< 0.1%	1	0.2%	3	0.2%
Corrosion	2	< 0.1%	0	0%	1	0.1%

*No data is available to indicate the cause of UD/SSO incidents reported as “Other”

Source: TCEQ



*Infiltration and Inflow
**Non-Grease Line Blockages

Figure 5-25. Reported causes of UD/SSO incidents by incident volume

The distribution of the reported causes of all UD/SSO incidents within the dataset period of record is shown below in **Figure 5-26**.

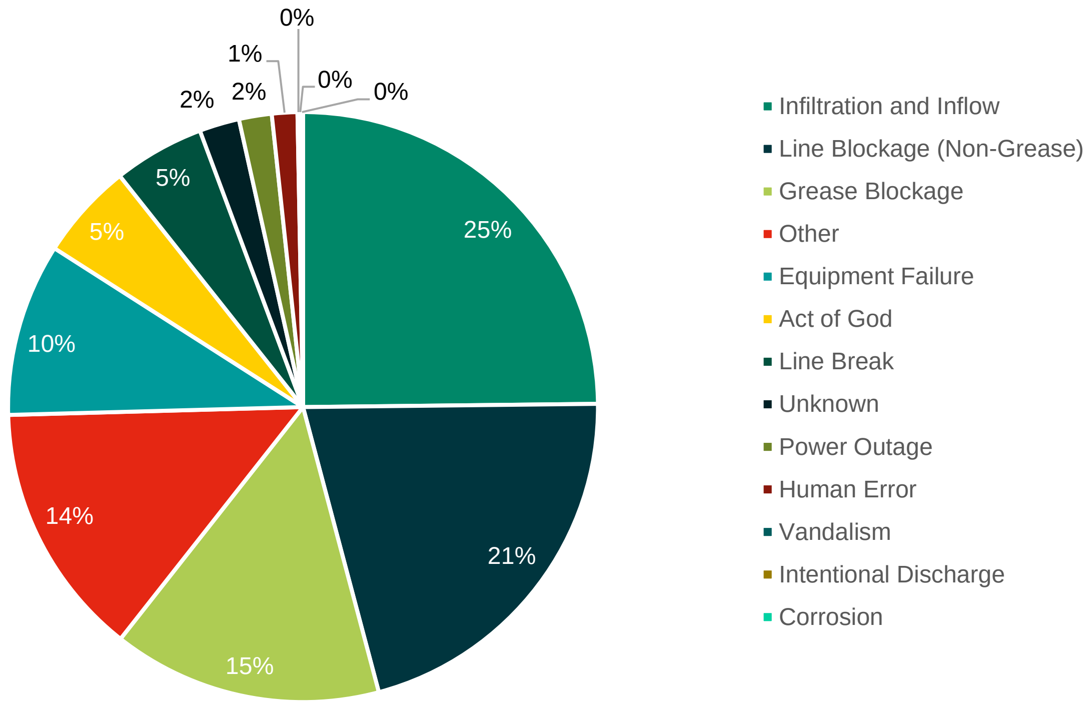


Figure 5-26. Reported causes of UD/SSO incidents (all incidents)

Most Incidents by Number of Incidents and Total Cumulative Incident Volume

Considering WCTS individually can provide insight on which WWTPs, and their associated collection systems, are reporting the highest cumulative UD/SSO volumes, as well as which WCTS reported the greatest number of incidents. The top ten WCTSs for both total cumulative discharge volume and total number of incidents represent most of the total reported incident volume. There appears to be no natural break in the data when considering either reporting designation. In general, the data indicates a few WTTPs report substantially larger numbers of UD/SSO incidents compared to the many other WWTPs in the dataset. The quantities for total cumulative discharge volume and number of reported incidents decrease substantially by WWTP as the list progresses beyond the top 10 in each category.

Table 5-19 shows the top ten ranked WCTSs (aggregated by reporting WWTP) by the total reported volume of discharge over the dataset period of record. As shown in **Table 5-19**, the top ten WWTPs ranked by UD/SSO volume are responsible for over 81.7% of the total overall volume of discharges from July 2012 – April 2022. TPDES permit numbers are also included in the table for future evaluation purposes.

Table , below, shows the top ten ranked WCTS (aggregated by reporting WWTP) by the total number of incidents reported over the dataset period of record. As shown in **Table** , the top ten ranked WCTS by total number of reported incidents account for 72.5% of the total number of incidents in the dataset. TPDES permit numbers are also included in the table for future evaluation purposes.

Table , below, provides detail on the 10 largest UD/SSO incidents by total reported volume. Eight of the 10 largest incidents were estimated to discharge into the Galveston Bay system. The top 10 incidents by UD/SSO volume contributed approximately 11.24 million gallons of contaminated water, or 17% of all UD/SSO volume, into Texas coastal waters from July 2012 – April 2022. The most common type of event for the top 10 largest incidents is ‘Other,’ accounting for five of 10 events).

Table 5-19. Ten WCTS with most UD/SSO incidents by total cumulative volume

Reporting WWTP	TPDES Permit Numbers	County	City	Bay System	No. of Incidents	Cumulative Volume (Gal.)	WWTP Vol. ÷ Total Vol. for all WCTS
East District	WQ0010395007	Harris	Baytown	Galveston	420	20,472,830	30.84%
Central District	TXR05T542 WQ0010395002	Harris	Baytown	Galveston	488	16,049,075	24.18%
Sims Bayou Plant	TXR05K065 WQ0010495002	Harris	Houston	Galveston	1,558	4,077,837	6.14%
Anahuac	WQ0010396001	Chambers	Anahuac	Galveston	23	3,105,780	4.68%
West District	TXR1580IS WQ0010395008	Harris	Baytown	Galveston	58	2,852,885	4.30%
Oso	TXR05X003 WQ0010401004	Nueces	Corpus Christi	Corpus Christi	191	1,608,764	2.42%
City Of Rockport	TXR05FO44 WQ0010054001	Aransas	Rockport	Aransas	30	1,603,825	2.42%
City Of Port Arthur Main	WQ0010364001	Jefferson	Port Arthur	Sabine	232	1,569,773	2.36%
New Broadway	TXR05X005 WQ0010401005	Nueces	Corpus Christi	Corpus Christi	153	1,559,630	2.35%
Blackhawk Regional	TXR05FG89 WQ0011571001	Harris	Friendswood	Galveston	66	1,308,393	1.97%
Top 10 Total	-	-	-	-	**3,219**	**54,208,792**	**81.66%**
Total for all WCTS		-	-	-	**4,864**	**66,379,078**	**100.00%**

Source: TCEQ

Table 5-20. Ten WCTS reporting most UD/SSO incidents

Reporting WWTP	WWTP Permit Numbers	County	City	Bay System	No. of Incidents	WWTP Incidents / Total Incidents for all WCTS
Sims Bayou Plant	TXR05K065 WQ0010495002	Harris	Houston	Galveston	1,558	31.96%
Central District	TXR05T542 WQ0010395002	Harris	Baytown	Galveston	488	10.01%
East District	WQ0010395007	Harris	Baytown	Galveston	420	8.62%
City Of Port Arthur Main	WQ0010364001	Jefferson	Port Arthur	Sabine Lake	232	4.76%
Oso	TXR05X003 WQ0010401004	Nueces	Corpus Christi	Corpus Christi	191	3.92%
Oak Lane	WQ0010875001	Orange	Vidor	Sabine Lake	172	3.53%
New Broadway	TXR05X005 WQ0010401005	Nueces	Corpus Christi	Corpus Christi	153	3.14%
City Of Galveston	TXR05DZ65 WQ0010688001	Galveston	Galveston	Galveston	127	2.61%
Laguna Harbor	TX0125776 WQ0014452001	Galveston	Port Bolivar	Galveston	111	2.28%
Lake Jackson	TXR05AL65 WQ0010047001	Brazoria	Lake Jackson	None	84	1.72%
Top 10 Total	-	-	-	-	**3,536**	**72.53%**
Total for all WWTPs		-	-	-	**4,864**	**100.00%**

Source: TCEQ

Table 5-21. Ten largest UD/SSO incidents by volume

Reporting WWTP	Date	City	County	Bay System	Cause	Volume (Gal.)	% of Total UD/SSO Volume
East District	10/24/2015	Baytown	Harris	Galveston	Other	2,326,475	4%
San Jacinto Battleground SHP & Battleship Texas	8/28/2017	La Porte	Harris	Galveston	Act Of God	1,272,300	2%
East District	3/21/2015	Baytown	Harris	Galveston	Other	1,219,250	2%
Central District	10/24/2015	Baytown	Harris	Galveston	Other	1,047,010	2%
City Of Port Arthur Main	2/9/2018	Port Arthur	Jefferson	Sabine	Line Break	1,000,000	2%
New Broadway	5/19/2021	Corpus Christi	Nueces	Corpus Christi	Infiltration and Inflow	945,000	1%
Airport Plant	11/29/2021	Galveston	Galveston	Galveston	Line Break	900,000	1%
Anahuac	6/2/2016	Anahuac	Chambers	Galveston	Act Of God	864,000	1%
East District	10/31/2015	Baytown	Harris	Galveston	Other	837,810	1%
Anahuac	4/21/2016	Anahuac	Chambers	Galveston	Other	828,000	1%
Top 10 Total						**11,239,845**	**17%**

Source: TCEQ

As shown in **Table** , only one of the top 10 largest UD/SSO incidents appears to be directly related to Hurricane Harvey (the San Jacinto Battleground reported discharge in August 2017). During that storm, several WWTPs were completely inundated and without power, and more extreme SSO impacts from the hurricane would therefore have been expected to be reflected in this dataset. However, during certain time periods or circumstances, emergency orders can be given to waive UD/SSO reporting requirements which could alternatively explain why this event was not recorded. According to the Texas Section of the ASCE, approximately 1,500 SSOs were reported in the aftermath of Harvey (ASCE, 2021).

Comparing Tables 5-19, 5-20, and 5-21, there is no clear correlation between the number of reported incidents, cumulative incident volume for all UDs/SSOs, and total incident volume for each UD/SSO for a given reporting WWTP. Some WWTPs—Sims Bayou for example (see **Table**)—report a very large number of discharges but did not report one of the 10 largest volumes of discharges. The East District WWTP reported three of the top 10 reported discharges, while the Anahuac WWTP reported two of the top 10 reported discharges. The largest discharge in the dataset was reported by the East District WWTP with a volume of 2.33 million gallons, accounting for 4% of the total UD/SSO volumes reported in the dataset. Two of the top 10 largest discharges reported by San Jacinto Battleground SHP & Battleship Texas WWTP (reported cause 'Act of God') and the Airport Plant WWTP (reported cause 'Line Break') were reported by plants that ranked in the top 10 neither for total cumulative discharge volume (**Table 5-19**) nor for total number of incidents (**Table**).

Results of further investigation of the relationship between number of incidents reported by a WWTP during the period of record and cumulative UD/SSO volume can be seen in **Figure 5-27**. On a log-log scale, the power trendline captures the strictly general relationship between these two records. However, the strength of the correlation has an R^2 value of 0.1155, which indicates very low correlation. Therefore, given the existing data, there is no certifiable relationship between the total number of UD/SSO incidents reported within a WCTS and the cumulative UD/SSO volume reported by that entity. This indicates that the volume of UD/SSO events is not related to the total number of UD/SSO incidents observed at a plant. Given the uncertainties regarding the dataset used for this analysis (see the **Data Limitations** section, above), it is possible that a more comprehensive dataset of reported incidents would indicate whether there is any observable relationship between the reported number of UD/SSO incidents by a WWTP and the total volume of UDs/SSOs produced by that WCTS.

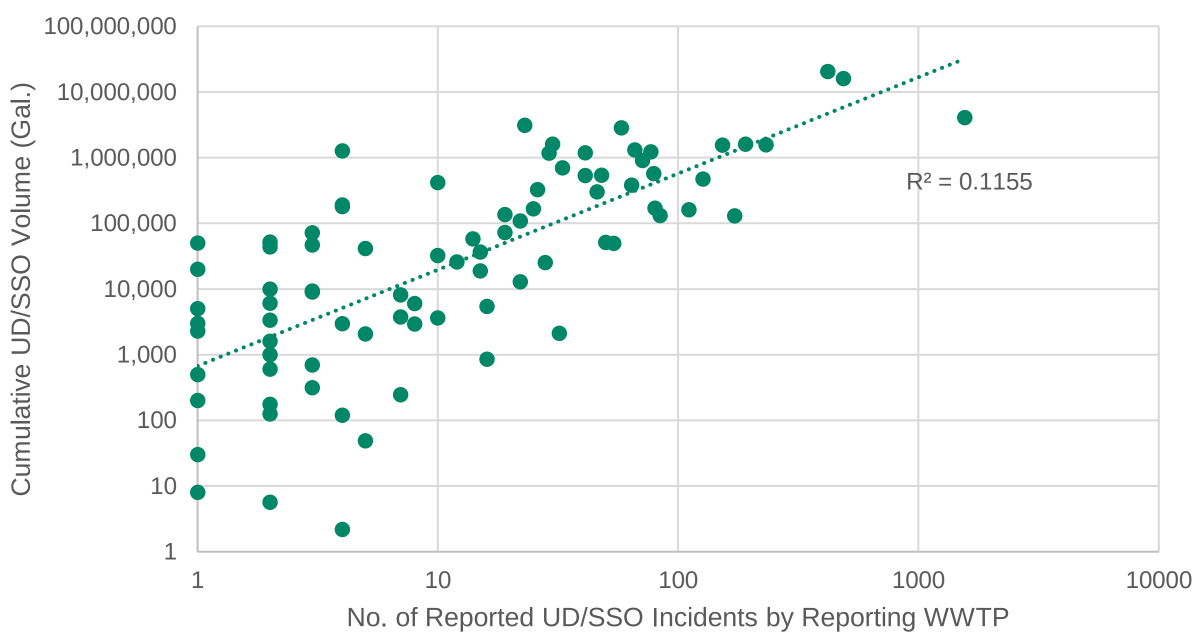


Figure 5-27. Relationship of number of UD/SSO incidents reported per WCTS to cumulative UD/SSO volume

Table 5-22 provides detail on the distribution of UD/SSO volumes within the dataset. UD/SSO discharges can range from tens of gallons to millions of gallons. The largest discharges shown in **Table 5-22** (1 to 2.5 million gallons, and also the least frequently reported incident type by volume) produce 10.3% of the total reported UD/SSO volume, while the most frequently reported small discharges (0.1 to 1,000 gallons) produce 0.74% of the total reported UD/SSO volume. Incidents with volumes between 100,000 and 1 million gallons produce roughly half of all reported UD/SSO volumes (48.6%), but account for only 2.7% of reported incidents.

Table 5-22. Frequency of reported incidents by incident UD/SSO volume

Incident Volume (Gal.)	No. of Incidents	Incident Volume Percent Occurrence	Total Volume Produced (Gal.)	Percent of Total Volume Produced
0 – 0.1	790	16.2%	0.1	0.00%
0.1 – 1,000	2,146	44.1%	492,045	0.74%
1,000 – 10,000	1,044	21.5%	3,823,359	5.76%
10,000 – 100,000	749	15.4%	22,965,297	34.6%
100,000 – 1M	130	2.70%	32,233,342	48.6%
1M – 2.5M	5	0.10%	6,865,035	10.3%
Total	**4,864**	**100%**	**66,379,078**	**100%**

Source: TCEQ

The percent occurrence by UD/SSO incident volume increments is shown graphically in **Figure 5-28**.

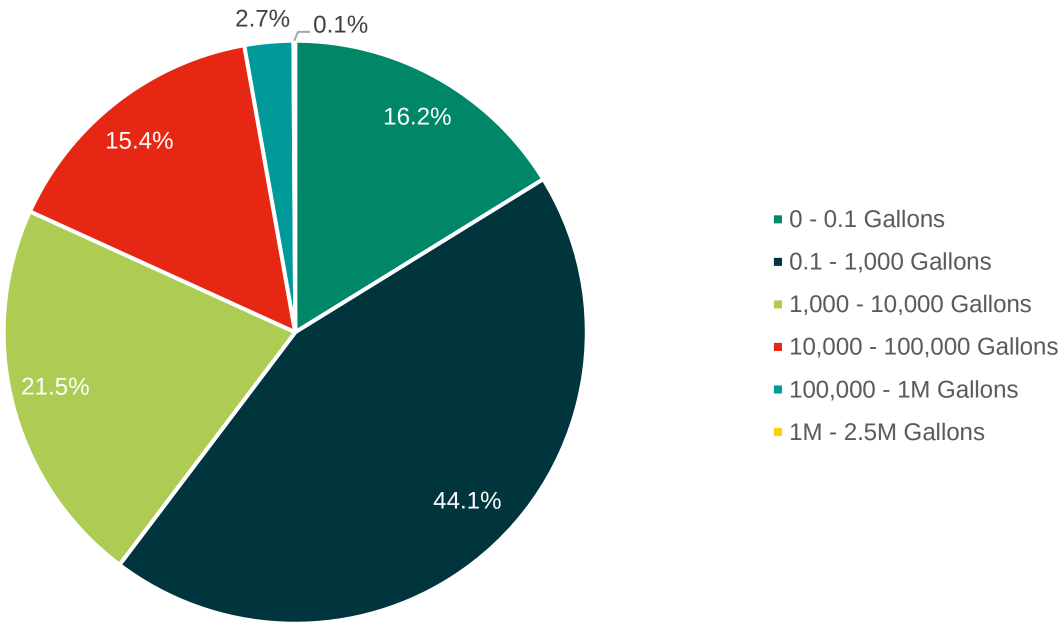


Figure 5-28. Percent occurrence of UD/SSO incidents by volume

Seasonal Distribution of UDs/SSOs

Over the reporting period of July 2012 – April 2022, the monthly distribution of UD/SSO incidents indicate a potential monthly pattern when comparing large UDs/SSOs to small UDs/SSOs using the methodology described in the **Reported Causes of UD/SSO Incidents** section above.

As shown in **Figure 5-29** and **Table 5-23**, large UD/SSO events may be more likely to occur in May and June, possibly related to increased rainfall during those months (see **Area Rainfall and Urban Density** section for more discussion on this point). Smaller discharges appear to be more evenly distributed throughout the year. For all reported UD/SSO incidents, there is a 4% and 3% increase from the mean (8%) in May and June respectively, possibly influenced by the increased number of incidents in the same months for the largest UD/SSO category. In May, the number of UDs/SSOs (603 of 4,864) is 2.1 standard deviations above the mean for the entire dataset.

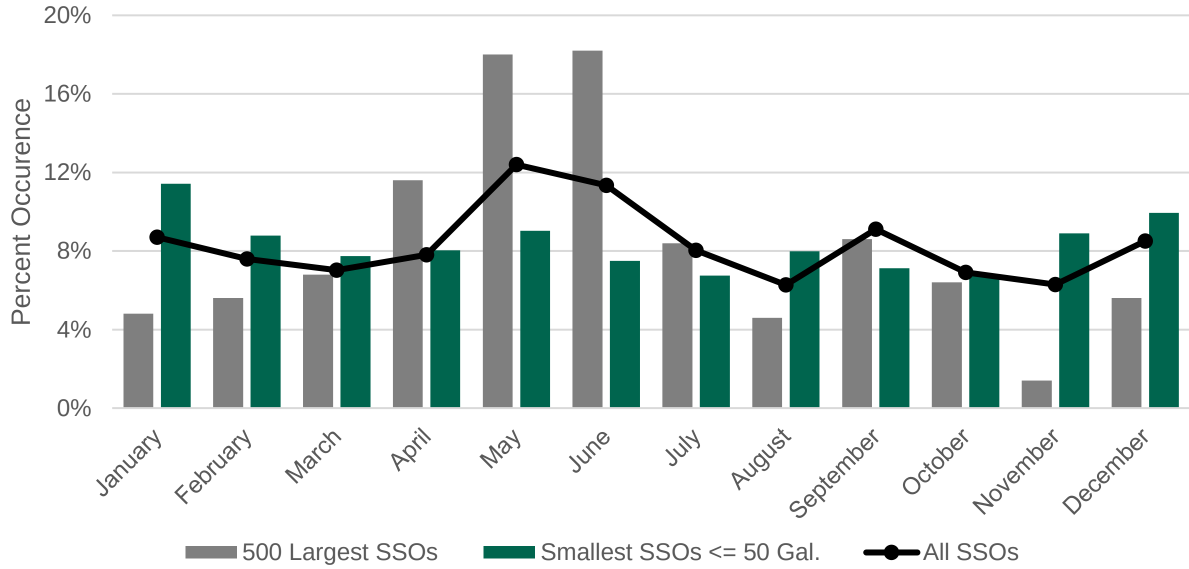


Figure 5-29. UD/SSO occurrence by month

Table 5-23. UDs/SSOs by month, July 2012 – April 2022 (top producing months shaded green)

	All UDs/SSOs		500 Largest UDs/SSOs (By Volume of Incident)		Smallest UDs/SSOs (Volume of Incidents Less Than/Equal to 50 Gal.)	
Month	**Number of UDs/SSOs**	**Percent Occurrence**	**Number of UDs/SSOs**	**Percent Occurrence**	**Number of UDs/SSOs**	**Percent Occurrence**
January	423	9%	24	5%	**186**	**11%**
February	369	8%	28	6%	143	9%
March	342	7%	34	7%	126	8%
April	380	8%	58	12%	131	8%
May	**603**	**12%**	**90**	**18%**	147	9%
June	552	11%	**91**	**18%**	122	7%
July	391	8%	42	8%	110	7%
August	305	6%	23	5%	130	8%
September	443	9%	43	9%	116	7%
October	336	7%	32	6%	111	7%
November	306	6%	7	1%	145	9%
December	414	9%	28	6%	162	10%
Mean	405.3	8%	41.7	8%	135.8	8%
Median	385.5	8%	33.0	7%	130.5	8%
Standard Deviation	92.1	2%	26.0	5%	22.3	1%

Source: TCEQ

UDs/SSOs recorded across 2012 – 2022 do not seem to have a clear trend when considered annually, as shown in **Figure 5-30**. It should be noted that the beginning and end of the data collection period are not full years, and only contain 5 months during 2012 and 1 month during 2022. From 2013 to 2015, full years of data were recorded, but very low numbers of UDs/SSOs were reported compared to 2016 – 2021.

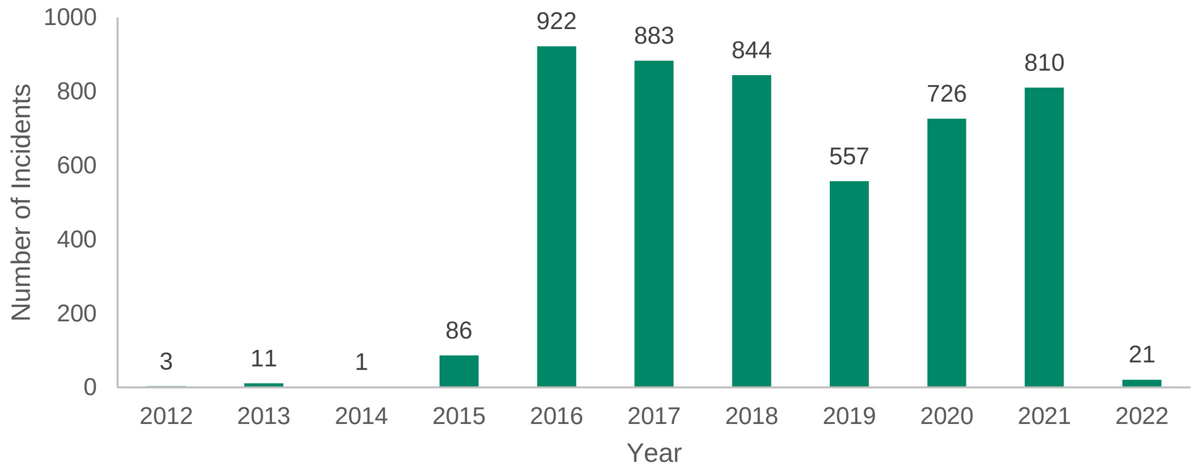


Figure 5-30. Reported UD/SSO incidents per year from 2012-2022

Area Rainfall and Urban Density

Precipitation in the CZB region from 2012 to 2022 is shown below in **Figure 5-31.** This 10-year dataset is a subset of a 41-year rainfall dataset developed by the TWDB; the subset gives the average annual precipitation over approximately the same period of record as the UD/SSO incident data. Along with this dataset, precipitation data over the full 41-year period of record from 1981 to 2022, as developed by the TWDB, is shown to give the longer-term trend of monthly annual average rainfall in the CZB.

The two monthly averages for the datasets follow the same general trends across the year, with the highest rainfall occurring during the months of May, June, and September for both datasets. When comparing the 41-year monthly average and the 10-year monthly average, it can also be seen that during these high rainfall months, the 10-year average gives a larger average monthly precipitation in the months of May, June, and September than in the 41-year average. Between the 10-year and 41-year precipitation averages, 34.7, 34.7, and 22.4 more inches of precipitation were recorded to have fallen in the 10-year dataset, on average, in the months of May, June, and September, respectively.

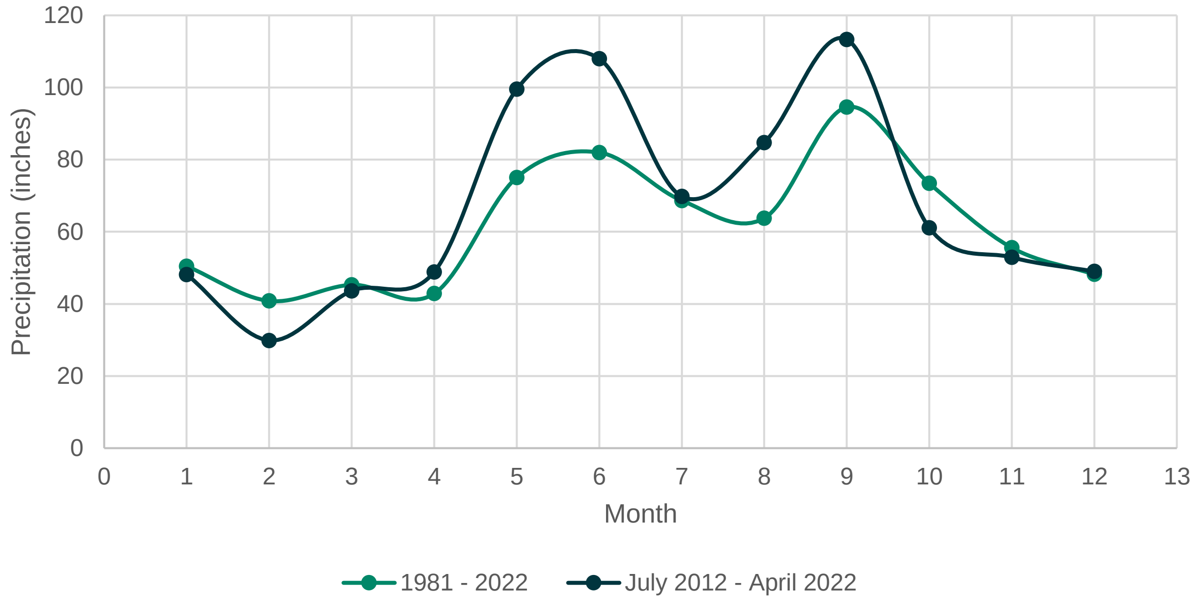


Figure 5-31. Precipitation in the CZB by Month (Weather Data for Texas, 2022)

Because infiltration and inflow is the most commonly reported cause of UD/SSO events, the locations of WWTPs with one or more reported UDs/SSOs were compared to average annual areal rainfall volumes from 2012 to 2021 (using a spatial dataset of annual average rainfall developed by the PRISM Climate Group and Oregon State University) and urban density data (denoting areas with large amounts of impervious cover in 2022). The findings are shown in **Figure 5-32**, where areas with high urban density (red polygons) as developed by TxDOT and larger rainfall totals (blue/purple bands) coincide with WCTS associated with high cumulative UD/SSO incident volumes in gallons. Log scale increments were used on the color scale to give a more linear distribution of pollution volumes. Rainfall contours are shown in 2-inch increments.

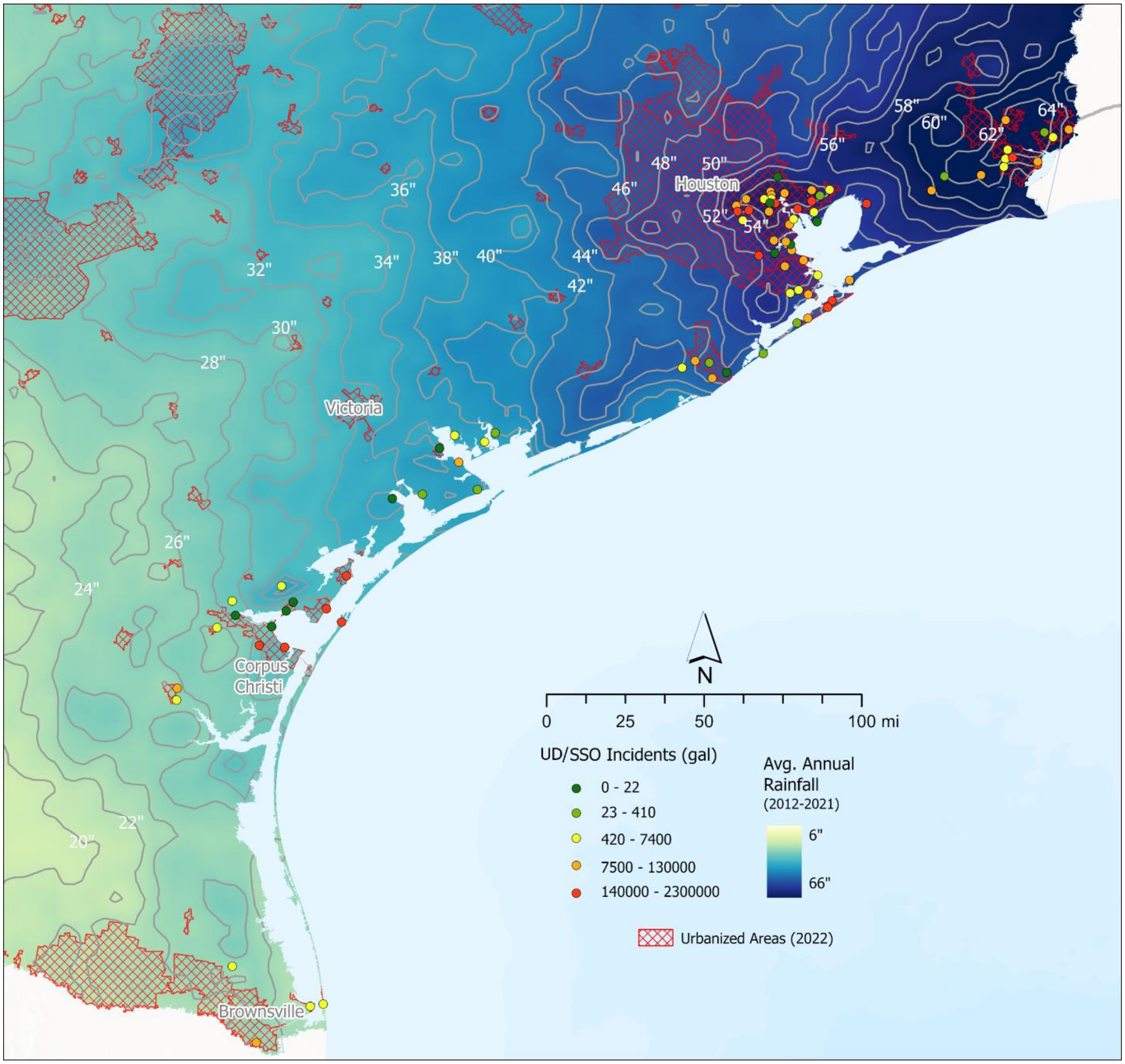


Figure 5-32. Average annual rainfall (Prism Climate Group, 2021), urban areas (TxDOT, 2016), and cumulative WCTS UD/SSO volume

Heavy precipitation and high urban density seem to correspond reasonably well to WWTPs reporting increased cumulative UD/SSO volumes within the WCTS (i.e., areas with higher average rainfall and more impervious cover tend to record greater UDs/SSOs by cumulative volume). The age of individual WCTS infrastructure could increase possibilities of UD/SSO events; however, this information was not available to be evaluated. This analysis supports the data that reports infiltration and inflow as the most common cause of UDs/SSOs but does not provide additional information regarding correlation or causation beyond what is reported in the dataset as the cause of the UD/SSO incident.

5.6.3 Existing and Future Conditions

Sea Level Rise Effects on WWTPs and OSSFs

WWTPs in the CZB, specifically those adjacent to a bay, the Gulf of Mexico, or that are in extremely low elevation areas, are at higher risk of inundation in the future as sea levels rise. As shown in **Figure 5-33**, all WWTPs that would be inundated under a 3 ft SLR scenario are located close to the water on peninsulas or barrier islands. Of the 154

WWTPs located in the CZB, six (3.9%) are at risk under a 3 ft SLR, as shown in **Table 5-24**, below. Of the six at-risk WWTPs, only one reported UDs/SSOs from July 2012 – April 2022. Although five out of six at-risk WWTPs did not report UDs/SSOs, rising sea levels may exacerbate drivers of UDs/SSOs and increase possibilities of future incidents occurring.

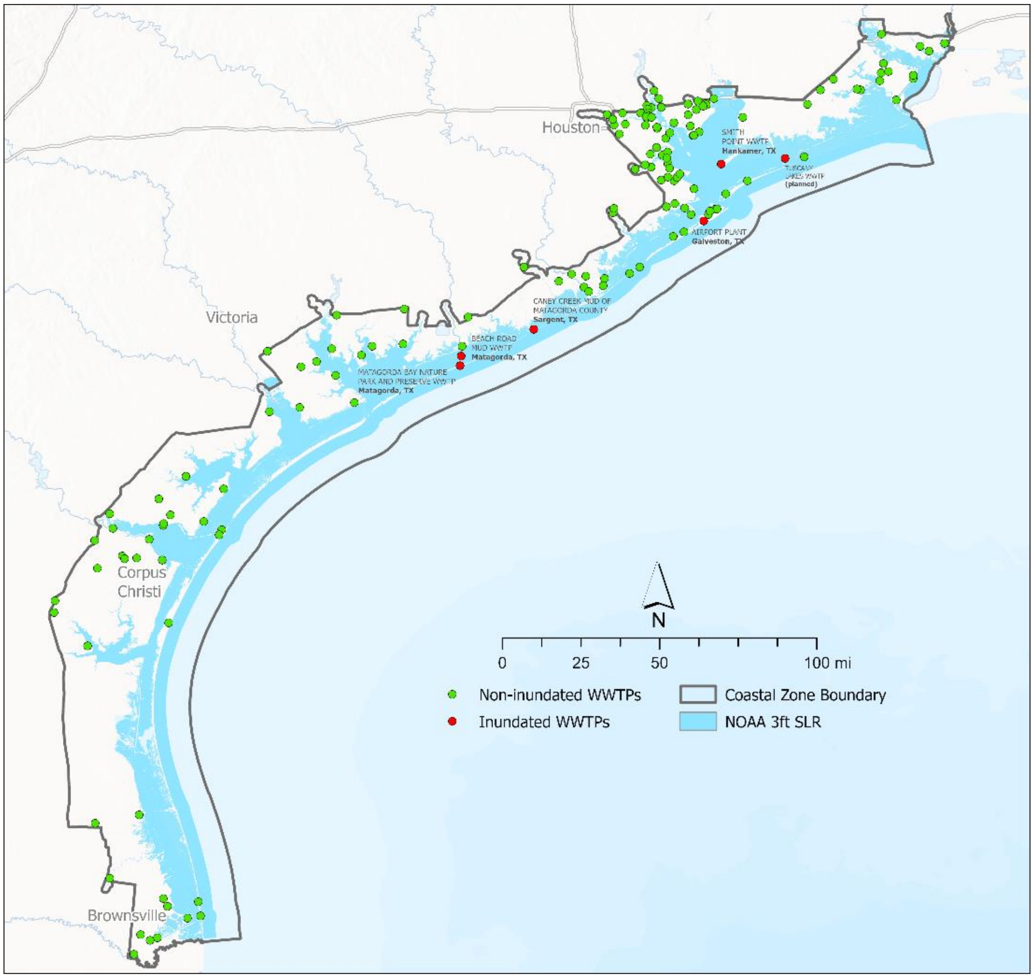


Figure 5-33. Inundated WWTPs in CZB from 3 ft of SLR (NOAA, 2022)

Table 5-24. Inundated WWTPs from 3 ft SLR

WWTP	County	Bay System	No. Incidents	Cumulative Reported UD/SSO Vol. (Gal.)
Beach Road Mud	Matagorda	East Matagorda	-	-
Matagorda Bay Nature Park and Preserve	Matagorda	East Matagorda	-	-
Caney Creek Mud of Matagorda County	Matagorda	East Matagorda	-	-
Airport Plant	Galveston	Galveston	29	1,166,160
Smith Point	Chambers	Galveston	-	-
Tuscany Lakes	Galveston	Galveston	-	-

As SLR increases, OSSFs also have increased potential to be inundated and pollute the surrounding bay systems and Gulf of Mexico. Of the recorded 62,645 OSSF systems in the CZB, 2,271 OSSFs (3.6%) would be inundated by a 3 ft SLR scenario based on NOAA predictions. A map showing the relative location density of inundated OSSFs is shown in **Figure 5-34**.

The densest inundated clusters of OSSFs are in Galveston, Brazoria, and Matagorda counties (see **Table 5-25**). Many of the areas at risk of inundation are located on barrier islands and peninsulas in the northern region of Texas's CZB. Counties with the greatest percent of potentially inundated OSSFs are shown in the table in descending order.

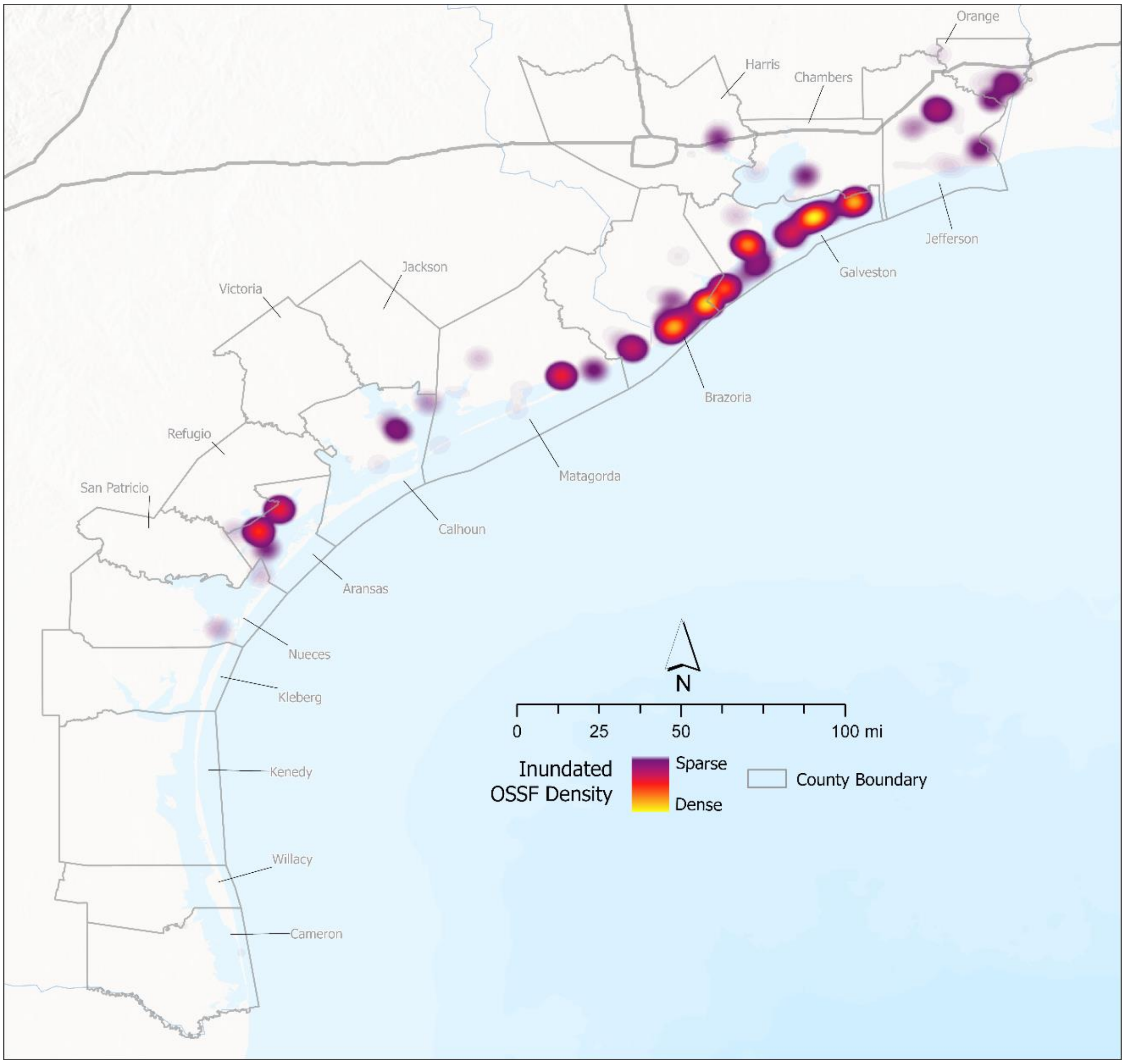


Figure 5-34. Inundated OSSFs in CZB from 3 ft SLR

Table 5-25. Inundated OSSFs from 3 ft SLR

County	No. Inundated OSSFs	Percent of Total Inundated OSSFs
Galveston	981	43.0%
Brazoria	604	26.6%
Aransas	259	11.4%
Matagorda	139	6.10%
Jefferson	131	5.80%
Calhoun	49	2.20%

County	No. Inundated OSSFs	Percent of Total Inundated OSSFs
Orange	49	2.20%
Chambers	24	1.10%
Harris	20	0.90%
Nueces	13	0.60%
Cameron	2	0.10%
Inundated Total	**2,271**	**100.0%**

Water Quality

UDs/SSOs have a role to play in the overall water quality of Texas's water bodies, including bayous, rivers, bays, and estuaries, several of which are designated by the TCEQ to be impaired from bacteria and other pollutants. TCEQ impaired water segments, shown in **Figure 5-35**, account for most of Texas's bay systems and shorelines. Few segments along the coast, such as in the Sabine Lake, Matagorda Bay, Corpus Christi Bay, and Baffin Bay areas, are declared as non-impaired by the TCEQ. Many of the impaired water bodies are classified as having dioxins and PCBs in edible tissue that come from industrial processes, refining, and manufacturing. More pertinent to this analysis, however, are the water bodies listed as impaired due to presence of bacteria from human and animal waste in waters or those listed as impaired for "bacteria in water" where waterbodies are classified for recreational use or recreational beach use (2022 Texas IR Index of Impairments Report, 2022).

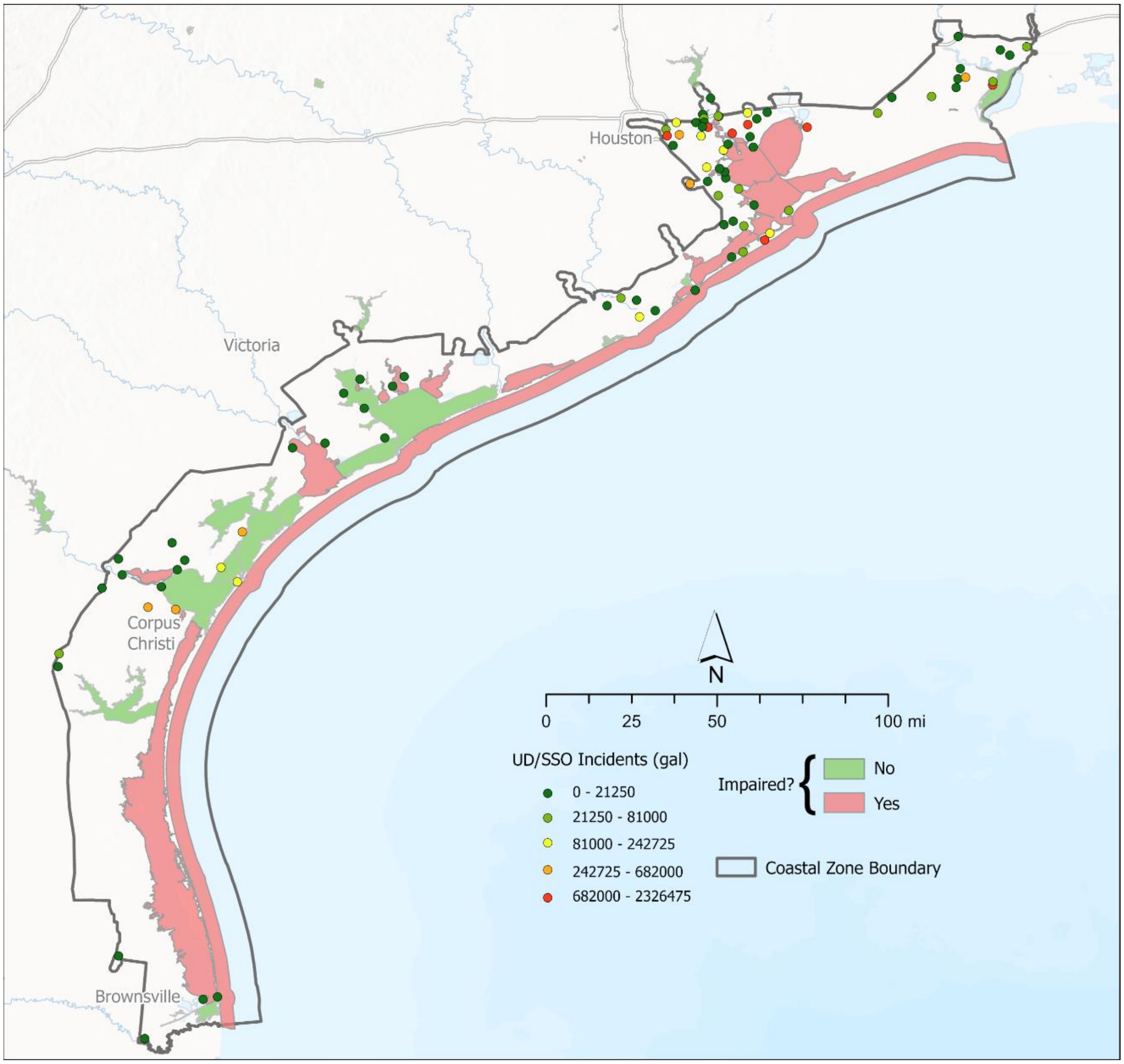


Figure 5-35. TCEQ impaired water segments (TCEQ, 2022a) and UD/SSO incidents by volume

5.6.4 Findings

Data Limitations

The incompleteness of the dataset described above in the **Available Data** section limits the ability to draw detailed conclusions pertaining to this analysis. As the dataset is known to have missing records, there continue to be questions about the completeness of existing reported data, as well as the scale of unreported data. Records of UDs/SSOs are self-reported by the individual WWTP staff, which could explain why some plants have no record at all.

The available set of 4,864 UD/SSO reported incidents are useful for examining some trends of WCTS with incidents using best available data; however, correlation and causality remain in large part undetermined. Results in this memo represent only the WCTS with reported UDs/SSOs during the 2012-2022 data collection period.

More rigorous and systematic data reporting is encouraged, not to cast a negative spotlight on WWTPs reporting UDs/SSOs, but to identify WCTSs that need assistance to prevent continued or future UDs/SSOs. Additional reporting requirements, such as specifying what type of UD was identified (i.e., SSO or other), is needed to further analysis of incidents in more detail. Policy making improvements aimed at preventing UDs/SSOs in the CZB would benefit from accurate and consistent reporting of all UD/SSO incidents from all permitted facilities. Without this information, local authorities are at a disadvantage for understanding and addressing UD/SSO issues that are adversely affecting their environment and residents.

County and Bay System UD/SSO Incidents

Distribution of reported UD/SSO events across Texas appear deeply disproportional, potentially causing extreme pollution rates for localized areas. The Galveston Bay system received approximately 82.6% (54.8 million gallons) of the total reported UD/SSO volume in the CZB from 2012-2022. The second most UD/SSO-impacted bay system is Corpus Christi Bay, which received approximately 9.5% (6.3 million gallons) of the total UD/SSO reported volume, a fraction of the pollution discharged into Galveston Bay, but substantially larger than other bay systems (the next reported bay system, Sabine Lake, received just 4.0%, or 2.7 million gallons, of all reported UDs/SSOs). Harris County facilities contributed 74.7% (49.6 million gallons) of all reported UDs/SSOs the Galveston Bay system, and Nueces County facilities contributed 7.5% (5.0 million gallons) of all reported UDs/SSOs to the Corpus Christi Bay system.

Other bay systems are affected by UD/SSO events, but at significantly lower volumes. The ten remaining bay systems besides Galveston and Corpus Christi received less than 8% of the overall reported UD/SSO pollution by volume from 2012-2022. This disproportion of reported discharges could indicate that there are more challenges with collecting and treating wastewater in the Harris County area, due to possible factors like increased impervious cover and potential for infiltration and inflow in the region and an extensive and aging network of collection systems. However, it could also indicate that reporting is less frequent in other bay systems than in the Galveston Bay region, or it could be a sign of other unknown factors that were not able to be evaluated by this assessment, such as infrastructure deficiencies. Corpus Christi Bay also stands out as a system of clear concern, with UD/SSO pollution volumes much higher than neighboring bay systems.

Causality of the reported UDs/SSOs is not able to be determined using the available data, and more data may need to be evaluated to determine if the Galveston Bay and Corpus Christi Bay systems are, in fact, experiencing high rates of UD/SSO incidents compared to other bay systems.

WCTS-Specific UDs/SSOs

Based on reported data, disproportionate bay system pollution appears to be driven by specific WCTSs within an individual bay system. Investigating the top 10 largest UD/SSO events by volume and, separately, the top ten UD/SSO-producing WCTSs by number of UD/SSO incidents, highlights specific WCTSs that have repeat occurrences of discharge events and/or have a higher UD/SSO footprint by total UD/SSO volume relative to other collection systems.

Highest Producers by Total Discharge Volume: The 10 WCTSs producing the largest volumes of UDs/SSOs from 2012-2022 are responsible for over 81% of the total reported UD/SSO pollution by volume across the CZB. These 10 WCTSs are likely to be highly influential factors on local environments due to the amount of untreated or partially treated wastewater being discharged at the point sources. Five of the top 10 WCTSs by UD/SSO volume are in Harris County (the leading producer of UDs/SSOs by county) and one is in Chambers County, all feeding into Galveston Bay (the leading bay system recipient of UDs/SSOs by volume). Two of the top 10 systems by UD/SSO volume are in Nueces County (the second most prominent producer of UDs/SSOs by county), feeding into the Corpus Christi Bay system (the second most bay system recipient of UDs/SSOs by volume). Reforming and addressing problems at the WCTS that is single largest producer of UDs/SSOs (East District WWTP in Baytown) could reduce the reported UD/SSO output across Texas's CZB by over 30%. Fixing problems at the two largest WCTSs by cumulative UD/SSO volume over the total number of events at those plants (East District WWTP and Central District WWTP in Baytown) could yield an overall 55% reduction of reported UDs/SSOs across CZB.

Highest Producers by Number of Incidents: Six of the top ten WCTSs with the most UD/SSO incidents are also in the top 10 WCTSs by total cumulative UD/SSO volume. However, there is insufficient information to determine if a higher cumulative number of incidents for a given WCTS also corresponds to a higher cumulative UD/SSO volume released. Frequency and cumulative volume of all discharges can vary on a system-to-system basis and more consistently reported data would be needed to determine if the frequency of incidents and cumulative volume of a WCTS's reported UD/SSO incidents are correlated. It is possible, for example, that an individual WWTP that consistently reports any UDs/SSOs will report more UDs/SSOs than other WWTPs that less consistently report incidents which may seem to create a correlation where one does not actually exist. Until more accurate data is available, however, the list of plants producing more frequent UDs/SSOs may nonetheless indicate individual plants that would benefit from technical or financial assistance. The Sims Bayou Plant in Houston had the greatest number of reported incidents in the dataset. The East District WWTP and Central District WWTP in Baytown, mentioned above as two of the highest reporters of UDs/SSOs by cumulative volume, rank as the 2nd and 3rd plants by number of total reported UD/SSO incidents.

Evaluation of UD/SSO severity solely by the number of incidents should be met with caution. While it may be generally logical to assume that more incidents associated with a WCTS results in higher cumulative volume output, the relationship has proven to be quite weak (see **Figure 5-27**). Evaluation by number and volume of incidents should be investigated further to understand the full extent of UDs/SSOs within a given WCTS.

At-Risk Plants to SLR: SLR can increase the risk of UDs/SSOs, and six existing WWTPs are at risk of future inundation due to SLR, one of which has previously reported UD/SSO incidents. It is recommended that mitigation measures or action plans be investigated for these systems in the near-term to plan for potential future risk to those WCTSs.

Other UD/SSO Trends and Patterns

Other patterns and trends resulting from the dataset are described below. Given the data limitations described above, additional reporting information is needed to confirm the existence of these trends.

Reported Causes of UDs/*SSOs:* The leading cause across all reported UDs/SSOs from July 2012 – April 2022 was infiltration and inflow related incidents, accounting for roughly one quarter (24.9%) of the reported incidents, followed by non-grease line blockages (21.1%), grease blockages (14.8%), and other (14.0%).

Seasonal Distribution of UDs/SSOs: Reported UDs/SSOs of specific volumes show reported cause and seasonality trends. The top 500 largest UDs/SSOs recorded were typically infiltration and inflow incidents (48.2%) and most frequently occurred during May and June and decreased in the wintertime. Smaller UD/SSO (≤ 50 gallons) incidents were primarily line blockage-related (grease [22.0%] and non-grease [40.0%]) and were, in general, steadily present year-round. Overall, reported UDs/SSOs of any volume in the CZB appeared to be steadily present year-round with a slight increase in May and June, driven by the increase in large volume UDs/SSOs during those months. Considering the entire dataset, UDs/SSOs of all sizes were most frequently reported in May (12% of all reported UDs/SSOs) and June (11% of all reported UDs/SSOs), having a 4% and 3% higher chance of occurrence, respectively, than the average monthly mean of 8%. When compared to the monthly average precipitation within the CZB, the aforementioned increases in reported UDs/SSOs during May and June align with spikes in average rainfall data over the same months. May and June had the 2nd and 3rd highest rainfalls among months within this time period, totaling 112.6 and 116.6 inches, respectively, both close to double the 41-year annual average of 61.7 inches.

Area Rainfall and Urban Density: Across the state, UD/SSO incidents appear more concentrated in urbanized areas and tend to be concentrated in upper coast. Urban developments tend to contain more municipal infrastructure, higher populations densities, higher sewage volume outputs, and greater numbers of WCTSs to process household waste than less developed areas. These factors collectively create more opportunities for stormwater to inundate sewage lines on the upper coast, and it is possible that this could lead to greater likelihoods of UD/SSO events occurring. However, it is similarly possible that more reporting of incidents is available from WCTSs situated in more urban areas, so these factors are not able to be considered independently.

OSSFs in the CZB

There are no incident data available within the OSSF dataset. General findings from the OSSF data are described below.

Lack of Reported Incident Data: Failing OSSFs will typically be low volume and long duration, or chronic, events. Information on discharges, malfunctions, and failures for OSSFs is typically dependent on what homeowners to report; the Texas Section of the ASCE documents that there is inconsistent performance in O&M for OSSFs (ASCE, 2021). Incidents resulting from OSSFs can greatly affect the environment if the systems are not properly maintained and inspected. Improving reporting of OSSF incidents may be useful for future analysis.

At-Risk OSSFs to SLR: Because OSSFs are frequently located near waterbodies, they can have a significant impact on direct bacteria loading into waterways. Over time, the compounding effects of sea levels rising, the groundwater table rising, existing infrastructure aging, and more infrastructure being built in the CZB, will likely increase the potential for OSSF-related pollution. SLR and a rising water table can increase the risk of OSSF inundation, which could create large-scale malfunction events regardless of the OSSF conditions; it is uncertain whether these malfunctions are being reported now or, likewise, if they will be reported in the future. The dense clusters of OSSF systems that are the most at risk of inundation are located on barrier islands, peninsulas, and bay areas, and are concentrated in the upper coast. However, at risk systems to SLR only account for 3.6% of all OSSF systems in the CZB. Despite the low percentage of systems that are currently at risk to SLR, it may be of concern that the most at risk OSSF systems to SLR impacts are in Galveston County (43% of all inundated OSSFs) near the Galveston Bay system, where WCTS malfunctions are similarly most prevalent according to available data. Nueces County, feeding to the Corpus Christi Bay system, the second most at impacted bay system by UDs/SSOs, is comparatively home to only 0.6% of all inundated OSSFs.

Non-Rural OSSF Systems: OSSFs are typically associated with rural communities, but some areas of highest OSSF densities by number of systems along the Texas Gulf coast are not in rural areas. High population densities in areas without centralized public or private domestic wastewater treatment infrastructure create hot spots of OSSFs, as each household or business must process their own wastewater by means of an OSSF. It could be beneficial for the densest regions of non-rural OSSF systems to be migrated to a public or private system, but this would need to be determined by others on a case-by-case basis. Addressing failed or malfunctioning OSSFs through repair, replacement, or decommissioning and connecting to a nearby residential sanitary sewer, when practicable, are recommended practices.

Effects of UDs/SSOs

UDs/SSOs have direct effects on the overall water quality of Texas bays and may be partially responsible, along with other contributors, to impaired water determinations. Reducing UDs/SSOs produced in the CZB in the long-term may benefit water quality designations on the coast.

Impaired Waters: UDs/SSOs can contribute to contamination of public waters with fecal bacteria, which may deteriorate water quality and, in turn, affect the environment, recreational activities, and the seafood industry. Most of the waterbodies in the CZB are designated as impaired by the TCEQ, with several of these waterbodies noted to be impaired due to bacteria in water and total dissolved solids in water. Poor water quality can harm the recreational industry, such as beachgoers and fishermen, and endanger swimmers with waterborne illnesses. When they occur, UDs/SSOs and malfunctions from OSSFs are likely to contribute, at least in part, to impaired water quality designations. However, they are also likely not the sole source of the impairments that lead to such designations.

Recommendations

UD/SSO incidents have the potential to become more prevalent in the future if action is not taken to address underlying issues within the WCTS. The representations of UDs/SSO data provided herein are intended to aid the coordination of logistics, additional study, support, and efforts related to addressing and reducing pollution adversely impacting Texas Coastal Zone water resources and economy. General recommendations based on the findings of this study are included below.

Improve Reporting Consistency and Accuracy: Across the CZB, policy adjustments may be useful to further understand incident sources and reduce UDs/SSOs. More consistent reporting and accurate reporting measures are needed to gain better insight on the UD/SSO situation and better identify causes, trends, and patterns. It may be beneficial to further define categories, such as developing specific sub-categories of reported causes for “Other” and “Act of God” UDs/SSOs. Additionally, designating the reported discharge as either an SSO or other UD may aid in further, more detailed, analysis of these events. The extent of unreported UDs/SSOs should be investigated to understand the scale of underreported incidents in comparison to what has been recorded. These data are crucial for growing the knowledge and understanding of how, when, where, and why UDs/SSOs develop, as well as pathways for remediating and reducing UDs/SSO pollution in the future. Additional training could be required for individuals responsible for recording and reporting UDs/SSOs to address data gaps.

Focus Efforts on Individual WCTS in Most Impacted Bay Systems: Using the available data, certain coastal areas appear to be disproportionally affected by UDs/SSOs. Within the most impacted bay systems, there are a mix of WWTPs that report a significant number of UDs/SSOs and WWTPs that have few to no reported UDs/SSOs. If it is assumed that UD/SSO incident data (e.g., occurrence, volume, and frequency) were reported consistently and accurately by plants that reported any or no incidents whatsoever, this indicates that there are likely issues, even if the cause is indeterminate, specific to individual WCTSs experiencing the largest number of incidents or UD/SSO volumes that may not be affecting neighboring systems. Because of this, it is recommended to understand problems and implement solutions at local levels for individual WCTSs with extensive UD/SSO releases and to address those issues on a case-by-case basis, especially in the Galveston Bay and Corpus Christi Bay systems.

Begin Adaptive Management for Future Conditions: SLR is expected to present a growing risk for inundation of WWTPs and OSSFs; with six of 154 WWTPs and 3.6% of OSSFs expected to be inundated under the NOAA 3-ft SLR scenario, there are opportunities to begin adaptive management planning now for systems that are expected to have increased risk of incidents due to future water levels. Increasing weather intensification patterns could put additional strain on WCTSs, exacerbating the existing issues driving UD/SSO events. Population influx could provide further pressure on Texas's coastal wastewater systems. The overall CZB is expected to keep increasing in population, with Harris County expecting to add over 1.65 million residents between 2020 and 2050, "and in the coming decades, the ability to make informed decisions regarding water quality and wastewater infrastructure development will be crucial" (Population Projections, 2006; Houston-Galveston Area Council, 2020). All these factors compounded together have the potential to cause more frequent and larger UD/SSO events that damage Texas's coastal environments.

5.7 Actions

Implementing the TCRMP requires responses at multiple scales, beginning with at a statewide level and continuing to at local levels. The Planning Framework developed for the 2023 TCRMP, shown in **Figure 4-9**, defines these needed responses as Actions. In the 2019 TCRMP, Actions were presented as collections of individual projects in a specific geographical area that functioned together to mitigate the coastal pressures and vulnerabilities of that area. However, to support refining and further implementing the 2023 TCRMP, new, data-driven Actions were developed. Forming these Actions relied on relevant, up-to-date coastal datasets and stakeholder inputs from the TAC to synthesize information regarding current vulnerabilities facing the Texas coast. Furthermore, by shifting the Actions from simply groupings of similar or related projects toward a data-driven and stakeholder-informed approach, new projects can be proposed that directly address the vulnerabilities indicated by the data. This “data first” approach will equip project proponents to utilize specific resiliency strategies to alleviate coastal vulnerabilities and further enhance coastal resiliency in a targeted and effective manner. This Action Development Memo details each of the ten Actions identified to address coastal vulnerabilities for the 2023 TCRMP.

- Managing Coastal Habitats
- Managing Gulf Shorelines
- Managing Bay Shorelines
- Improving Community Resilience
- Adapting to Changing Conditions
- Managing Watersheds
- Growing Key Knowledge and Experience
- Enhancing Emergency Preparation and Response
- Addressing Under-Represented Needs
- Maintaining Coastal Economic Growth

Each Action description will include information about the importance of the Action, the vulnerabilities being addressed by the Action, and the resiliency strategies anticipated to be most applicable for specific projects within the Action. The data inputs used to inform developing the Action, including TAC-provided assessment data, will be documented to maintain overall transparency. Additionally, brief descriptions of the activity occurring as part of the GLO’s effort to increase cross-agency collaboration are included within the memo. Since the TCRMP is an ongoing and long-term planning effort, this memo will continue to be updated as new data is collected and new collaborations are formed and will ultimately be incorporated into the 2023 TCRMP. Overall, this memo will provide an overview of the Action development process and the resulting 2023 TCRMP Actions.

5.7.1 Vulnerability Icons


Degraded or Lost Habitat


Gulf Shoreline Change


Bay Shoreline Change


Inland Flooding


Storm Surge


Tidal Flooding


Degraded Water Quality


Degraded Water Quantity

5.7.2 Data Sources


Basemap Data


Inventory Data


Monitoring Data


Model Data


Study Analysis Data


TAC Data

5.7.3 Cross-Agency Collaboration

As an effort to further implementation of Tier 1 projects and enhance the TCRMP Planning Process, the GLO is actively engaging in collaboration with other state agencies and key stakeholders. Goals of the cross-agency collaboration task include identifying additional funding sources that may be applicable to TCRMP Tier 1 projects, understanding and aligning with other state agency planning efforts, and identifying new data sources that can be leveraged to refine the process of identifying vulnerability "hot-spots" along the Texas coast. As the collaborative efforts are still continuing, a list of outcomes up to this point are provided below, which will continue to evolve leading into the 2023 TCRMP. The collaborations are listed by entity and provide information on the strategies that are potentially applicable to that outcome.

Multi-Agency Programs

- **GLO/Texas A&M Corpus Christi:** The Bay Report Card effort led by Texas A&M Corpus Christi could help in identifying knowledge gaps along the coast with respect to ecological systems. This effort would potentially utilize Ecological Resiliency Strategies and Administrative Resiliency Strategies.
- **GLO/TCEQ/TWDB/TSSWCB/TPWD:** Clean Coast Texas is a collaboration of several state and local agencies and many others devoted to protecting waterways in the coastal zone. Both programs work to manage and prevent the introduction of nonpoint source pollution into Texas watersheds. Through the TCRMP, projects can be identified that work toward a holistic approach to managing watershed inputs, both within and beyond the coastal zone, by aligning with the goals of both the TCEQ Nonpoint Source Program and the Clean Coast Texas Program. This effort would potentially utilize both Ecological and Administrative Resiliency Strategies.

- **TCEQ/TWDB**: Collaboration with TCEQ, TWDB, other state agencies, river authorities, and federal agencies (NOAA & USGS) can help coordinate existing monitoring station locations (i.e., bay and river) and identify holistic data gaps and needs. This effort would potentially utilize both Ecological and Administrative Resiliency Strategies.
- **TxDOT/Texas Division of Emergency Management**: Collaboration in the form of coordinating data inputs and analyses regarding current and future vulnerabilities to critical infrastructure, including key roadways and evacuation routes. This effort would potentially utilize Societal Resiliency Strategies and Administrative Resiliency Strategies.

CBBEP

- Recognizing that projects should be prioritized by their ability to increase long-term resilience instead of continually beginning new restoration efforts, CBBEP developed a pilot study to identify and rank habitat types based on health and resilience related metrics when compared to the broader ecosystem. Although the intent of the pilot project is to begin on a local scale, CBBEP's goal is to leverage this effort on a coastwide scale through the TCRMP. By developing a method to assess a specific habitat on a system-wide scale, this study could help prioritize projects that increase the long-term resiliency of the overall Texas coastal system. This effort would potentially utilize Ecological Resiliency Strategies and Administrative Resiliency Strategies.

Texas A&M Corpus Christi-HRI

- Scientists and researchers at HRI developed an oyster restoration siting tool and performed bayhead delta monitoring and shoreline erosion risk classifications for Texas bay features. This effort would potentially utilize Ecological Resiliency Strategies.

TCEQ

- Through partnership with TCEQ and the Total Daily Maximum Load Program, the TCRMP could be leveraged to highlight the impaired WWTPs that are most vulnerable to coastal hazards and in need of funding. This effort would potentially utilize Societal Resiliency Strategies.
- The TCRMP could be leveraged to support water quality improvement efforts, such as TCEQ's Nonpoint Source Program, a statewide water quality program. This effort would potentially utilize Administrative Resiliency Strategies and Ecological Resiliency Strategies.

TxDOT

- TxDOT currently conducts long-term planning of state infrastructure under the Texas Transportation Plan. Efforts like this provide an ideal collaboration point to align priorities and identify unique future-focused considerations for infrastructure planning. This effort would utilize Administrative Resiliency Strategies.
- Under the TXDOT long-term planning and investment plans for roadway infrastructure, there is an opportunity to align TCRMP resilience needs and infrastructure planning in under-represented communities. This effort would utilize Administrative and Societal Resiliency Strategies.
- The TxDOT Maritime Division develops the Port Mission Plan that presents port system investment needs regarding inland connectivity, port facilities, and ship channel improvements. Collaboration may identify projects that can mutually benefit the Texas ports and coastal resilience. This effort would utilize Administrative Resiliency Strategies.

GLO

- The GLO's beach and dune management team is working closely with the TCRMP Planning Team to develop technical guidance for project proponents looking to implement beach and dune nourishment projects. This collaboration will help the TCRMP and other agency efforts publish complementary material to guide stakeholders in building out and implementing these vital projects. This effort would utilize Ecological and Administrative Resiliency Strategies.

- Regional flood hazard mitigation studies, referred to as River Basin Studies, funded by HUD CDBG and implemented by the GLO could be leveraged in the TCRMP. This effort would utilize Administrative and Societal Resiliency Strategies.

TPWD

- Ongoing fisheries and oyster reef programs would be beneficial to include as data sources within the TCRMP Planning efforts. This would utilize Ecological Resiliency Strategies.

TWDB

- Programs such as the statewide base-level engineering flood studies, regional flood planning groups, and the statewide flood plan would all be relevant for collaboration under the TCRMP. This would utilize Societal and Administrative Resiliency Strategies.
- Under the Flood Infrastructure Fund efforts of the TWDB, the TCRMP can potentially use past applications to identify areas of unaddressed needs that align with SVI data. This would utilize Societal and Administrative Resiliency Strategies.

USACE

- Coastal Texas Study and their regional sediment management efforts in coordination with the GLO's own would utilize Ecological, Societal, and Administrative Resiliency Strategies.

5.7.4 Managing Coastal Habitats

Action Description

Managing Texas's diverse coastal ecosystems contain habitats that are imperative to maintaining a healthy and dynamic coastal environment. Targeted habitats include those that are the most heavily stressed by persistent vulnerabilities and that are, according to available data, deteriorating in health, quantity, or quality. Targeted habitats provide for a wide range of aquatic, terrestrial, and avian species. The resulting ecosystems provide valuable provisioning, regulating, supporting, and cultural services that maintain coastal environments and their functionalities, improve human quality of life, and serve as integral elements of the state's multiple lines of defense from the range of coastal hazards that threaten the coast.

While proper management and restoration of a broad range of natural coastal ecosystems is supported throughout the TCRMP, this Action identifies specific and targeted ecosystems through the use of agency-collected monitoring data, habitat modeling analyses and long-term projections of ecosystem/land use changes, and local expert insight. Understanding the current and future needs of critical ecosystems will better inform preventive measures that project proponents can undertake to more efficiently protect and restore coastal habitats and complement other planned mitigation and enhancement activities.

Data Inputs

Many of the data inputs for this Action, including monitoring, modeling, and data analyses, are ecosystem specific. Because of this, input from the TAC is vital to provide a broader understanding of all ecosystems holistically. The complexity of ecosystem management, and especially the difficulty of identifying the most critical

Vulnerabilities Addressed

elements of a vast number of Texas coastal ecosystems amongst many independent datasets, requires that the datasets be synthesized through planning tools.

Specific inputs include ( indicates aging data):

Dataset	Source	Year
Rookery Island	Audubon Texas	2020
Seagrass	TPWD	2016
Coastal Wetlands	USFWS – NWI	2019
Rivers	TWDB	2009
Oysters	HRI (via NOAA Data Atlas)	2011 
Oyster Restoration Siting Tool	HRI	TBD
Bay Report Card Data	HRI	TBD
Texas Bayhead Delta Modeling	HRI	2021
Sea Level Affecting Marshes Model (SLAMM) 2100 Land Cover Output	HRI	2020
Soil Survey Geographic Database	United States Department of Agriculture	2021
WMAs and NWRs	TPWD	2014

Resiliency Strategies

To realize this Action, select individual projects, ranging from local to regional, will be necessary. In most cases, the Ecological Resiliency Strategies will be preeminent for proposed projects. The most effective projects, however, would likely merge Ecological and Societal Resiliency Strategies when opportunities for larger, more comprehensive projects are available. Subcategories within the Ecological Resiliency Strategy category that are of the greatest focus within this Action include:

Wetland Planning, Restoration, and Monitoring

Upland Planning, Conservation, and Monitoring

Oyster Reef Planning, Restoration, and Monitoring

Rookery Island Protection, Restoration and Creation

Beach Nourishment and Dune Restoration

Freshwater Inflow and Tidal Exchange Enhancement

5.7.5 Managing Gulf Shorelines

Action Description

Vulnerabilities Addressed

The Texas Gulf shoreline is in a state of sediment starvation, with an average beach erosion rate of greater than 2 ft per year along 62 percent of the Texas coastline and an overall trend of land loss. This consistent trend places extreme economic and environmental pressures on several coastal communities in Gulf-adjacent areas to maintain their Gulf beaches, both for community development and ecological health. In areas where it is undeveloped, the Texas Gulf shoreline is dynamic, with beach and dune systems readily migrating to various states of equilibrium and relatively rapid post-storm-event recovery is observed. Elsewhere in Texas, a mix of coastal and upstream development, as well as inlet modifications and the construction of coastal structures (jetties, etc.) have created challenges when attempting to establish static, or even accretionary, shoreline conditions for maintaining shoreline health and the wellbeing of those that live, work, or play along the coast.

The Managing Gulf Shorelines Action is focused on efforts that provide the benefits of shoreline stability, whether structural or non-structural, while also working to maintain the natural beach ecosystem. In many cases, this Action focuses on the responsible management of sediment supply as a critical Texas resource. Engineers, scientists, and researchers are still working to understand complex sediment transport patterns that characterize the Texas coast, and to place new findings alongside the demand for sediment across the coastline. Furthermore, efforts to identify viable offshore sediment sources and beneficial use material will be supported under this Action. Despite the manifold efforts that have occurred to date, there is still significant effort needed to find workable solutions to the state's Gulf shoreline erosion problems (solutions, for example, that align permitting, dredging, and project design timelines). Perhaps most critically, the Texas Gulf shoreline is the state's first line of defense from violent hurricanes, storm surge, and waves. A healthy beach and dune environment has the potential to save Texans billions of dollars in damage from a single weather event, creating significant justification to invest in regional solutions and motivate community members to work together to maintain this resource.

Data Inputs

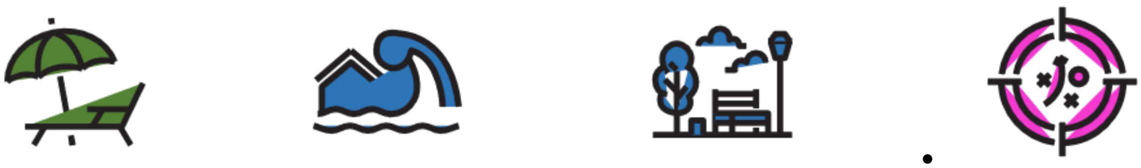
Much of the data-driven approach to managing the Texas Gulf shoreline comes from long-term monitoring of its migration, studies of nourishment projects, sediment budgeting, modeling shoreline response, and local insights as to what happens on-the-ground, particularly during and after storm events.

Specific inputs include:

Dataset	Source	Year
Gulf Shoreline Change Rates	UT-BEG	1930s-2019; 1950s-2019; 2000-2019
BUDM Master Plan	Ducks Unlimited	TBD
Open Water Conversion	HRI	2021
TCRMP Gulf Shoreline Annualized Sediment Budget Estimates	GLO	2021
Regional Sediment Management Data	USACE/GLO	TBD

Resiliency Strategies

To realize this Action, projects are needed from the full trio of Strategy categories to identify the best and most holistic opportunities to implement long-term shoreline management. The methods would include Beach Nourishment and Dune Restoration under the Ecological Resiliency Strategy to propose innovative, industry-leading techniques to take advantage of all available sediment resources. Also needed are both the Storm Surge Suppression and Community Infrastructure Planning and Development methods under the Societal Resiliency category to integrate the beach and dune system into extreme event planning, as well as working to develop alongside this resource responsibly in existing and proposed communities. Lastly, efforts that incorporate Policy and/or Program changes from the Administrative Resiliency category are needed to create long-lasting and meaningful approaches to protecting Texas beaches and dunes.



Beach Nourishment and Dune Restoration | ***Storm Surge Suppression*** | ***Community Infrastructure Planning and Development*** | ***Policy/ Program***

5.7.6 Managing Bay Shorelines

Action Description

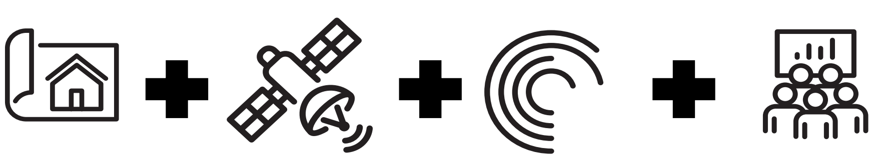
Texas bays have a wide range of shoreline types, with geographies, geophysical characteristics, development patterns, and habitat types that vary greatly across the thousands of miles of bay shorelines. Bay shorelines are often either direct links between our communities and the coast or make up critical habitat corridors and fringe areas that provide valuable ecosystem services to a broader coastal landscape. These intrinsic functions of bay shorelines are stressed as shorelines erode, habitats become more fragmented, or land use changes due to coastal stresses.

The Managing Bay Shorelines Action will determine the most critically changing bay shoreline areas and work toward stabilizing and enhancing those areas to mitigate vulnerabilities shown in the data collected for this Action. The efforts within this Action are especially focused on identifying opportunities to improve the connection between built and natural systems along the coast by finding hybrid (green/gray) approaches to make shorelines more resilient. Areas where managing bay shorelines can enhance protection of communities, protect and/or restore natural ecosystems (such as rookery islands), provide economic development opportunities, and improve community access to the coast are the primary focus of this Action. Additionally, efforts to identify beneficial use material will be supported under this Action. This Action will propose sustainable solutions that are more likely to improve project longevity when considering increasing storm intensities and rising sea levels.

Vulnerabilities Addressed

Data Inputs

This action is driven through mapping of bay shoreline change rates, modeling of vulnerable shorelines to RSLR, mapping of current and future development, and local stakeholder input on historical shoreline change impacts to the region.



Specific inputs include:

Dataset	Source	Year
Bay Shoreline Change Rates	UT-BEG	1950s-2010’s
GIWW Channel	USACE	
GIWW Prioritization Mapping	Ducks Unlimited	TBD
Hardened Shoreline Locations	GLO	
Living Shoreline Suitability Model	HRI	TBD
SLAMM Analysis Results	HRI	2020
BUDM Master Plan Data	Ducks Unlimited	TBD
Regional Sediment Management Data	USACE/GLO	TBD

Resiliency Strategies

This strategy focuses on both Ecological and Societal Resiliency Strategies to provide strategic efforts for bay shoreline maintenance. In the effort to find projects that approach this Action with a hybrid vision, both the robust protection of engineered solutions and adaptive capability of natural solutions are intended, often referred to as living shorelines. This includes Wetland Planning, Restoration, and Monitoring, Oyster Reef Planning, Restoration, and Monitoring, and Community Infrastructure Planning and Development. It is critical to the success of this Action that project scale is considered to see coastwide improvements in resilience. To that point, smaller projects should be viewed through a large-scale lens, working towards a strategic regional vision. Blending shoreline benefits across our ecological and community needs is vital to the success of this Action.

Wetland Planning, Restoration, and Monitoring

Oyster Reef Planning, Restoration, and Monitoring

Community Infrastructure Planning and Development

5.7.7 Improving Community Resilience

Action Description

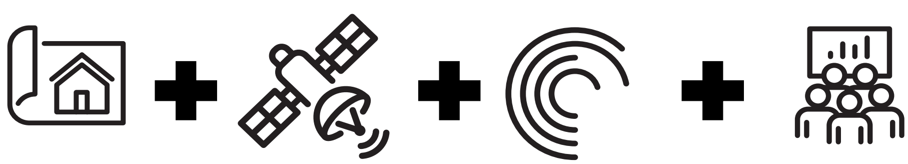
Community infrastructure and water management needs along the Texas coast are wide ranging, with varying resilience concerns (often depending on the size or age of a given community) that, when addressed, can lead to significant positive impacts on the quality of life for coastal populations. For the purposes of this Action, projects that are expected to significantly improve coastal community infrastructure resilience in the face of both short- and long-term hazards—including storm surge, wave effects, and inland flooding—are prioritized. It also incorporates other elements of water management, including urban considerations for water quality and quantity, which can often be directly correlated to rainfall events, drought cycles, stormwater runoff, and more extreme coastal storms. Long-term hazards include impacts to infrastructure caused by rising water levels from RSLR, especially when adaptive capacity and/or retrofit measures were not considered as part of original project designs or community planning.

The Improving Community Resilience Action will be used to identify local and regional project needs to mitigate water quality and quantity hazards for coastal communities, working to both reduce exposure and minimize system vulnerabilities. It is critical under this Action to consider full project life cycles, including thorough infrastructure planning all the way through project implementation and adaptive management. Major future risks for this Action are community development and changing coastal landscapes and it will become increasingly more important to create science-based decision frameworks for community infrastructure development and improvements. Harnessing the adaptive abilities of natural systems that make space for the functional need for engineered solutions through hybrid (green/gray) infrastructure will be important. Developing a path forward for coastal communities to exist independently of constant threats of infrastructure damage and impacts to daily life is the ultimate goal.

Vulnerabilities Addressed

Data Inputs

This action is driven through inventory of critical facilities, understanding areas of planned development, stormwater management modeling, and local insights for the need and possibility of evolution in community development practices.



Specific inputs include ( indicates aging data):

Dataset	Source	Year
Number of Buildings	RSMeans/Census Bureau	2018
Total Exposure Value	HRI/AECOM	2019
Percent Developed/Impervious Cover	USGS NLCD	2019
Total Population	Census Bureau	2010/2020
NFHL 1% Annual Flood Risk Zone	FEMA	2020
Wave Impact Index	AECOM	2020
Storm Surge Inundation	HRI/AECOM	2019
SLAMM 2100 Land Cover Output	HRI	2020

Dataset	Source	Year
SVI	NOAA	2006-2010
Historical Claims/Repetitive Losses	FEMA	Continuous
Community Rating System	FEMA	2021
Flood Risk	FloodFactor	2020
Floodplain Quilt	TWDB	2021

Resiliency Strategies

To realize this Action, projects are needed from all three Strategy categories. This multiple lines of defense approach includes Freshwater Inflow and Tidal Exchange Enhancement from the Ecological Resiliency category to ensure a continuous flow of freshwater to avoid water quantity and quality issues, as well as to maintain natural pathways through which water can flow following storm events. The Action also includes Community Infrastructure Planning and Development and Storm Surge Suppression under the Societal Resiliency category to identify areas within coastal communities where implementing storm surge risk reduction measures would be expected to increase the long-term resilience of the community. Finally, under the Administrative Resiliency category, developing Policies and Plans to increase community awareness, limit improper development or management practices, and promote measures to increase resilience can help communities reduce risk to coastal hazards.

Freshwater Inflow and Tidal Exchange Enhancement

Community Infrastructure Planning and Development

Storm Surge Suppression

Policy/Plan

5.7.8 Adapting to Changing Conditions

Action Description

While other Actions developed for the 2023 TCRMP point to specific concerns (for example, data needs, watershed needs, habitat needs) that are commonplace along the Texas coast, the Adapting to Changing Conditions Action is formulated to provide an avenue to identify a wider set of potential future measures that could be needed along the Texas coast by predicting what a future Texas coastal environment could look like and then identifying steps to achieve that vision. The coast is meaningful to Texans in a variety of ways—it drives industries that are the backbone of our state economy, is home to diverse habitats and landscapes that are unique to Texas, or is simply home to millions of coastal county residents—and yet it is constantly changing in response to coastal, economic, and societal pressures. Understanding that the risk to the Texas coastal region is changing over time is vital to effectively implementing resilient measures throughout the coast.

The Adapting to Changing Conditions Action is focused on broad scale, proactive planning that can enhance our state's future. Historically, the majority of coastal resilience projects along the Texas coast have been reactive, aiming to address problems that had already arisen by restoring habitat, coastlines, and development to historical or other prior conditions. As a state, we must begin to think about what has yet to happen and decide what the best course of action will be to respond. This Action could ask questions such as:

(1) How can our communities grow and flourish along the coast while maintaining independence from the threats of increasing water levels and flood risk?

(2) What type of habitat is going to be most viable in 30 years, given future weather patterns and SLR projections?

(3) What knowledge will we need to make informed decisions going forward?

Vulnerabilities Addressed

Data Inputs

This Action is directed by understanding of how our coastal pressures will change and evolve over time. Understanding challenges such as relative SLR, increasing storm risk, and potential negative impacts of human development patterns will better prepare Texan communities for taking proactive measures to achieve coastal resilience.

Specific inputs include:

Dataset	Source	Year
Future Storm Surge Inundation	HRI	2021
Open Water Conversion	HRI	2021
Marsh Migration Corridors	USGS – Wetland and Aquatic Research Center	2015
SLAMM 2100 Land Cover Output (including future development projections)	HRI	2020
Future Rainfall-based Hydraulic Analyses		
Future Roadway Planning Data	TxDOT	2021
SSO Data	TCEQ	TBD

Resiliency Strategies

This Action is not applicable to specific TCRMP Strategies but can be applied to any strategy, as applicable to the intent of the Action.

5.7.9 Managing Watersheds

Action Description

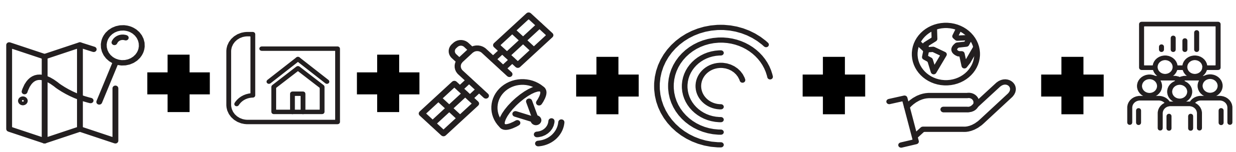
Coastal watersheds have unique complications when compared to inland watersheds, which can make them more challenging to manage. In addition to riverine conditions common to all watersheds, the interfaces of riverine and bay systems are tidally influenced and have bay specific characteristics (e.g., deltaic formation, fluctuating salinity gradients, presence of tidal forces). Tidal considerations can also vary by coastal watershed, creating unique tidal flushing characteristics that generate watershed-wide impacts to water quality and quantity. Given the complexity of these and other, similar concerns (e.g., large rainfall events, stormwater runoff, periods of drought), there is much to consider related to comprehensive coastal water resources management.

Vulnerabilities Addressed

The Managing Watersheds Action is focused on capturing the above considerations within projects that can span a single watershed or a network of watersheds. Texas coastal watersheds vary significantly in natural processes and environmental features, as noted, but also in human development within the watersheds. This Action will work to establish management priorities that are suitable for both rural and urban needs, ranging from best practices that can be implemented at local levels to large-scale, regional plans.

Data Inputs

Key data inputs for this effort include watershed monitoring and model data.



Specific inputs include:

Dataset	Source	Year
Water Quality Data	TWDB	Continuous
Harmful Algal Bloom Reports	TPWD	2014-2021
NFHL 1% Annual Flood Risk Zone	FEMA	2020
Freshwater Inflow Data	TWDB	2010-2012; Under-Development
SSO Data	TCEQ	TBD
Septic Systems Vulnerable to SLR	TBD	TBD

Resiliency Strategies

To implement this Action, projects from all three Resiliency Strategy categories will be needed to develop a holistic approach to managing watersheds on all scales. This will include a multitude of methods under the Ecological Resiliency Strategy, such as Wetland Enhancement, Upland Enhancement, and Freshwater Inflow and Tidal Exchange Enhancement, in an effort to enhance watershed inputs and outputs, improve the overall water quality and function of the watershed, and stabilize the quantity of water flowing through the system. From the Societal Resiliency category, the most impactful method for this Action will be Community Infrastructure Planning and Development to understand how potential future development will impact watersheds and identify the best approach to managing the two interests adaptively.

Wetland Planning, Restoration, and Monitoring

Upland Planning, Conservation, and Monitoring

Freshwater Inflow and Tidal Exchange Enhancement

Community Infrastructure Planning and Development

5.7.10 Growing Key Knowledge and Experience

Action Description

A common concern for achieving coastal resilience is a lack of up-to-date data and information that would better inform areas most at risk to coastal vulnerabilities or that would provide more insight into how to effectively execute resilience projects. While there have been and continue to be studies, monitoring sites, data collection efforts, and resilience projects up and down the Texas coast, throughout the Gulf Coast, and around the globe, it is still common to find subjects that are under-informed. Often, resolving these needs is left to independent efforts to fill in the data gaps, which gradually happens over time. However, time is sacrificed in this approach and as there is a lack of an overarching mission for the various data collection tasks, significant inefficiencies are created.

To help resolve this, the Growing Key Knowledge and Experience Action is proposed to provide structure and vision for gathering data and information needed to improve coastal resilience in Texas. This Action is intended to focus the goals of previously independent data collection and study efforts, organizing the efforts to fill any gaps in the current knowledge base that would be impactful for furthering the overall goals of the TCRMP. In addition to data gathering and studies, there are novel techniques proposed for resilience in our coastal ecosystems and communities that are not well understood or have yet to be attempted that could prove pivotal in furthering coastal resilience. This Action will support these techniques in the form of pilot projects or programs to provide a pathway to coastal stakeholders for future implementation. Promoting pilot-type efforts under this Action will help the GLO reduce risk through the initial understanding that some of these pilot efforts may not return promising results, yet may still be important in informing the broader picture of coastal resilience.

Vulnerabilities Addressed

Data Inputs

To inform this Action, TAC expertise in data gaps will be critical, and will be paired with an understanding of existing basemap, monitoring, and study analysis data.

Specific inputs include:

Dataset	Source	Year
Present Land Cover	USFWS – NWI + NOAA C-CAP	2020
WMA	TPWD	2014
Wildlife Refuges	USFWS/TPWD	2008
National Wetlands Inventory	USFWS	2019
Bay Report Card Data	HRI	TBD

Resiliency Strategies

This Action will focus on projects that fall under the Administrative Resiliency category to introduce or further refine coastal resilience data and information gathering techniques along the Texas coast. This will primarily include Programs and Plans that will be used to identify or address critical knowledge gaps but could also include developing pilot studies to collect key information and data to broaden the scope of coastal resilience. The pilot studies could implement methods under Ecological or Societal Resiliency Strategies but are expected to be formulated under the Administrative Resiliency Strategy.

Programs/Plans

5.7.11 Enhancing Emergency Preparation and Response

Action Description

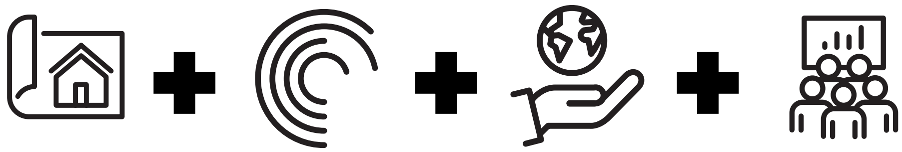
Emergency scenarios and hazard response are inevitable along the Texas coast. A range of hazards are possible, including those captured within other Actions, but perhaps the most prevalent include major tropical and other heavy rainfall event response. Preparing for and responding to these hazards is important for the safety and wellbeing of coastal communities. Many communities along the Texas coast are not well-equipped to prepare for or respond to major emergency scenarios. In many cases, this is due to increased risk caused by deteriorating critical infrastructure and facilities or lack of public awareness. Particularly in smaller communities, there may also be a lack of personnel capacity (for instance, when local governments are short-staffed) to make proper preparations to prevent or reduce the impact (e.g., emergency personnel response time) of emergency situations.

Under the Enhancing Emergency Preparation and Response Action, projects that increase community awareness, maintain and protect evacuation routes, improve critical data systems, enhance risk studies, and implement resiliency measures to protect critical facilities will be considered. This Action is intended to promote proactive administrative planning to anticipate and respond to coastal disasters through improving vital coastal infrastructure, developing public education campaigns, and developing and enacting emergency response plans to lessen the impacts of extreme weather events and natural disasters on coastal communities.

Vulnerabilities Addressed

Data Inputs

The data inputs relevant to this Action include identifying important evacuation routes and critical facilities that are vulnerable to coastal hazards, reviewing existing data and emergency alert systems, and collecting on-the-ground insights to identify administrative needs within local and regional government offices.



Specific inputs include:

Dataset	Source	Year
Storm Surge Inundation	HRI/AECOM	2020
NFHL 1% Annual Flood Risk Zone	FEMA	2020
Wave Impact Index	AECOM	2020
Transportation Facilities, Critical Facilities, Essential Facilities	Hazards U.S. (Hazus)	2015 - 2019
Historical Roadway Inundation Database	TxDOT	
Evacuation Routes	TxDOT	

Resiliency Strategies

To implement this Action, projects are needed from the Administrative and Societal Strategies to enhance coastal emergency preparation and response. The Societal Resiliency Strategy will include Land-Based Transit Enhancement to identify, maintain, and protect important evacuation routes, as well as Storm Surge Suppression to implement measures to reduce the impact of storm surge events on homes, businesses, and critical facilities. Additionally, projects that promote developing or refining Programs or Plans from the Administrative Resiliency Strategy are needed to build community awareness around coastal vulnerabilities and create or enhance emergency response plans to inform communities on how to best prepare and take action during emergency situations.

Land-Based Transit Enhancement

Storm Surge Suppression

Programs/Plans

5.7.12 Addressing Under-Represented Needs

Action Description

Specific areas along the Texas coast have historically been less represented in coastal resiliency initiatives by studies, project implementation, and stakeholders. As a result, there are portions of the Texas coast that could be or already are at risk for damages or degradation, but where action is not being taken due to a lack of awareness or leadership. This Action will be an avenue to equitably support coastal resilience planning and projects along the entire coast.

Under the Addressing Under-Represented Needs Action, multiple types of opportunities for projects may be considered. These opportunities broadly fall into three main categories: (1) Minimal organized or active stakeholders, (2) Historically few Tier 1 projects or TAC participation, (3) Communities identified as socially vulnerable (due to socioeconomic status, access to housing/transportation, race/ethnicity/language, mobility, etc.). In some cases, vulnerabilities are understood to exist for portions of the coast; however, there may not be organized or active stakeholders to take the lead on resiliency projects intended to mitigate the vulnerabilities. Similarly, locations or subregions that have historically had few or no Tier 1 projects would potentially be ideal areas to investigate under this Action, as a historical lack of supported projects might indicate that there has been less advocacy for priorities in the area. Beyond the frequency of projects performed previously, socially vulnerable communities along the coast will also be considered. Identifying opportunities to enhance coastal resources (e.g., identifying vulnerable fisheries that support subsistence harvesting of seafood for local populations) and mitigate hazards for socially vulnerable populations will help the GLO be a good steward of its economic resources.

Public access to coastal areas and resources are assets for all Texans, regardless of occupation, income, or race. This Action works to provide an equitable approach to coastal resilience in Texas.

Vulnerabilities Addressed

Data Inputs

This Action is steered largely by historical data. Understanding where vulnerabilities exist, but where there have been few projects to address those vulnerabilities will be critical in evaluating this Action. Additionally, having insight into coastal stakeholders that are more prone to have challenges with implementing and executing projects, particularly as a result of financial capabilities, will provide indicators of target areas. This Action could be informed by datasets such as LMI or SVI.

Specific inputs include (⚠ indicates aging data):

Dataset	Source	Year
SVI	NOAA	2006-2010 ⚠
LMI Data	HUD (GLO-CDR Guidance)	2019
Demographics	Census Bureau	2010/2020
Total Population	Census Bureau	2010/2020
Storm Surge Inundation	HRI/AECOM	2019
NFHL 1% Annual Flood Risk Zone	FEMA	
Populations at Risk	Headwaters Economics	2013

Resiliency Strategies

This Action is not applicable to specific TCRMP Strategies but can be applied to any strategy as applicable to the intent of the Action.

5.7.13 Maintaining Coastal Economic Growth

Action Description

The Texas coast—home to all or much of its waterborne commerce, energy and chemical, military, commercial and recreational fishing, and tourism and nature tourism industries—can rightly be considered the economic engine for the state. The impact that the Texas coast has on the state's economy is a foundational reason for the GLO being able to invest state funding into improving coastal resilience. It is also the reason why the TCRMP represents a statewide investment, not simply an investment for those who live or work on the coast.

The Maintaining Coastal Economic Growth Action will serve as a vehicle to identify resilience efforts that have a direct benefit to the state's economy. These projects should incorporate multiple resilience components, but ultimately have a foundation focused on economic growth and opportunity. This Action will be used to incorporate the Texas port system (including the GIWW), coastal tourism and ecotourism, and commercial fishing into identified projects.

Vulnerabilities Addressed

Data Inputs

Due to the economic basis of this Action, understanding how the Texas coast impacts the state economy will be foundational. Leveraging TCRMP economic analyses, along with other state and federal studies, will best inform meaningful elements of the coastal economy and opportunities to enhance coastal resilience through economically focused projects.

Specific inputs include:

Dataset	Source	Year
Economic Datasets	Texas Comptroller	
Port Strategic Plans	TxDOT	2020
Commercial Fishing Data	NOAA	2020
Coastal Tourism Data	Travel Texas	2020
TxDOT Maritime Port Mission Plan Data	TxDOT	2020
GIWW Prioritization Mapping	Ducks Unlimited	TBD
Present Land Cover	USFWS – NWI + NOAA C-CAP	2020
GIWW Resiliency Study	USACE	TBD

Resiliency Strategies

This Action is not applicable to specific TCRMP Strategies but can be applied to any strategy, as applicable to the intent of the Action.

6 Coastal Modeling and Vulnerability Assessment

6.1 Introduction

The Harte Research Institute (HRI) conducted SLR, storm surge, and wave modeling to provide quantitative information about the potential environmental impacts due to rising sea level and concomitant enhanced storm surge caused by higher sea level and changes in land cover in the Texas coast. This work follows on progress made during the development of the 2019 Plan, where analysis of recent coastal change, model projections of future change, and map visualizations, provided a preliminary understanding of the dynamics of the coastal zone affecting the ecosystem and community resiliency. The prior modeling was an important component of the Plan, however, the results were limited because only 6 storm scenarios and 1 SLR scenario were modeled.

This study used the same successful modeling approach implemented in the 2019 Plan but used ensembles of storms and SLR scenarios to better gauge the human and natural vulnerabilities of the coastal zone. By compiling new and improving existing geospatial data layers of topography, geoenvironments, socio-economic setting, and model projections of change caused by SLR and hurricanes, this study provided a fuller range of vulnerability, and therefore, better defined the requirements for projects and programs to address resiliency now and in the future.

The intent of the modeling effort was to further understand and quantify the future impacts of SLR and storm surge events, and to compare a no-action scenario without any additional resiliency projects vs. a future with-project scenario by incorporating both Tier 1 and conceptual resiliency projects. Additionally, geohazard and vulnerability maps were also developed showing the changes or vulnerabilities relative to time due to these gradual (SLR) and immediate (storm surge) coastal changes.

6.2 Methods

6.2.1 The Modeling Framework

For the 2019 Plan modeling study, HRI developed a dynamic modeling framework to assess quantitative information regarding the impacts of SLR and associated enhanced future storm surge caused by higher sea level and changes in land cover (Subedee et al. 2019). The framework comprised of the state-of-the-art and computationally expensive models including SLAMM, ADCIRC, Simulating Waves in the Nearshore (SWAN), and HAZUS-MH (**Figure 6-1**). The same successful modeling approach is used with ensembles of storms and SLR scenarios to better assess the human and natural vulnerability of the Texas coastal zone for the 2023 Plan.

Given the vulnerability of wetland habitats to SLR, this study employed the SLAMM to project future changes in the distribution of specific environments in a quantitative and spatiotemporal manner. SLAMM is a rule-based spatial model that predicts landcover changes induced by SLR in coastal areas at a local or regional scale. It uses a complex decision tree that incorporates geometric and qualitative relationships to determine transitions among habitat classes as sea level rises (Clough, Park, and Fuller 2010). SLAMM requires several map-based inputs and numerical parameters along with SLR condition in the year 2100 and it gives maps of updated elevations and land cover classes in the year 2100 along with other numerical outputs. Two SLR scenarios were used for this study as it is recommended to use a range of future conditions to support a diversity of users who potentially may have very different decision contexts and risk tolerances in their planning (Parris et al. 2012; Sweet et al. 2017). This approach allows for a range of potential SLR scenarios to be considered in the coastal resilience planning process.

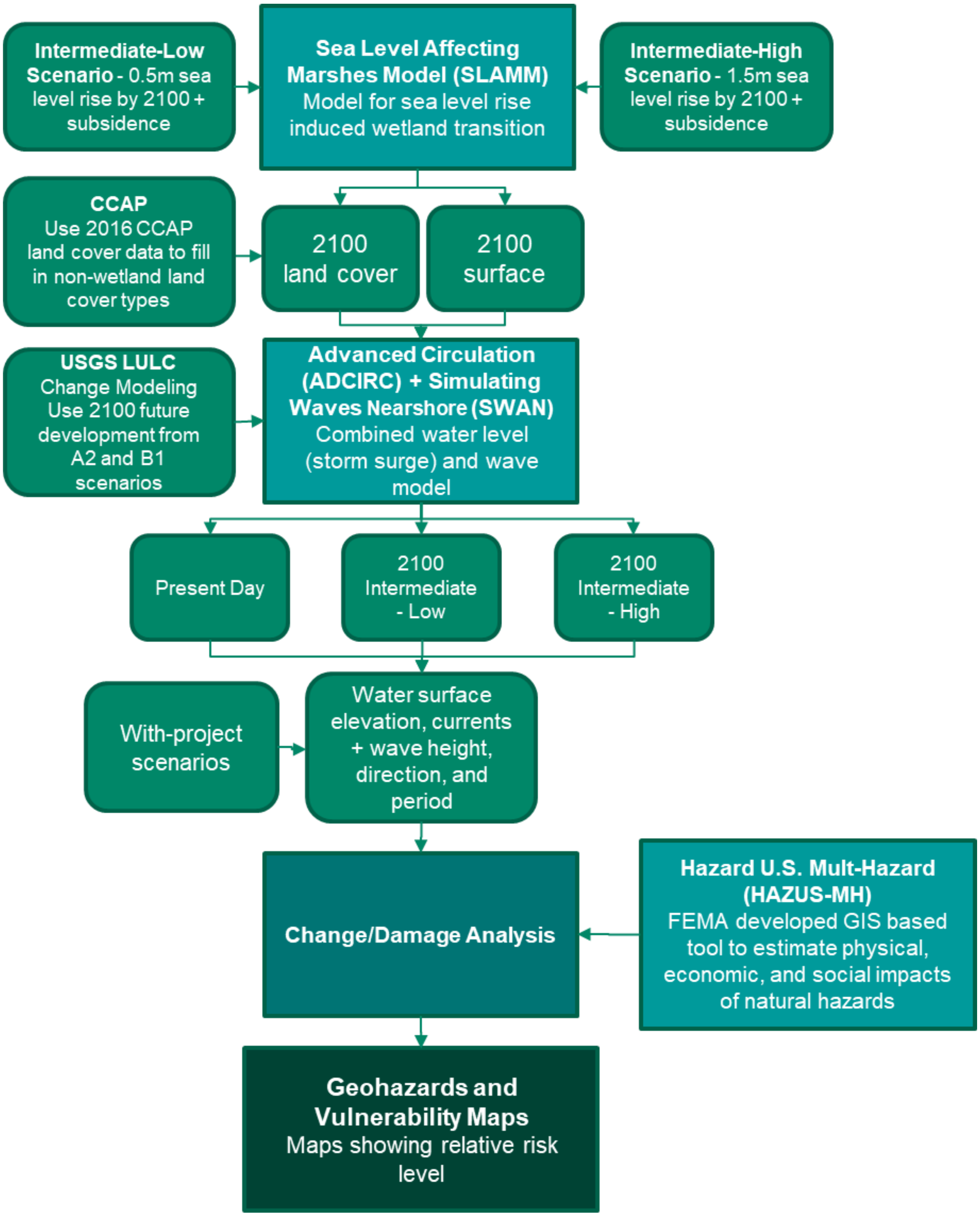


Figure 6-1. Modeling framework showing the input/output data, modeling tools and processes used in this study

The future topographic surface output by SLAMM was used to update the computational mesh for storm surge analysis. Similarly, the future landcover output by SLAMM was used to generate the Manning's *n* friction coefficients representative of future conditions for the storm surge analysis. The future landcover dataset developed by the USGS (Sohl et al. 2014) was also used to generate the Manning's n coefficients for the inland area where the SLAMM modeling was not possible.

This study employed the coupled ADCIRC+SWAN model for the storm surge analysis. Both these models are tightly coupled as an integrated circulation and wave model that operates on the same unstructured mesh and gives the time and spatially varying water surface elevation, currents, wave height, wave direction, and wave period. The model was forced using meteorological wind and pressure fields of 19 synthetic storm events making landfall in different parts of the Texas coast. The same 19 storms were forced to the present-day surface and landcover condition as well as the two modeled future landscape conditions considering two SLR scenarios. Therefore, a total of 57 ADCIRC+SWAN simulations were performed for three scenarios.

Subedee et al. 2019 have provided details of each of these modeling tools as the same modeling framework has been used for the 2023 Plan. Similarly, Subedee et al. 2019 provide granular details of each input used in the SLAMM and ADCIRC+SWAN modeling, methods used to update and run these models for different scenarios, numerical parameters used to run each model, and model calibration and validation steps. This study used the same approach and parameters as in the 2019 Plan described in Subedee et al. 2019. This report only focuses on the enhancements made to each of the models in the framework. The major updates made for the 2023 Plan are the model inputs, SLR scenarios, storm scenarios, and improved with-project modeling, and are explained in the following sections. The major enhancements to the modeling process from the previous version of the Plan include:

- Updates to SLAMM and the ADCIRC+SWAN inputs, including land cover and topography – development of high-resolution seamless Digital Elevation Model (DEM) of the coastal plain
- Modeling of multiple global mean SLR scenarios from the NOAA 2017 Technical Report Global and Regional Sea Level Rise Scenarios for the United States (Sweet et al. 2017) Scenarios modeled in this Plan include the Intermediate-Low and Intermediate-High (0.5m and 1.5m by 2100 respectively). The 2019 Plan modeled one scenario from the report, Intermediate (1.0m by 2100).
- Modeling additional hypothetical storms from the U.S. Army Corp of Engineers synthetic storm suite. Nineteen total storms were modeled for this Plan – 10 Category 1, 3 Category 3, and 6 Category 2 storms. The 2019 Plan modeled only the 6 Category 2 storms.
- Analysis of SWAN model output for with-project scenarios, a new approach to assessing the efficacy of the projects on the future condition landscape

6.2.2 Improvements to Sea Level Rise and Landscape Change Modeling

Digital Elevation Model (DEM)

The topographic digital elevation model (DEM) is one of the key inputs to SLAMM as well as ADCIRC+SWAN, and an extensive effort was put to generate a high-resolution DEM of the Texas coast using the latest and most accurate lidar-derived datasets. For the 2019 TCRMP, topographic DEM with 3 m resolution was developed using a fusion of 35 airborne topographic lidar surveys conducted between the years 2005 – 2016. Newer lidar surveys have been available since the publication of 2019 Plan. Therefore, a new seamless high resolution, 2 m, DEM of the Texas coast was developed for this study (**Figure 6-2**). The elevations in the DEM represent the topographic bare-earth surface. The dataset is a fusion of several airborne topographic light detection and ranging (lidar) surveys acquired by various surveyors primarily from 2018 and 2019. The landward extent of the lidar surveys selected for the creation of this DEM was determined by the boundary of the ADCIRC mesh used for the storm surge modeling in this study. Elevations in the DEM were in meters relative to the NAVD88 datum, geoid2012b. A very similar approach as used in the 2019 TCRMP was used for processing the lidar data as explained below.

The las files were first checked if they fall in the boundary of the ADCIRC mesh for further processing. A las tile is considered being inside the boundary if any one of its four corners falls within the mesh boundary. All selected las file's horizontal coordinates were converted to either UTM 14 or 15 and vertical coordinates to NAVD88. Furthermore, any files that used geoid1999, geoid2003, or other geoids were converted to geoid2012b. The las files were then gridded by inverse distance weighting (IDW) with the three nearest points to produce 2 m cell raster files. If no lidar points are within the search range of 3 m, the cell was assigned no data. Five parameters were computed for each 2 m cell: point density, average elevation, minimal elevation, maximum elevation, and elevation variance. Only ground points within a 2 m cell were included.

A lidar survey usually had 10 to 2000 files that gave 10 to 2000 raster tiles after gridding lidar points in those las files. These raster tiles were then mosaicked into larger images to fuse multiple surveys. The algorithm to mosaic these tiles first collected the geographic range of all tiles and also gathered the extent of each lidar survey. If the range of the survey was larger than 15,000 x 15,000 pixels of 2 m cell, it was divided into 2 to 10 sub-ranges, so that each sub-range was smaller than 15,000 cells. After obtaining the geographic extent of each sub-range, all tiles were mosaicked into a sub-range if the left-upper corner of a tile was in the geographic extent of a sub-range. This finally gave 2 to 10 mosaic images based on the number of sub-ranges obtained earlier.

Some mosaicked images had data holes due to the presence of water bodies or gaps between the raster tiles in a mosaic image. To fill in the no data holes that existed in new mosaicked images, a morphology closing operation was used to close all holes that are less than 41 x 41 pixels in the mosaicked images. To fill in these holes of size equal to or less than 80 m x 80 m, a buffer of 50 pixels from the boundary of any no data area (hole) was generated. The no data cells next to valid elevation data were assigned a value of 1, the no data cells next to value 1 cells were assigned a value of 2, and so on until all no data cells were filled within the 50 buffer cells. The computed elevation for a buffer cell was the average elevation of its 3x3 neighboring cells. First the elevation of cell of value 1 were computed, then cell of value 2, and so on until 30 buffer cells for all no data areas were closed using this morphology closing operation. Therefore, all holes less than 41 x 41 pixels were filled in the mosaicked images.

Table 6-1 lists multiple lidar surveys used to develop the seamless DEM of the entire Texas coast. The las files in each survey were gridded separately and were combined to get the final seamless DEM. To make a smooth surface along the edges of lidar surveys so that there were no sharp edges between the surveys, a similar method used to fill no data holes was used by considering a buffer of 10 pixels instead of 50 pixels used for the hole filling. However, if multiple surveys were available and there was an overlap along the edges, a weighted average method was used to compute the elevation for 10 cells along the edges. Once these smooth gaps-filled raster tiles were generated, they were mosaicked together to obtain final seamless DEM of the Texas coast.

Table 6-1 List and description of lidar surveys used to develop bare-earth topographic surface of Texas

Name	Published Date	Originator	UTM
Texas Coastal Lidar Mapping Project (Upper Coast Lidar)	2018/04/08	TWDB	15
Texas Coastal Lidar Mapping Project (Jefferson, Liberty, & Chambers Counties Lidar)	2017/04/20	TWDB	15
Texas Neches Lidar Project	2017/11/21	USGS	15
2015 Matagorda Bay Topographic Lidar	2016/11/09	UT-BEG	15
South Texas Lidar	2019/04/29	USGS	14
2010-2011 ARRA Lidar: Calhoun, Nueces, Willacy, & Hidalgo Counties Lidar	2011/01/01	USGS	14
Texas Coastal Lidar: Kleberg & Kenedy Counties Lidar	2008/11/01	USGS	14
Matagorda Bay Lidar	2019/09/17	USGS	14

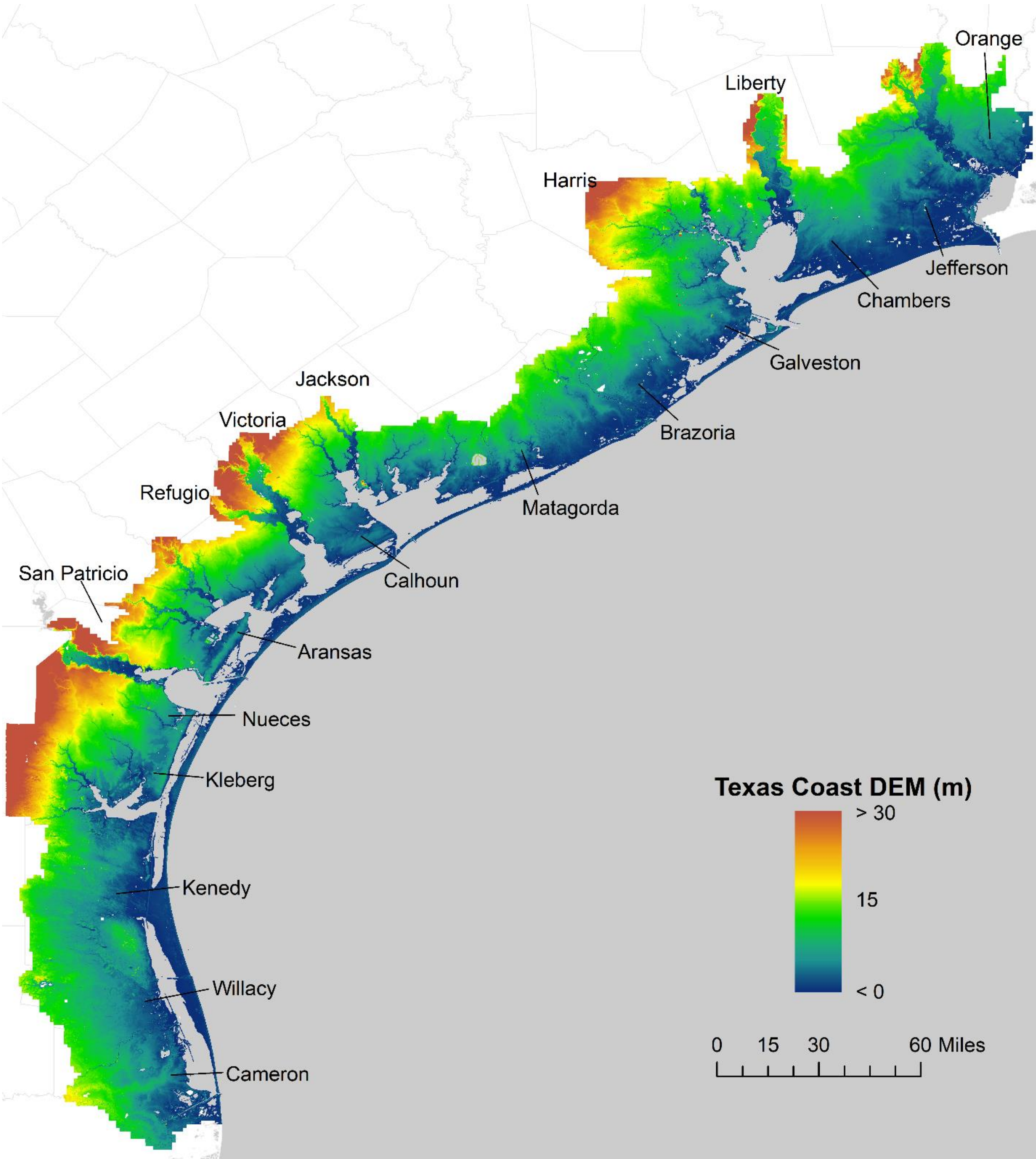


Figure 6-2. Topographic bare-earth DEM of the Texas coast in meter with coastal county labels

Land Cover Inputs

The latest National Wetlands Inventory (NW) dataset for Texas at the time of modeling (U.S. Department of the Interior, Fish and Wildlife Service 2019) was downloaded from the USFWS website. The NWI utilizes the Cowardin classification system, where wetland classes describe generic habitat type more than specific species composition (Cowardin et al. 1979). This dataset was cross-walked from Cowardin codes to the SLAMM land cover classes using the lookup table provided in the SLAMM's supporting documentation. All dry land within the study region that did not have NWI data were assigned the Undeveloped Dry Land classification, since the NWI only describes wetlands and not upland land cover. The NWI, which is provided by USFWS as a shapefile, was then rasterized to a 2m resolution grid to be used in the SLAMM.

To determine where upland areas are developed, the National Land Cover Database percent impervious cover raster was overlayed on top of the land cover raster derived from the NWI. Developed areas are classified where the input land-cover class is Undeveloped Dry Land and percent impervious cover is greater than or equal to 25%.

For the ADCIRC-SWAN models, the Undeveloped Dry Land class needed to be classified as a more specific land cover type to provide a more accurate roughness coefficient. The latest release of the Coastal Change Analysis Program Regional Land Cover and Change raster was downloaded from the NOAA Office for Coastal Management website. This dataset provided upland land cover classes such as forests, grasslands, agricultural lands, and other non-wetland land cover types.

Furthermore, to estimate future development in 2100 as an additional input to the ADCIRC+SWAN models, output from the United States Geological Society's FORE-SCE land cover change projection datasets (Sohl et al. 2014) were added to the 2100 SLAMM land cover outputs wherever SLAMM output predicted undeveloped dry land and the USGS predicted developed dry land in 2100. The USGS model uses IPCC Special Report on Emissions Scenarios (SRES) to predict changes in land cover, with a focus on anthropogenic land use versus natural environments. The SRES storylines modeled by USGS are the A1B, A2, B1, and B2 scenarios. Of the SRES scenarios, "A" represents more economically driven future conditions ("business as usual"), whereas "B" scenarios are representative of more environmentally conscious policies being enacted to reduce carbon emissions over time (Eggleston et al. 2006).

This study used two SLR scenarios for modeling based on Sweet et al. 2017 – Intermediate-Low (0.5m of SLR by 2100) and Intermediate-High (1.5m of SLR by 2100) (more details in SLR Scenario section). The Intermediate-Low scenario used in this Plan was modeled after the B1 emissions scenario (Sweet et al. 2017). The B1 scenario forecasts increasing population and economic growth but with a greater focus on environmental conservation and global cooperation resulting on limited land-use impacts on natural land covers. In the SLAMM 2100 output of Intermediate-Low scenario, the projected future development from the USGS model for B1-2100 was superimposed on top of the SLAMM land cover. The NOAA Intermediate-High scenario, however, is based on the A1F scenario, which the USGS modeling team did not include in their projections. A1F is in the same A1 family as A1B, but A1F represents a fossil fuel intensive future whereas A1B's storyline shows a balance between fossil fuels and renewable energy. Based on this storyline, the closest scenario modeled by USGS is A2 which also shows an increase in reliance on fossil fuels and increasing carbon dioxide emissions into the next century. The planning team decided to use the A2 2100 output superimposed on the 2100 Intermediate-High SLAMM land cover.

Sea Level Rise Scenarios

The average global mean SLR rate was approximately 0.06 inches per year (in/yr) over the past century. However, the rate is accelerating – it has more than doubled throughout most of the twentieth century to 0.14 in/yr from 2006-2015 (Church and White 2011). Because sea level changes unevenly, some communities are at higher risk of being impacted than others. Relative SLR (RSLR) rates are different due to local factors like vertical land motion (subsidence), local wind, atmospheric pressure, and ocean circulation (Mimura 2013). The 367 miles of Texas Gulf coastline has varying RSLR rates ranging from 15 in/100 years in the lower coast to 26 in/100 years in the Galveston Bay region based on the tide gauge data (**Figure 6-3**).

Figure 6-3. Historic RSLR rates on the Texas coast measured by tide gauges

NOAA Technical Report NOS CO-OPS 083 provides a scenario range for possible global mean sea level (GMSL) rise for the 21st century and a set of 1-degree (~70 miles) gridded RSLR projections along the United States coastlines where no gauge data is available (Sweet et al. 2017). The methodology for determining scenarios and rates of both GMSL and RSLR are well documented and based on peer-reviewed, established methods. Additionally, the GMSL scenarios are built from the previous, extensively cited NOAA sea level report (Parris et al. 2012) and emissions pathways (RCPs, Representative Concentration Pathways) from van Vuuren et al. 2011 used in the IPCC Assessment Report 5 (Church et al. 2013) .

To address the impacts of RSLR through the year 2100, the 2019 Plan modeled only one SLR scenario which was an intermediate scenario of 1m of GMSLR by 2100. However, because of the large uncertainties involved in predictions of the contribution of land-based ice melting to the GMSLR, a scenario approach covering a broad range of existing sea level study results is recommended for robust planning decisions.

For this study, a probabilistic range approach was used by modeling intermediate-low and intermediate-high scenarios which are 0.5m and 1.5m of GMSLR by 2100 from (Sweet et al. 2017). The start date for these scenarios is the year 2000. According to (Kopp et al. 2014), under the RCP8.5 emissions scenario there is a 96% chance GMSLR will exceed 0.5m and a 1.3% chance it will exceed 1.5m (**Table 6-3**). These two GMSLR scenarios cover a probable range of possible SLR outcomes without going too low or too high – although there is precedent in other state plans for modeling up to 2m of GMSLR (0.3% chance of exceedance) (see **Table 6-4** and **Table 6-5**). The 2019 TCRMP already modeled a central estimate (1 m of SLR by 2100), so this is a step forward towards identifying areas at risk over multiple scenarios within a highly likely range.

To estimate the long-term contribution of non-climatic processes such as vertical land movement (VLM), tectonics, and sediment compaction to relative sea level change, results from a spatiotemporal statistical model of tide gauge data based upon methods described in Kopp et al., 2014. In this model, the spatiotemporal field of RSL change over 1900–2012 is represented as the sum of three signals: (1) a globally uniform sea level change, (2) a constant-rate average, long-term, regionally varying trend, and (3) temporally and spatially varying regional sea-level contributions. This model is separately fitted to tide gauge data in several different regions. The spatial scales of variability of processes 2 and 3, and the temporal scale of variability of process 3, are learned in each region from the tide gauge data. The globally uniform signal is assumed to match the GMSL signal estimated by Church and White 2011 (~1.4mm/year); the discrepancy among different estimates of this signal likely contributes ~0.2 mm/year uncertainty to estimates of the long-term background RSL trend, which is considered small enough to neglect.

The non-climatic background RSL trend is assumed to continue at a constant rate. This assumption is accurate for isostatic rebound, but likely less so for unsteady processes such as those resulting from tectonic processes and/or anthropogenic disturbances (e.g., subsurface fluid withdrawal), which may increase or decrease over time. Both the regional degree of spatial variability in the background RSL trend and the density of nearby tide gauges affects the magnitude of the standard error during trend computation at the center of each 1-degree grid point.

Non-climactic background RSL from tide gauges and GPS VLM trends were compared and found to be similar. This study assumed background RSLR rate persistence this century, but that assumption could become invalid if, for example, most of the underlying signal stems from anthropogenic-induced VLM, and the driving disturbance ceases at some point in the future. Additionally, larger discrepancies between background RSL and GPS VLM trends occur in regions where rates are high and likely influenced by human activities that have varied through time, such as pumping of groundwater/fossil fuels. This finding leads us into the conclusion that the subsidence rate grid developed by HRI should be used in Region 1, where subsidence is driven by subsurface fluid withdrawal.

Figure 6-4 shows the location of tide gauges and 1-degree grid centers with the RSLR rates along the Texas coast from Sweet et al. 2017. **Figure 6-5** shows the selected two GMSLR scenarios used in this study. The graph shows predicted changes in the sea level from the start date (2000 AD) to the end of this century (2100 AD) based on Sweet et al. 2017. Similarly, **Figure 6-6** - **Figure 6-9** shows the RSLR scenarios calculated based on Sweet et al. 2017 using a set of 1-degree gridded RSLR projections for four regions.

Table 6-2. GMSLR scenarios defined by Sweet et al., 2017

Scenario	Rise by 2100 (m) (Anchored in the year 2000)	Description
Low	0.3	Represents an amount about 5 cm above the extrapolated rate of the GMSL rise trend over the 20th century. Based on 3mm/year GMSL rise rate from altimeters and reconstruction of GMSL from tide gauge data over the last 30 years*
Intermediate-Low	0.5	Discretized 0.5-m increment
Intermediate	1.0	Discretized 0.5-m increment
Intermediate-High	1.5	Discretized 0.5-m increment. Rounded from (Rahmstorf et al., 2007; Horton et al., 2008) (1.2 to 1.4m)
High	2.0	Discretized 0.5-m increment
Extreme	2.5	Potential upper limit of GMSL rise. Increased from 2m in previous report based on updated Greenland & Antarctic ice sheet models showing accelerated loss

Table 6-3. Probability of Exceeding GMSL Scenarios in 2100 (Kopp et al., 2014)

GMSL rise Scenario	RCP2.6 (Strong mitigation, net-negative emissions by 2100)	RCP4.5 (Moderate mitigation, stabilizing emissions by 2050 and declining thereafter)	RCP8.5 (“Business as usual”, fossil-fuel intensive, continue increasing emissions)
Low (.3m)	94%	98%	100%
Intermediate-Low (.5m)	49%	73%	96%
Intermediate (1m)	2%	3%	17%
Intermediate-High (1.5m)	0.4%	0.5%	1.3%
High (2m)	0.1%	0.1%	0.3%
Extreme (2.5m)	0.05%	0.05%	0.1%

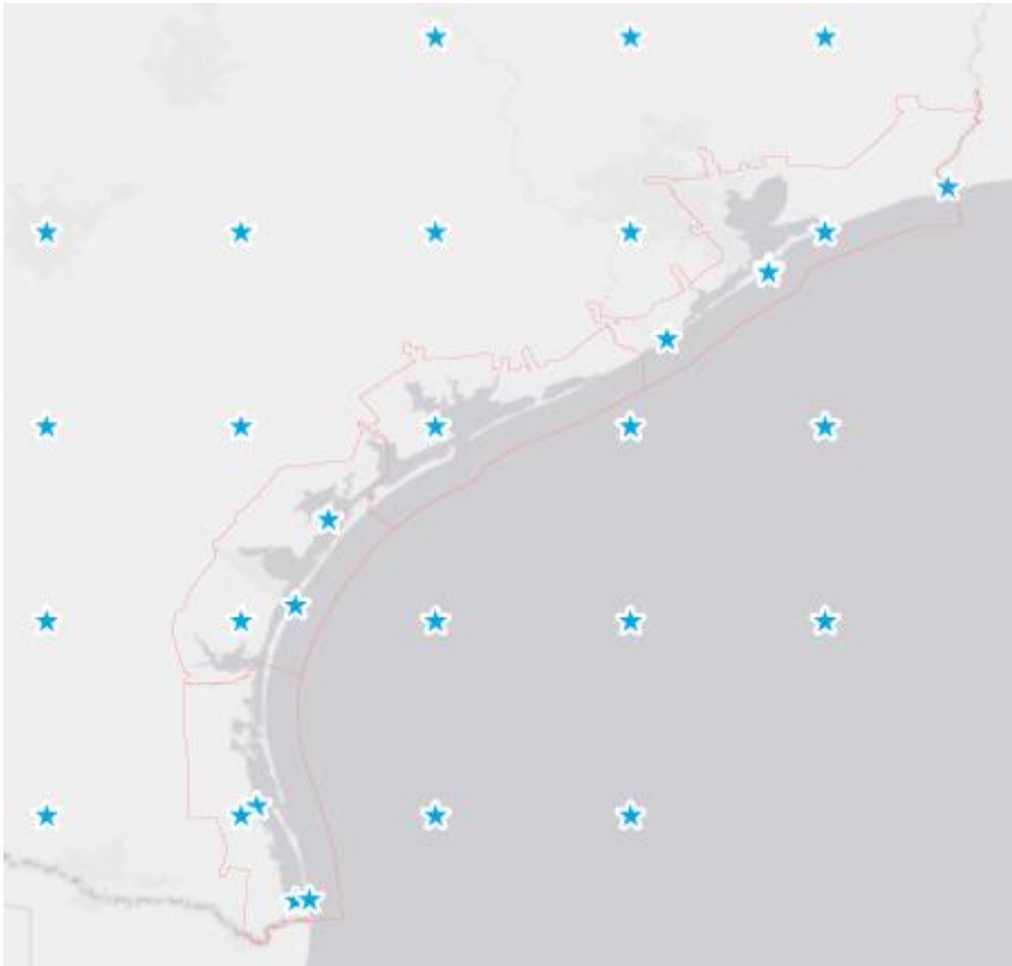


Figure 6-4. Locations of tide gauges and grid centers for NOAA RSLR rates along Texas coast.

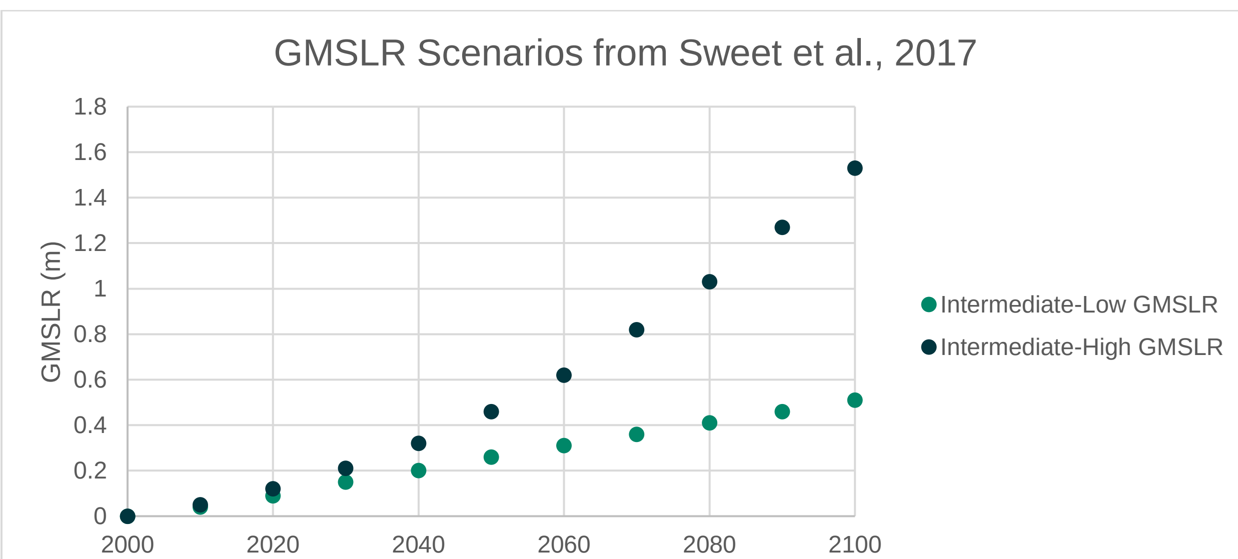


Figure 6-5. GMSLR scenarios used in this study from Sweet et al., 2017

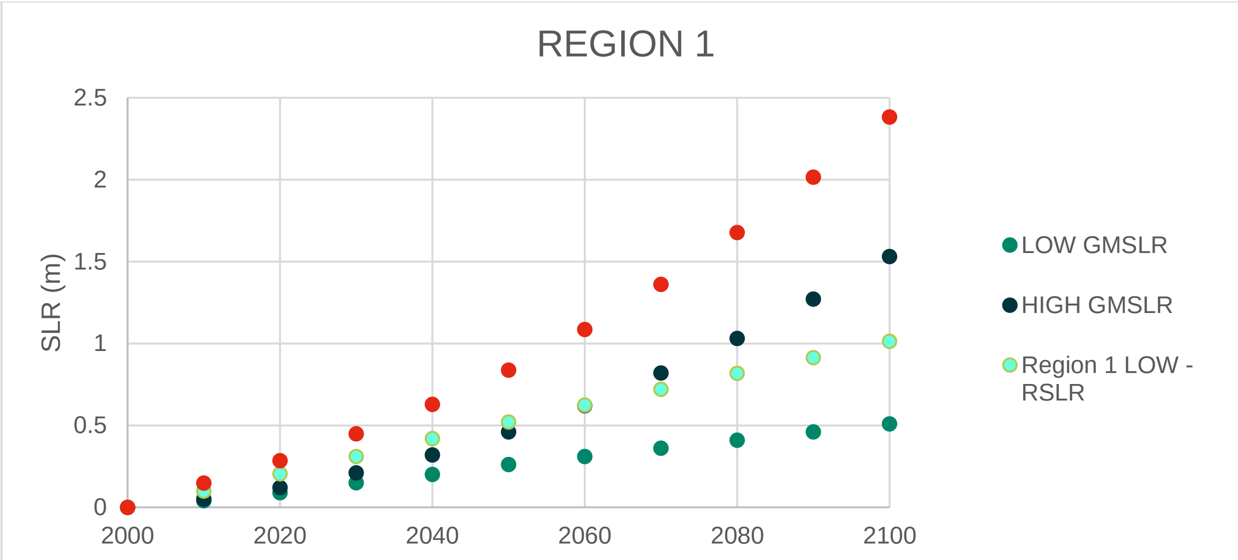


Figure 6-6. RSLR rate curve used in Region 1

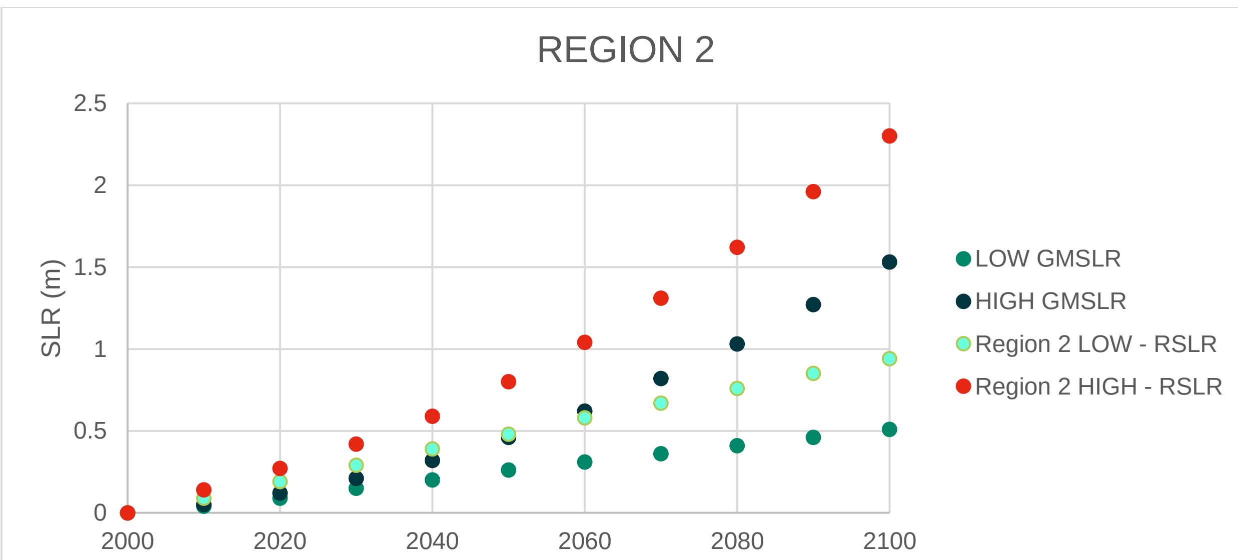


Figure 6-7. RSLR rate curve used in Region 2

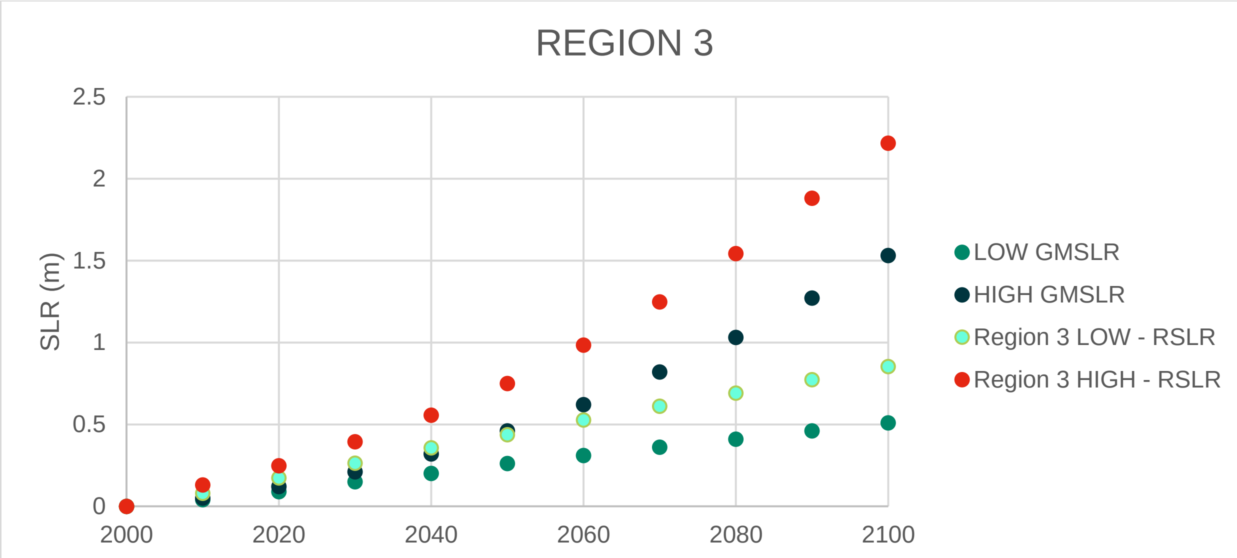


Figure 6-8. RSLR rate curve used in Region 3

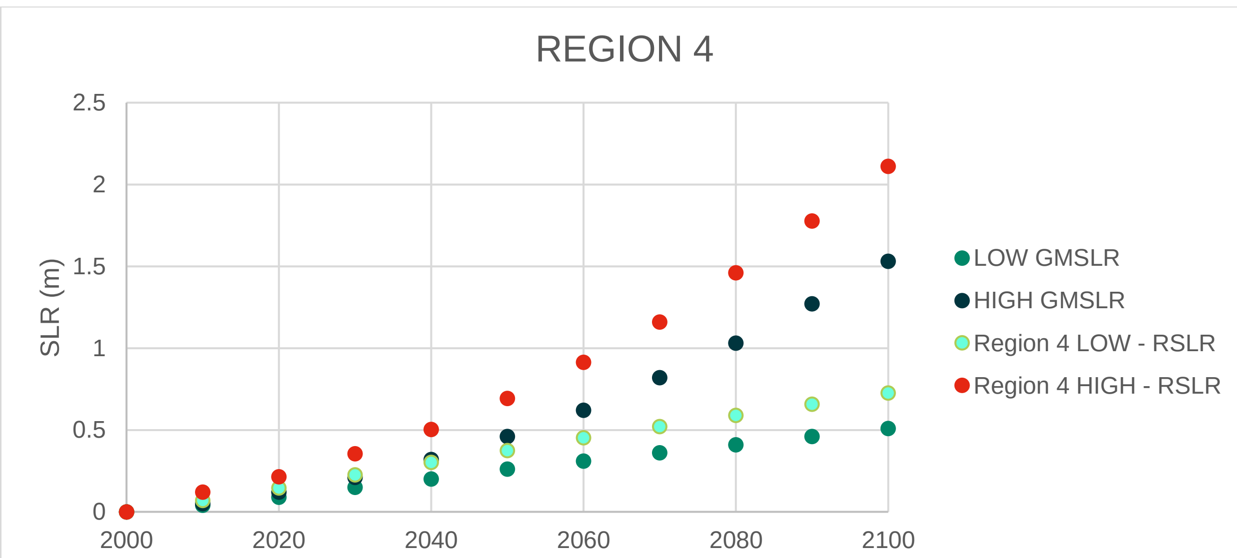


Figure 6-9. RSLR rate curve used in Region 4

Table 6-4. SLR planning scenarios used in Gulf States

State	Scenarios	Scenario sources	Link to Source
Louisiana	0.31m by 2100 1.98m by 2100	Church et al., 2013 Jevrejeva et al., 2012	Louisiana Coastal Master Plan, 2017, CPRA
Alabama	.5m by 2100 1m by 2100 2m by 2100	Sweet et al. , 2017 Intermediate-Low, Intermediate and High scenarios	Alabama State Hazard Mitigation Plan, 2018, State of Alabama

State	Scenarios	Scenario sources	Link to Source
Florida	0.7 - 1 ft by 2100 1.7 - 2 ft by 2100 4 - 4.3 ft by 2100 5 - 5.3 ft by 2100 6.6 - 7 ft by 2100	USACE Low (2013)/NOAA Low (2012) USACE Intermediate (2013)/NOAA Intermediate Low (2012 NOAA Intermediate High (2012) USACE High (2013) NOAA High (2012	Florida Sea Level Scenario Sketch Planning Tool, 2017, University of Florida GeoPlan Center
Mississippi	16.6 inches in twenty years, 41.5 inches in fifty years, and 74.7 inches by the year 2100.	n/a	Assessment of Sea Level Rise in Coastal Mississippi (no longer online), 2011, Mississippi Department of Marine Resources

Table 6-5. SLR planning scenarios used in other States

State	Scenarios	Scenario sources	Link to Source
Rhode Island	1 ft 3 ft 5 ft 7 ft	NOAA	Vulnerability of Municipal Transportation Assets to Sea Level Rise and Storm Surge, 2016, Rhode Island Statewide Planning Program
California	1.6 ft [RCP4.5] 2.5 ft [RCP8.5] 2.4 ft [RCP4.5] 3.4 ft [RCP8.5] 5.7 ft [RCP4.5] 6.9 ft [RCP8.5] 10.2 [Sweet et al., 2017]	Kopp et al., 2014 (used in Sweet 2017) Probabilistic Central Likely 1 in 20 Extreme	State of California Sea Level Rise Guidance, 2018, California Natural Resources Agency
Maryland	3 ft 2.0 to 4.2 ft 5.2 ft 6.9 ft (only listing RCP8.5)	Kopp et al., 2014 Probabilistic Central Likely 1 in 20 1 in 100	Sea Level Rise Projections for Maryland, 2018, University of Maryland Center for Environmental Science (In fulfillment of requirements of the Maryland Commission on Climate Change Act of 2015)

Updates to Storm Surge Modeling

Along with modeling additional SLR scenarios, the 2023 Plan included additional and more varied storm scenarios modeled using ADCIRC+SWAN models versus the 2019 Plan. These additional storms provided better understanding of relative vulnerability of the Texas coastal zone due to storm surge flooding. Nineteen total storms from the USACE synthetic storm suite that pass through different area along the coast were modeled, compared to 6 from 2019. Additionally, while the 2019 Plan only modeled Category 2 storms, the 2023 TCRMP also modeled Category 1 and 3 storms. To be able to compare outcomes with the previous plan, the 6 storms modeled from 2019 were also included in the 2023 effort.

The same computational mesh used in the 2019 Plan, referred to as *TX2008_R35H*, was used for the ADCIRC+SWAN modeling. The mesh has 3,352,598 nodes and 6,675,517 elements, and more than ninety percent of the computational nodes of the mesh reside in the Texas coast. The element size varies from multiple kilometers in the open ocean to resolutions as fine as 15 m in the channels and rivers. The existing bathymetric data in the mesh was not changed for this study, however, topographic data along the Texas coast was updated with the seamless high resolution, 2-m, lidar-based topographic DEM of the Texas coast for the present condition storm surge analysis. The Manning's *n* coefficient values that represent the frictional roughness was updated in the model as in the 2019 TCRMP. Please find more information about the model and methodology to update DEM and Manning's *n* values in Subedee et al. 2019.

Model Storm Selection

This study utilized the hypothetical storms developed by the USACE as the historical storms that have struck the Texas coast do not sufficiently cover the multiple storm conditions along the Texas coast. The USACE storm database has a set of 660 synthetic storms in 88 base tracks. Mostly Category 1 and 2 hurricanes were selected for this study from the database because they have a higher frequency of occurrence (**Figure 6-10**) and most of the coastal population have experienced them or can easily imagine themselves being impacted in their lifetime. Three Category 3 hurricanes that pass near to three major city centers in the Texas coast were also selected.

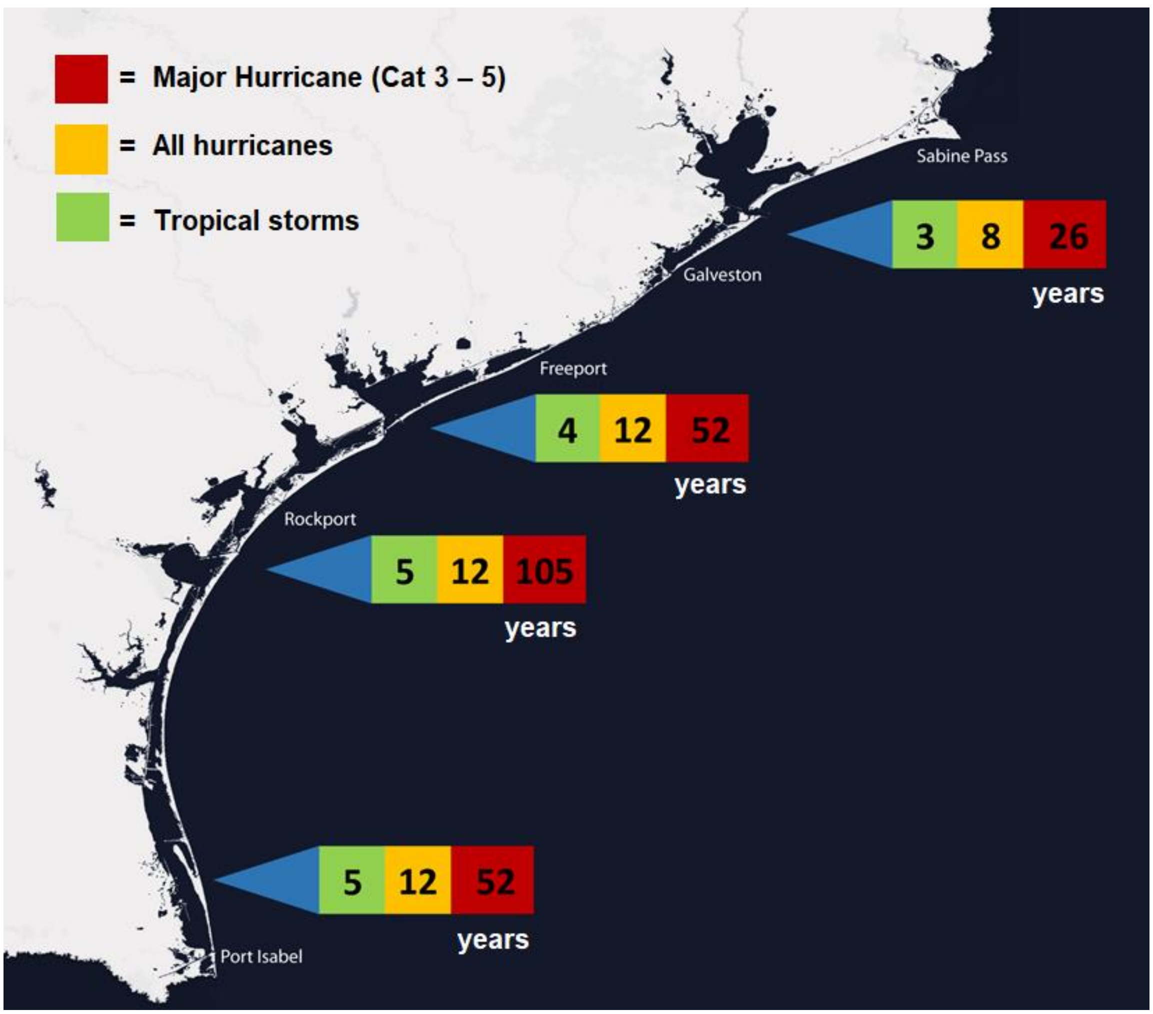


Figure 6-10. Frequency of tropical storms and hurricanes striking the Texas coast, 1901-2005, based on Keim et al. 2007

The following methodology was used to select storms for this study from a set of 660 synthetic storms:

1. Identified five city centers along the coast and also included Matagorda Bay region in Region 2:
    - Beaumont/Sabine Pass
    - Houston-Galveston
    - Freeport
    - Corpus Christi
    - South Padre Island
    - Port O'Connor/Port Lavaca (Matagorda Bay region)
2. Chose reference points which are the entrance channel of the adjacent major bay system in these six locations except for South Padre Island (see **Figure 6-11**)
    - Sabine Pass
    - Houston Ship Channel
    - Freeport Channel
    - Corpus Christi Ship Channel
    - South Padre Island
    - Matagorda Ship Channel
3. Selected storms that pass through 80 miles south of the US-Mexico border and 34 miles east of Texas-Louisiana border
4. Calculated the linear distance between the reference point and the storm landfall point
5. Calculated a non-dimensional comparative value: (distance between reference point and landfall point)/storm radius of maximum wind (RMW) at landfall
6. Prioritized the storms with distance between 1 and 2.5 times the RMW away from the reference point
7. Selected only Cat 1, 2 and 3 storms at landfall that pass southeast of the reference points, and ignored all storms that made landfall twice

From the analysis considering all the above-mentioned criteria, a total of 128 storms are selected (**Table**) which are individually screened by their characteristics (wind speed, forward speed, central pressure, RMW, track orientation, etc.) to narrow down to 19 storms. Finally, nineteen total storms including same six storms from the 2019 TCRMP were selected. Among these 19 storms, 6 are Category 1 hurricane, 10 are Category 2 hurricane and 3 are Category 3 hurricane (**Figure 6-12**, **Table**). **Figure 6-13** shows the RMW buffer of each storm at landfall. The color of each RMW buffer circle corresponds to the Saffir-Simpson hurricane wind scale. Most of the coast was impacted with the selected ten Category 2 storms as can be seen with the yellow buffer circles in the map.

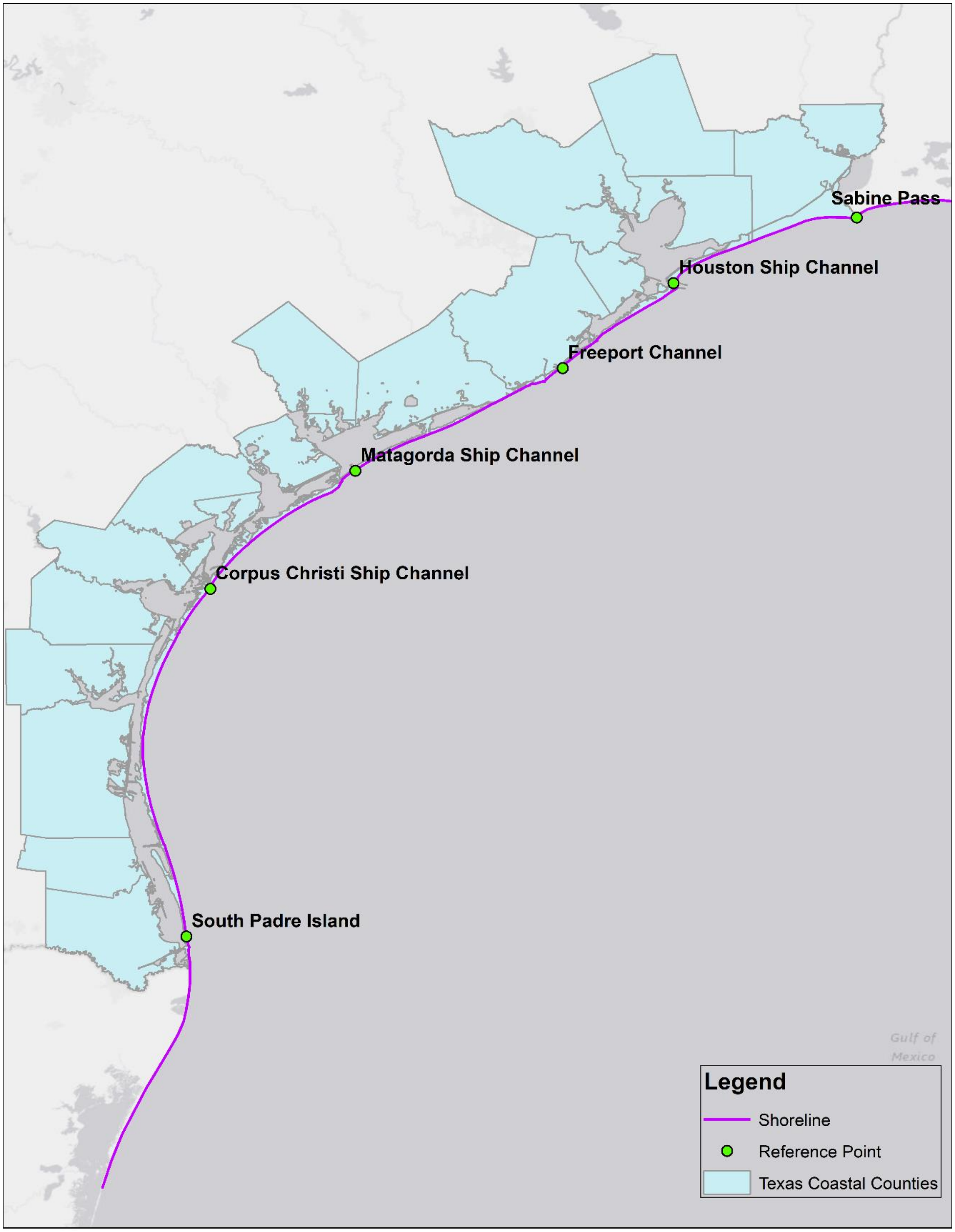


Figure 6-11. Selected reference points along the Texas coast and extended shoreline for the analysis south of the US-Mexico border and east of TX-LA border

Table 6-6. Selected storms in each city centers considering all 7 criteria

	Category 1	Category 2	Category 3	Total Storm
Beaumont/Sabine Pass	8	10	12	30
Houston-Galveston	6	4	11	21
Freeport	8	9	7	24
Port O'Connor/Port Lavaca	3	4	7	14
Corpus Christi	10	5	13	28
South Padre Island	4	2	5	11

Table 6-7. Selected storms and their characteristics (the yellow highlighted storms were used in the 2019 TCRMP)

Candidate Storm	Region	Wind Speed (kt)	Saffir–Simpson scale	RMW (Nmi)	Forward Speed (kt)	Distance from Reference Point (mile)	Central Pressure (mb)	Heading (deg)	Total Hour	Time Step (min)
TC_JPM0305	4	101.3	3	9.89	6.8	17	905.2	-40	282	15
TC_JPM0206	4	83.4	2	31.19	13.4	5.5 (N)	921.3	-60	222	5
TC_JPM0400	4	79.44	1	32.71	13.6	75	933.7	-20	222	5
TC_JPM0222	3	96.68	3	18.98	8.4	29	921.3	-60	282	15
TC_JPM0322	3	86.77	2	30.28	4.6	21	940.4	-40	312	15
TC_JPM0214	3	76.44	1	35.06	4.6	67	921.3	-60	312	15
TC_JPM0416	3	87	2	16.86	11	26.5	933.7	-20	252	5
TC_JPM0328	2	95	2	15.12	10.4	42	927.3	-40	252	5
TC_JPM0240	2	84.61	2	23.26	17.7	14	947.7	-60	162	5
TC_JPM0587	1A	96.55	3	17.33	7.9	26	910.2	20	282	15
TC_JPM0262	1A	84.21	2	22.86	5.9	6	921.3	-60	312	15
TC_JPM0358	1A	86.91	2	10.08	9.5	13	955.4	-40	252	15
TC_JPM0524	1A	81.35	1	23.58	13.1	7	940.4	0	222	5
TC_JPM0449	1A	74.67	1	34.9	19.5	47	947.7	-20	132	5
TC_JPM0146	1A	83.83	2	34.89	18.3	42	927.3	-80	162	5
TC_JPM0154	1A	87.77	2	34.71	10.3	31	940.4	-80	252	5
TC_JPM0160	1B	86.99	2	7.29	8.6	41	927.3	-80	282	15
TC_JPM0363	1B	76.84	1	20.17	6.2	36	927.3	-40	312	15
TC_JPM0466	1B	63.14	1	37.33	6.5	33	963.7	-20	282	15

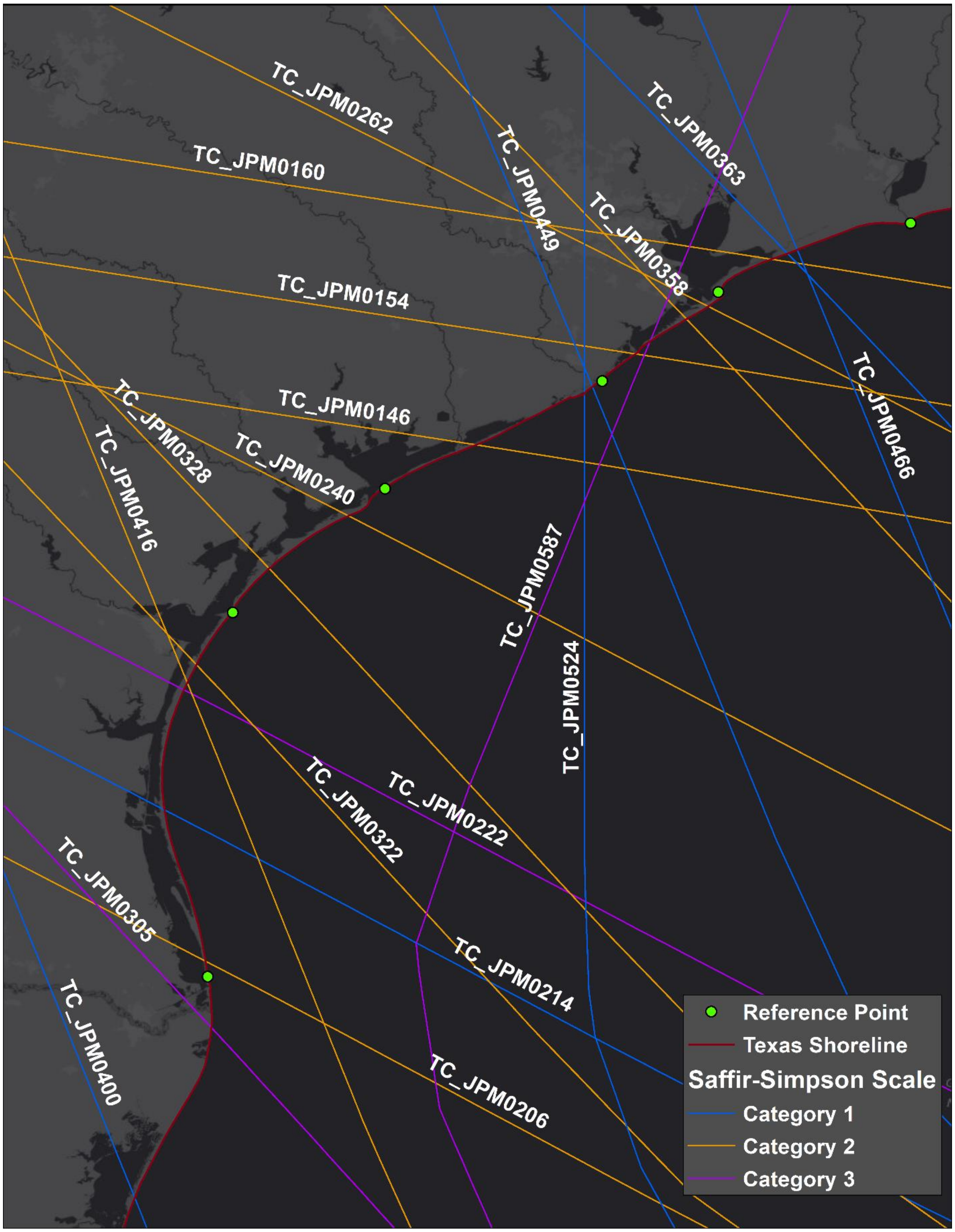


Figure 6-12. Storm tracks of total 19 storms selected. The reference points are the six city centers chosen for the storm selection process

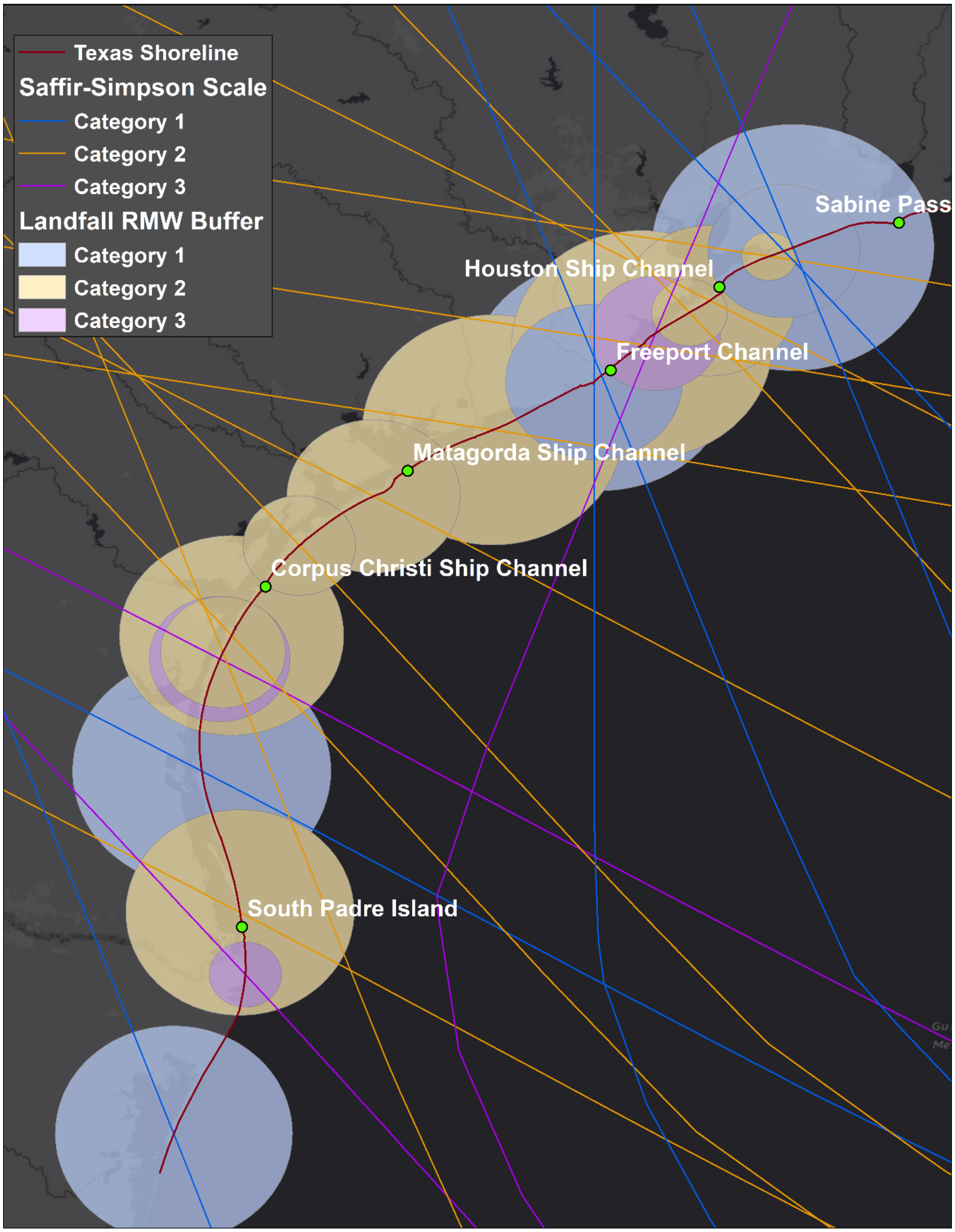


Figure 6-13. Storm tracks of 19 selected storms and the RMW buffer of each storm at landfall. The color of each RMW circles corresponds to the Saffir-Simpson hurricane wind scale

Resiliency Projects Modeling

The 2023 Plan also assessed how the implementation of conceptual coastal resiliency projects could mitigate negative impacts of RSLR and future storm surge. So, this study ran simulations of a select number of storms on future landscapes with ("with-project") and without ("no action") certain conceptual coastal resiliency projects, to determine the potential benefits of these projects on storm damage. The modeled projects include island restoration, breakwaters and living shorelines, as well as habitat restoration and conservation projects. These project types were chosen because they could be representative of large-scale sediment planning proposed by many of the 2023 Tier 1 projects, but they are not intended to directly represent the Tier 1 projects in this 2023 Plan. A detailed description of the “with-project” modeling scenarios is included in **Section 6.5** below.

The same storms were modeled over the conceptual “with-project” scenarios that were used for predicting landscape change to determine the benefits of these projects on future storms. The conceptual projects modeled for the 2023 Plan have more focus on reducing wave energy either directly through breakwaters and living shorelines or indirectly through habitat restoration and conservation as buffers to storm impacts. Reducing wave energy in turn reduces damages from storm surge and vulnerability to shoreline and habitat erosion.

Two bay environments, Sabine Lake and Corpus Christi Bay, were selected for the storm surge modeling to determine the potential benefits of various projects on storm damage in the intermediate-low SLR scenario. These two regions were chosen because they have different risk profiles and represent different vulnerability realities. The TAC identified Region 1 as being especially vulnerable to coastal storms and inland flooding, and so the projects modeled around Sabine Lake were primarily focused on reducing wave energy and the extent of storm surge penetration. The projects modeled here consist of marsh conservation projects and restoring the islands near Old River Cove and Pleasure Island as shown in Figure 6-14**.**

Similarly, the TAC identified the top vulnerabilities in Region 3 as habitat loss and bay shoreline erosion, so the projects modeled around Corpus Christi Bay were mainly focused on conserving habitat and stabilizing shorelines. Three large-scale coastal restoration projects - Beneficial Use of Dredge Material (BUDM), two living shoreline projects and two shoreline armoring projects were modeled in this region as shown in **Figure 6-15**.

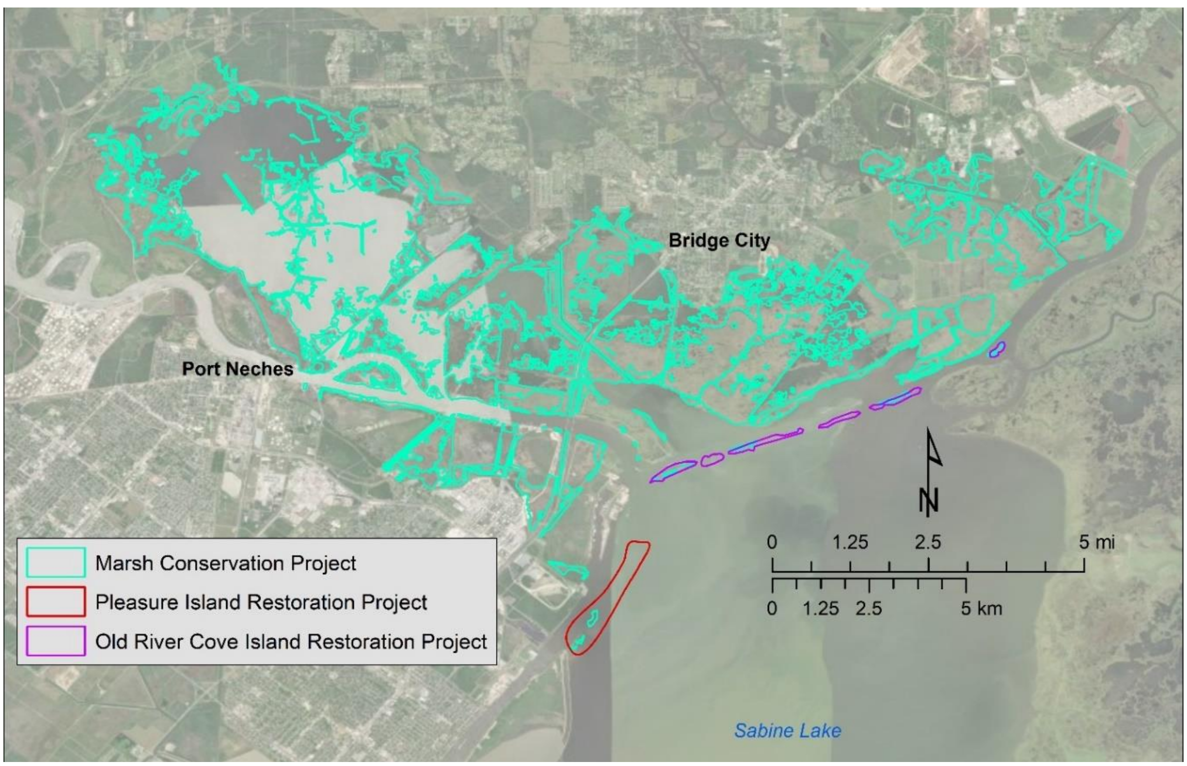


Figure 6-14. Location of modeled resiliency projects in Region 1 for the with-project modeling.

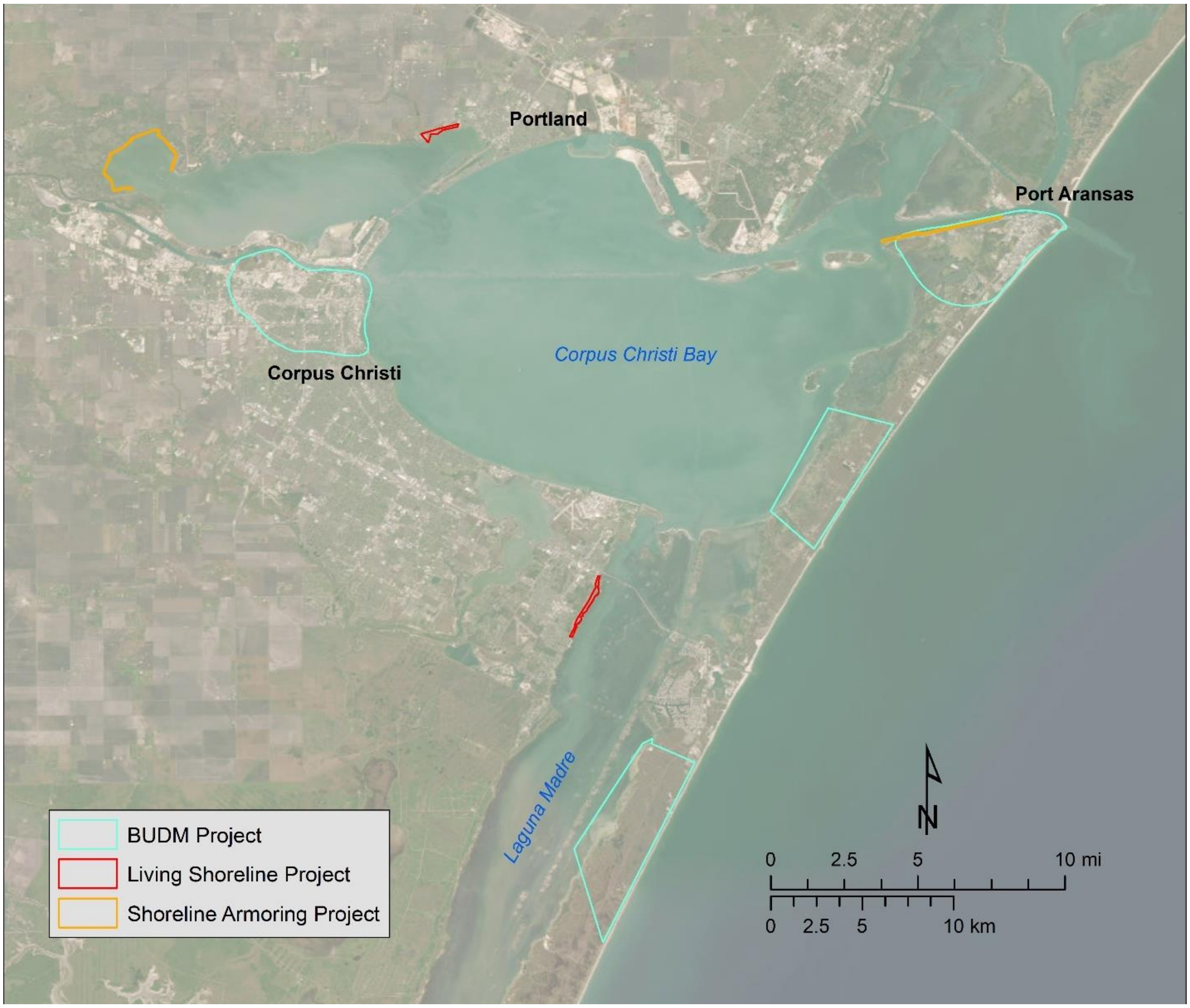


Figure 6-15. Location of modeled resiliency projects in Region 3 for the with-project modeling.

The results from the landscape change modeling done in these marsh conservation, island restoration, and BUDM-type resiliency projects were integrated into the storm surge and wave model. The updated future land cover obtained from the landscape change modeling in these project sites was inputted into the ADCIRC+SWAN model for the "with-project" modeling. Similarly, the shoreline armoring project in Region 3 was implemented by updating the 2100 DEM, which was incorporated into ADCIRC+SWAN modeling by updating the mesh file.

The same post-processing steps used for the future condition storm surge modeling were performed to obtain inputs for the "with-project" modeling. The Manning's *n* values of the land cover within the project area where the SLAMM modeling was done were updated in the future condition Manning's *n* file. This updated Manning's n file was interpolated to the ADCIRC nodal attribute file (fort.13) to model storm surge under 2100 conditions with the resiliency projects. Similarly, the topographic surfaces predicted by the SLAMM model within the project sites were updated in the future condition ADCIRC mesh file prepared for the future condition storm surge modeling. Two Category 2 storms that made landfall in the vicinity of these selected project locations were selected for the storm surge and wave modeling. Storm 160 was selected for Region 1, and Storm 416 was selected for Region 3. **Figure 6-16** shows the 2100 land cover after combining the C-CAP data and 2100 USGS land cover data around the selected resiliency projects in Region 1A, and Manning's n value based on the combined land covers.

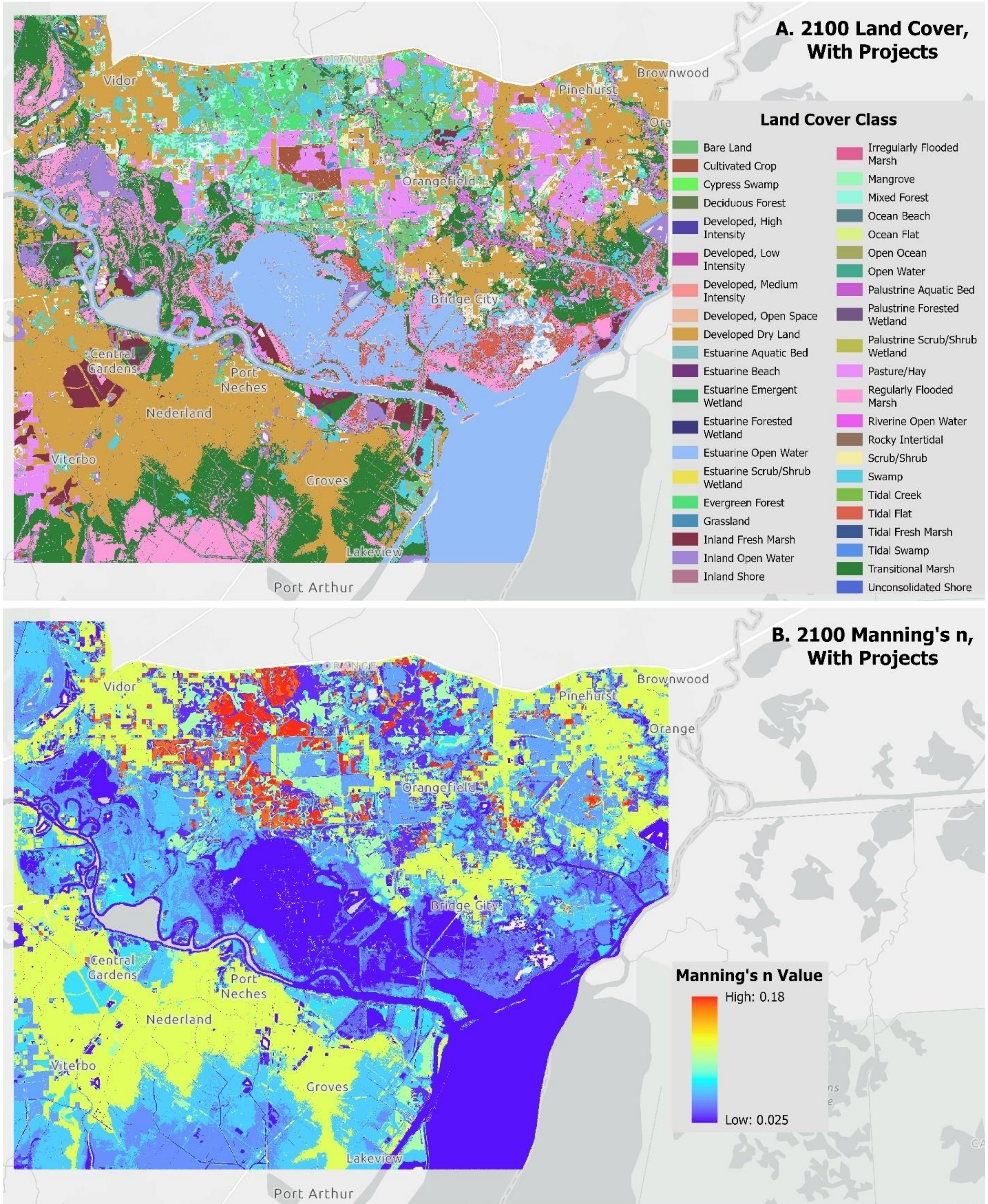


Figure 6-16. Map showing (A) The 2100 land cover "with-project" scenario around the selected resiliency projects in Region 1A with added C-CAP data and 2100 USGS model output, and (B) The 2100 Manning's n values for the 2100 "with-project" land cover classes used for input into the future condition storm surge and wave modeling.

6.2.3 Geohazards Mapping

The geohazards map is a synthesis of all the modeling work done for the TCRMP in one product as a map. It describes the effect of ongoing geological processes including relative sea-level rise (RSLR), erosion, historic washover locations, storm surge inundation, and future evolution of critical environments including wetlands, dunes, and beaches in response to RSLR and storm surge in the next 80 years. The map helps inform planners, decision-makers, and the public about the challenges and limitations of living on the coastal plain. The geohazards map also provides a picture of how the Texas coastal plain may look in the next 80 years in response to the effects of coastal hazards.

The geohazards maps show both the present hazardous areas and information about the future spatial location of critical coastal environments. They are different than coastal flood maps as they not only delineate hazardous areas but also provide a holistic understanding of how the coastal plain may look in the future, thus allowing the identification of critical areas to avoid or preserve. They also provide important information for developing resiliency and adaptation strategies for RSLR and storm surge inundation on the Texas coastal plain.

The geohazards map was developed with a detailed mapping of the different geo-environments currently present on the Texas coastal plain as well as modeling the future evolution of critical coastal environments along the Texas coast. It also incorporates the impacts of both present storm surge and enhanced storm surge caused by higher sea levels and changes in land cover in the future along the coastal plain. Several map-based inputs resulting in a comprehensive geo-environment spatial inventory were used to create the geohazards map that shows the relative susceptibility to negative impacts on the natural and built environments along the coast.

Development of the Geohazards Map

In response to the need for guiding development toward safer areas from the most populated barrier islands on the Texas coast, HRI developed a series of geohazards maps for three barrier islands: Galveston, Mustang and North Padre, and South Padre Islands in the past. A similar but an improved approach was taken to develop the geohazards map of the whole Texas coastal plain. These maps show hazardous areas coupled with information about the future spatial distribution of critical environments. These maps aid the assessment of an area's resilience by displaying where assets are subject to geohazards. The geohazards map was developed by combining multiple data layers through data development and modeling. Two sets of geohazards maps were developed for two sea-level rise scenarios modeled – Intermediate Low (0.5m of GSLR by 2100) and Intermediate High (1.5m of GSLR by 2100).

An SLR transition model (SLAMM) and an integrated wave and circulation model (SWAN+ADCIRC) were used to assess the vulnerabilities to RSLR and associated enhanced storm surge caused by higher sea levels and changes in land cover in the year 2100. Details of these modeling are presented earlier in this report and Subedee et al. 2019. By incorporating detailed lidar DEMs, the latest land-cover dataset, and geomorphic analyses in these models, a series of maps of the current and future distribution of critical geo-environments were developed and their hazardous potential related to RSLR, storm surge, and erosion are ranked. The six geohazard potentials in the map are based on this ranking which are described in the following section.

Storm Surge Vulnerability Mapping

The low-lying and gently sloping Texas coastal plain is highly vulnerable to storm surge and waves caused by hurricanes. Storm surge is also one of the top vulnerabilities listed by the TAC members who provide critical input throughout the entire planning process. Furthermore, the storm surge risk assessment provides the basis for risk mitigation and related decision-making for adaptation and resilience. Therefore, it is both sensible and imperative to incorporate exposure to the risks of storm surge and waves in the geohazards mapping.

A storm surge vulnerability map was developed by considering simulated storm surge inundation due to nineteen storms modeled. These selected storms of varied characteristics pass throughout the Texas coast and provide good coverage along the coast as shown by their RMW in **Figure 6-13**. **Table** summarizes the storm characteristics for each of the selected storms and **Figure 6-12** shows the storm tracks. A total of 57 ADCIRC+SWAN model simulations were forced using meteorological wind and pressure fields for each of the nineteen hurricane events. The nineteen hurricane events were simulated on the present landscape, and again on the two future 2100 landscapes - Intermediate Low (0.5m of GSLR by 2100) and Intermediate High (1.5m of GSLR by 2100). The maximum water surface elevation (MAXELE) was derived for each storm simulation and analyzed along the whole Texas coast which resulted in 57 MAXELE scenarios.

In order to calculate the storm surge vulnerability score along the Texas coast using these 57 scenarios, each node in the computational mesh is examined to find out how many times it is inundated in the 57 scenarios. It is then divided by the total 57 scenarios considered to obtain the storm surge vulnerability normalized index of the range 0 - 1, where a value of 1 means an area is inundated in all 57 scenarios, and 0 means it is not inundated in any scenarios. Once the index value in the range of 0 – 1 is assigned to each node in the computational mesh, a storm surge normalized vulnerability index raster was generated using Kernel Smoothing interpolation. The interpolation was done by breaking down the Texas coast into multiple regions to get better interpolation results. For Kernel Smoothing, the fifth-order polynomial function was used as a kernel function.

The Geohazards Maps

The geohazards map presents a synthesis of datasets developed through various modeling and the latest datasets obtained from multiple sources. It incorporates the topographic DEMs developed using the latest lidar surveys, future land cover data modeled by applying SLAMM, a storm surge vulnerability map developed by modeling multiple storms under three sea-level scenarios, and various publicly available datasets. It not only shows areas that are presently exposed to hazardous conditions that might be generally protected by regulations but also shows areas that are not protected and should receive special management consideration. It also shows the vulnerable infrastructure that will be exposed to hazardous conditions in the future and requires special attention if progress is to be made in how we live with RSLR. The geohazards map shows six geohazard potential categories: Extreme, Imminent, Future Flooding, High, Moderate, and Low.

The presently vulnerable habitats that will be open water in the future and historic storm washover channels were designated as **Extreme** geohazard potential areas. The future open water layer used in the Extreme category is based on the SLAMM modeling results. **Imminent** geohazard potential areas include the presently critical environments such as freshwater wetlands, transitional wetlands, regularly flooded estuarine wetlands, tidal flats, and beach/foredune systems. These areas are designated based on the latest NWI dataset. Areas of present development and road that are expected to flood due to SLR in the future are designated as a **Future Flooding** geohazard potential. The present development for this category was based on the 2019 NLCD dataset where classes 21 - 24 represent the different types of development, and the present road network was based on the latest road layer by the TxDOT.

The presently upland areas projected to become critical environments in the future due to SLR are designated as **High** geohazard potential areas and are based on the SLAMM modeling results. Areas designated as having **Moderate** geohazard potential are uplands that are neither currently nor expected to become critical environments in the future. Furthermore, these areas are prone to storm surge flooding causing them to be inundated during a storm event with a storm surge normalized vulnerability index value greater than 0.5. Finally, the remaining upland areas that are less susceptible to geohazards are designated as having a **Low** geohazard potential as they are inland at higher elevation or interior location to the island. These areas have a storm surge normalized vulnerability index value of less than 0.5. Therefore, the Moderate and Low geohazard potential areas were differentiated based on the storm surge normalized vulnerability index value considering 0.5 as a cutoff value. A value of 0.5means an area is inundated by at least half of the total 57 storm scenarios considered.

6.3 Results

6.3.1 Sea Level Rise Modeling

This section presents the results from the SLR modeling part of the study. Firstly, the study examines the entire Texas coast, comparing the 2100 land cover outputs in both intermediate-low and intermediate-high SLR scenarios to the initial conditions in the form of maps, graphs, and tables.

Subsequently, a more detailed approach is taken for each of the four regions, providing information on the vulnerability that each region faces as the sea level rises, altering the landscape into the future. The analysis offers insights on how the projected changes are likely to affect the region's environment, and community, highlighting the potential risks that may arise from SLR.

SLAMM includes 21 different land cover classes which are condensed into 6 classes for this analysis. **Table** shows what classes are aggregated for this study.

Table 6-8. Aggregation of SLAMM output land cover classes to new classes for change analysis

SLAMM Codes	SLAMM Description	New Code	New Description
1	Developed Dry Land	1	Developed Dry Land
2	Undeveloped Dry Land	2	Undeveloped Dry Land
3, 4, 5	Non-tidal Swamp, Cypress Swamp, Inland-Fresh Marsh	3	Freshwater, non-tidal
6, 7, 8, 9, 20, 23	Tidal-Fresh Marsh, Trans. Salt Marsh, Regularly-Flooded Marsh, Mangrove, Irreg.-Flooded Marsh, Tidal Swamp	4	Saltwater and Brackish tidal marshes
12, 22, 10, 11, 13, 14	Ocean Beach, Inland Shore, Estuarine Beach, Tidal Flat, Rocky Intertidal, Ocean flat	5	Beaches and flats
15, 16, 17, 19	Inland Open Water, Riverine Tidal, Estuarine Open Water, Tidal Creek, Open Ocean	6	Open water

Coastwide

The Texas coast is predicted to experience significant effects from SLR, which will vastly alter the landscape by 2100. **Figure 6-17** shows the current and future landscapes in 2100 under intermediate-low and intermediate-high SLR scenarios, while Figure 6-18 shows the areal changes in square miles by land cover type. **Figure 6-19** and **Figure 6-21** depict individual losses and gains of freshwater and saltwater marsh, and open water in the intermediate-low scenario, and **Figure 6-20** and **Figure 6-22** do the same in the intermediate-high scenario. With both 0.5meters and 1.5meters of SLR, combined with varying subsidence/uplift rates along the coast by 2100, a significant decrease in the amount of inland-fresh marshes and swamps is observed. Slightly more than 60% of their initial area is predicted to remain by the year 2100 in the intermediate-low scenario, and less than 27% of their initial area is predicted to remain by the year 2100 in the intermediate-high scenario (**Table**). The model suggests that these habitats will transition to transitional scrub-shrub wetlands, regularly flooded marsh, or tidal flats. Almost all saltwater and brackish marshes seen along the Texas coast are expected to be affected by SLR, with both loss through inundation and gain by upward migration. The lost low marsh area is likely to be converted to tidal flat or open water, while salt and brackish marshes will migrate landwards if migration space is available, contributing to a net gain of 86% by 2100 in the intermediate-low scenario and 82% in the intermediate-high scenario.

In addition to impacts on the natural environment, a substantial amount of developed land is also projected to be inundated by 2100 in both scenarios. A total of 108 square miles of developed land along the coast is expected to be impacted by 0.5meters of SLR, and the number is predicted to increase to 145 square miles with 1.5 meters of SLR. The majority of these areas at risk are low-lying coastal communities and critical infrastructure, including water treatment and power plants. These vulnerable areas will be discussed in subsequent sections.

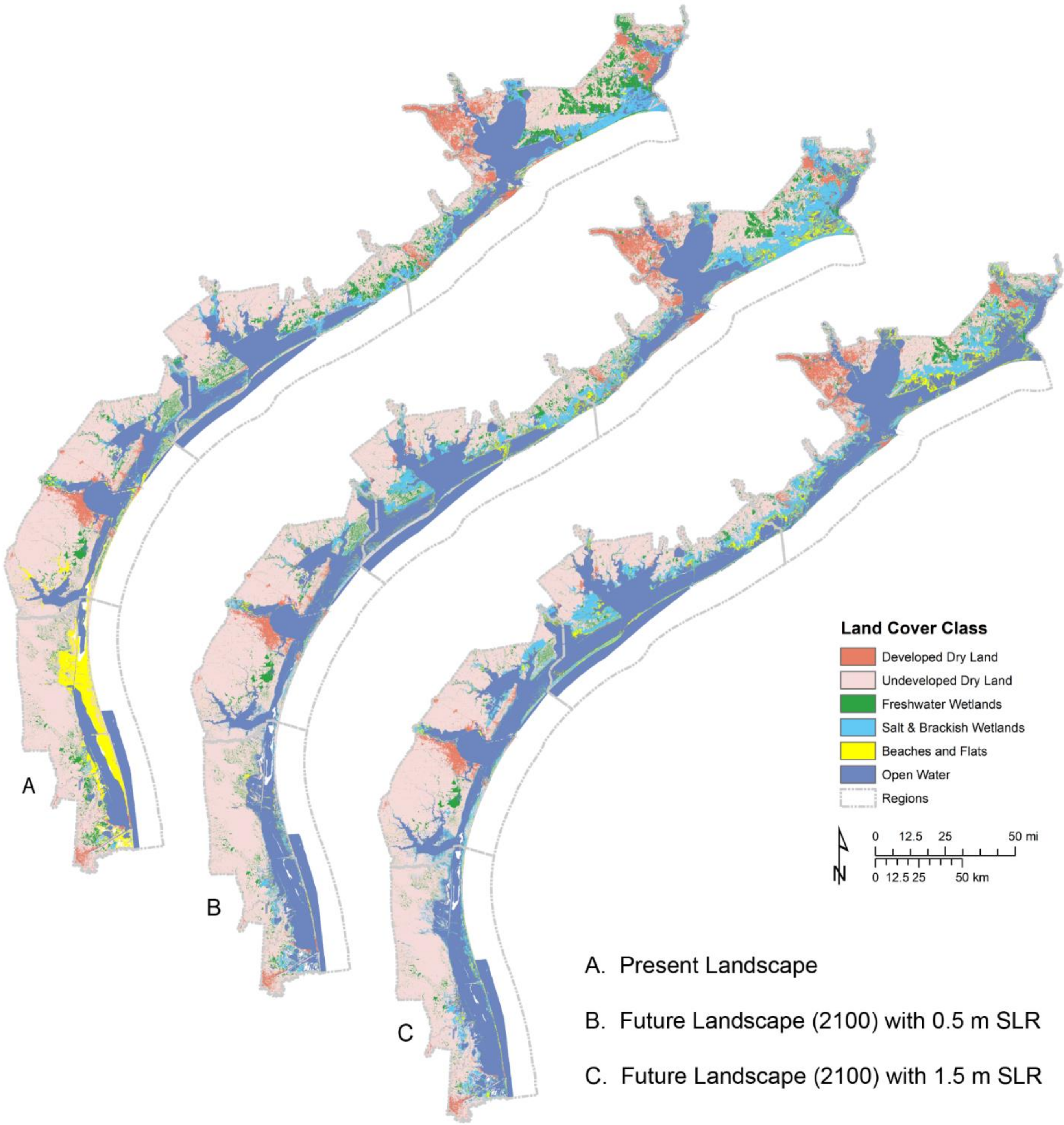


Figure 6-17. Comparison of Present Landscape and future landscapes along the Texas coast. (A) Present Condition (2019) land cover data used by SLAMM. (B) Future Condition with 0.5m SLR in 2100 land cover output from SLAMM. (C) Future Condition with 1.5m SLR in 2100 land cover output from SLAMM.

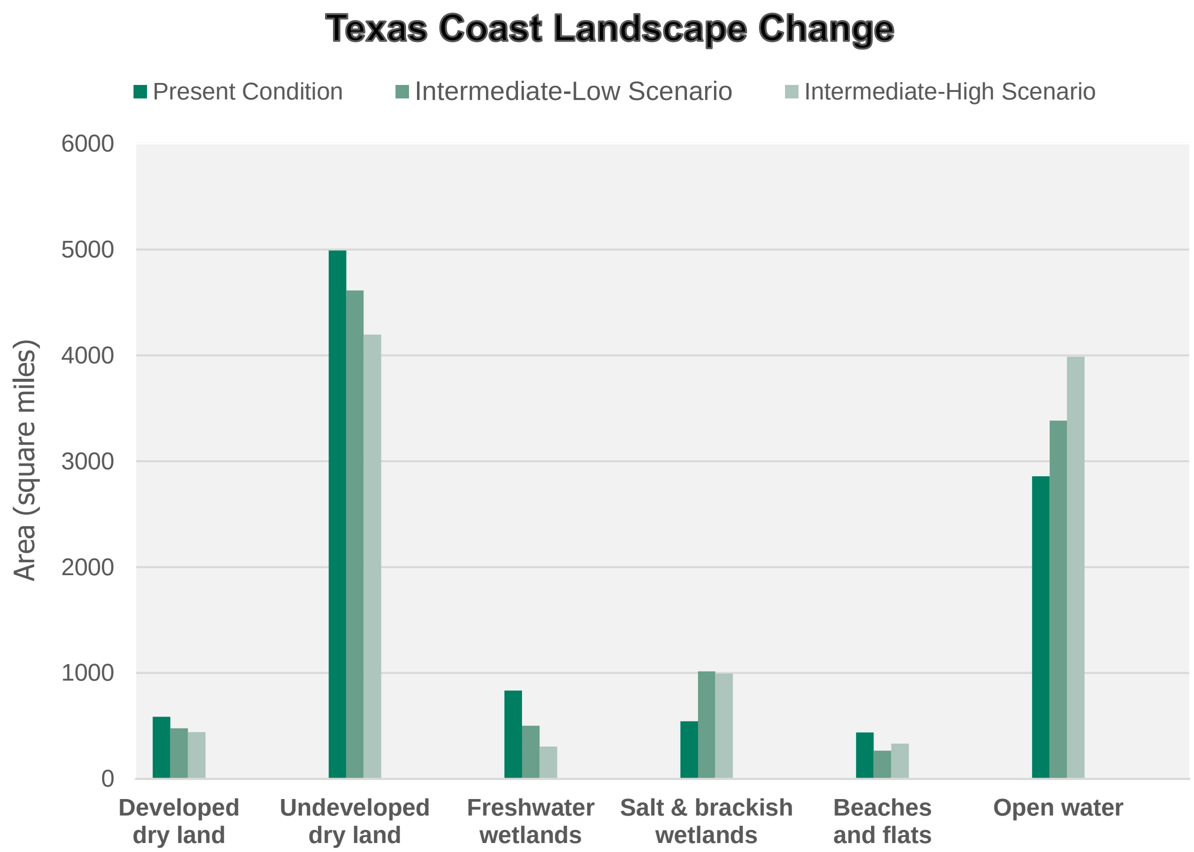


Figure 6-18. Areal changes (in square miles) of individual land cover types between Present Condition and Future Conditions along the Texas coast.

Table 6-9. Areal and percent difference of each land cover type between Present Condition (2019) and two Future Conditions (2100) along the Texas coast.

Land cover class	2019 (sq. miles)	Intermediate-Low (sq. miles)	% Difference	Intermediate-High (sq. miles)	% Difference
Developed dry land	586.99	479.17	-18.37	442.44	-24.63
Undeveloped dry land	4991.9	4613.78	-7.57	4196.02	-15.94
Freshwater wetlands, non-tidal	834.91	503.36	-39.71	305.95	-63.36
Salt & brackish emergent wetlands, tidal	546.11	1016.76	86.18	994.99	82.20
Beaches and flats	438.01	266.88	-39.07	332.26	-24.14
Open water	2858.2	3385.34	18.44	3987.59	39.51

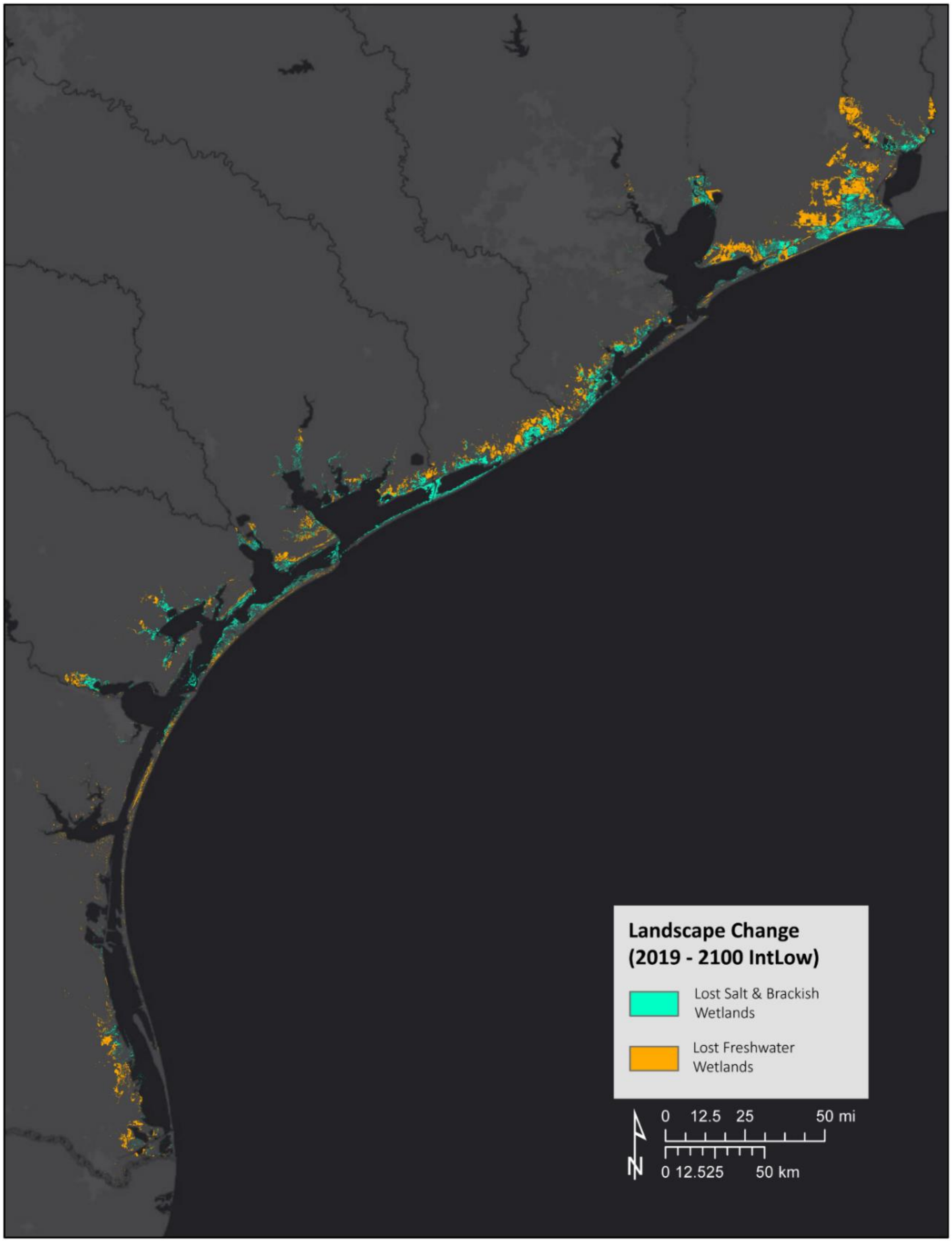


Figure 6-19. Map showing the extent of lost salt and brackish water wetlands and freshwater wetlands by the year 2100 in the intermediate-low SLR scenario.

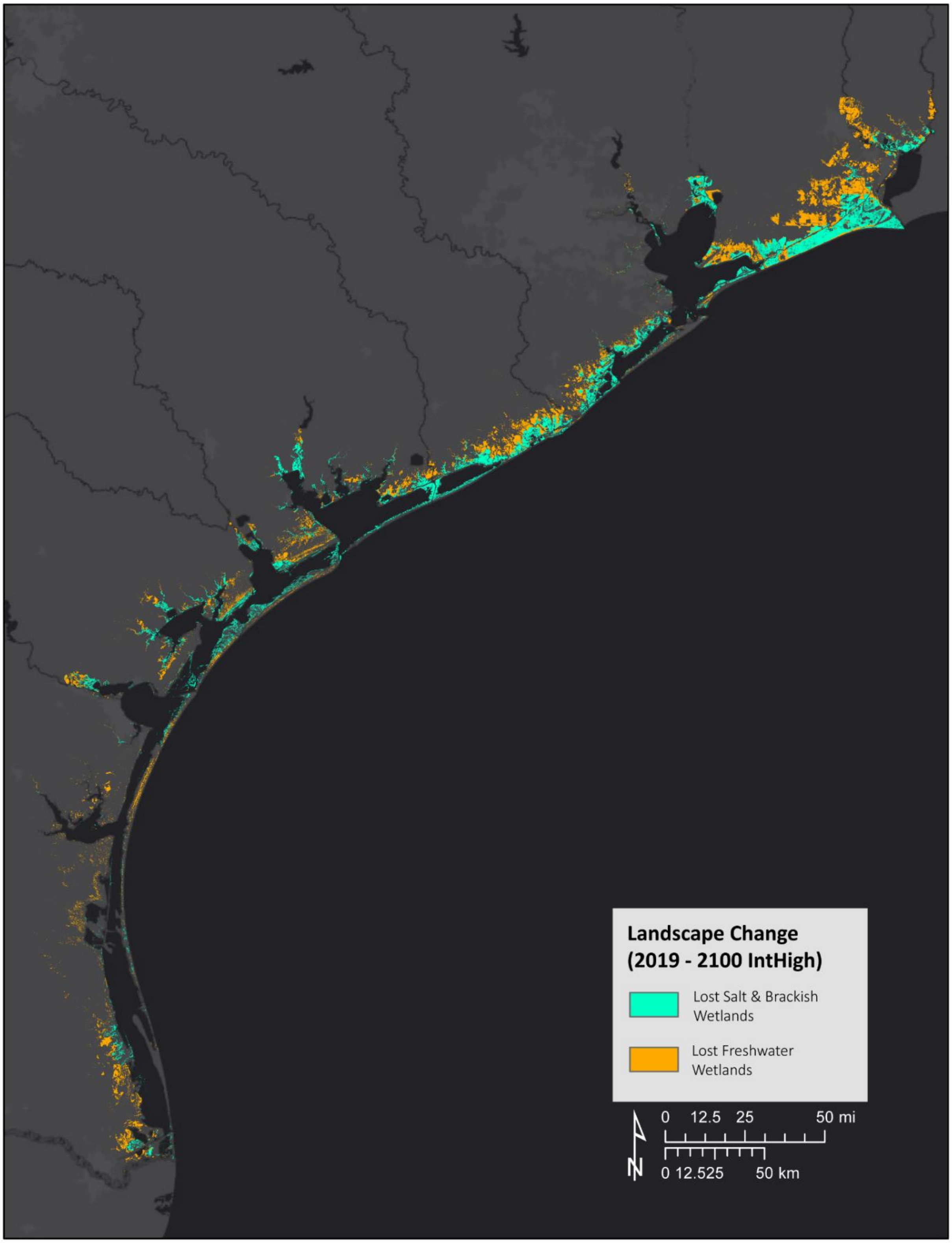


Figure 6-20. Map showing the extent of lost salt and brackish water wetlands and freshwater wetlands by the year 2100 in the intermediate-high SLR scenario.

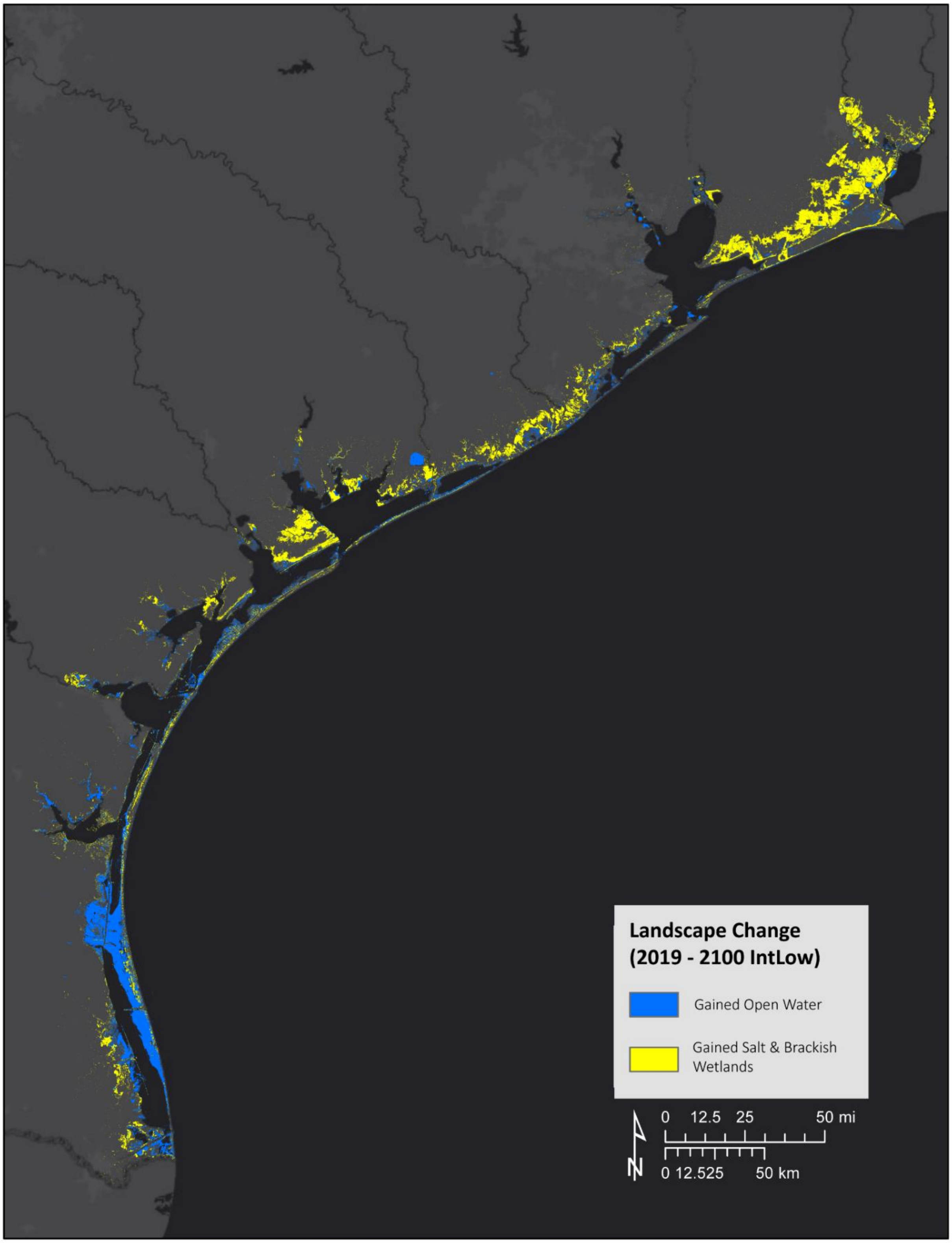


Figure 6-21. Map showing the extent of gained open water and salt and brackish wetlands by the year 2100 in the intermediate-low SLR scenario.

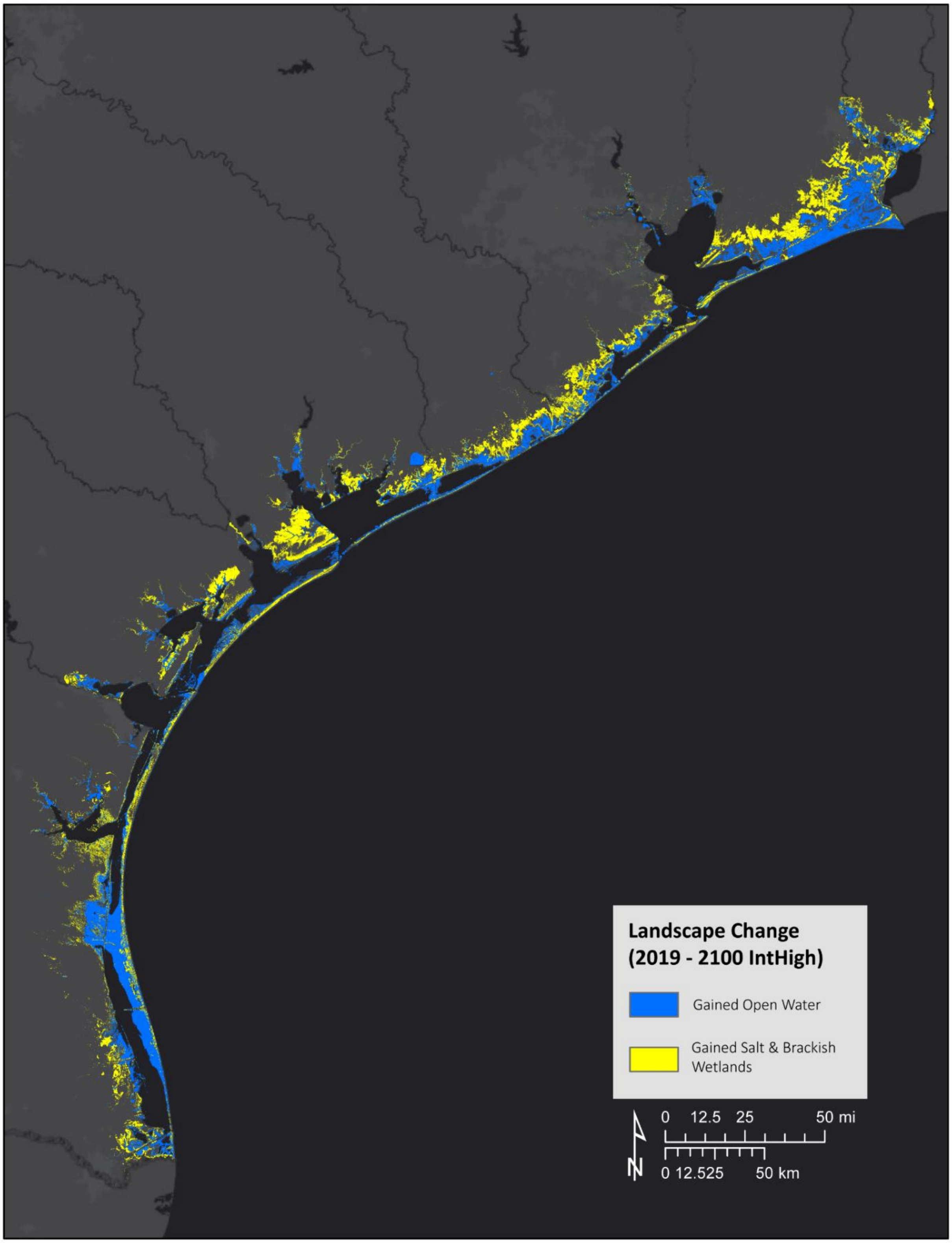


Figure 6-22. Map showing the extent of gained open water and salt and brackish wetlands by the year 2100 in the intermediate-high SLR scenario.

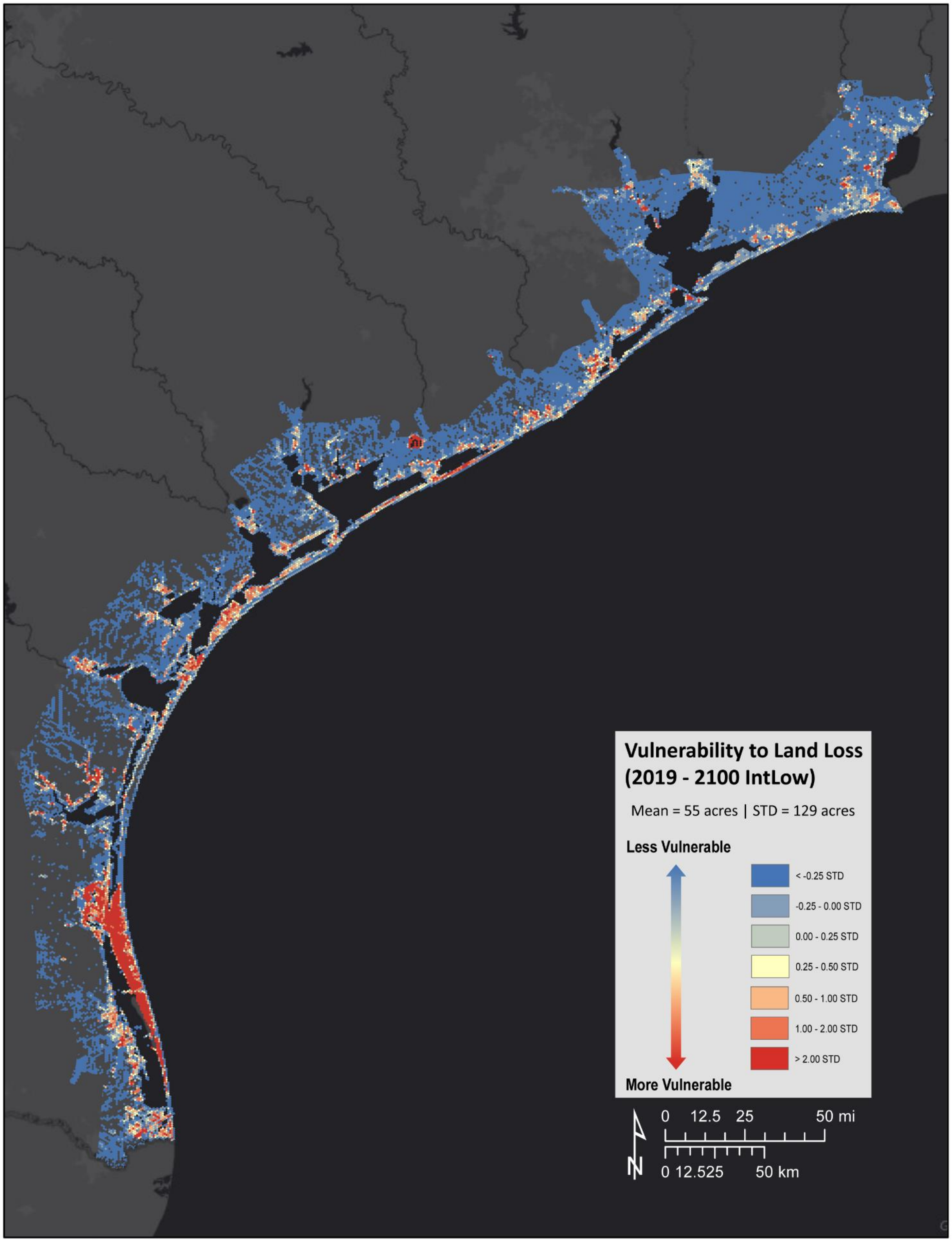


Figure 6-23. Map showing relative vulnerability to land loss, where land loss signifies any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in the intermediate-low SLR scenario. The map is symbolized by standard deviations (STD) from the mean.

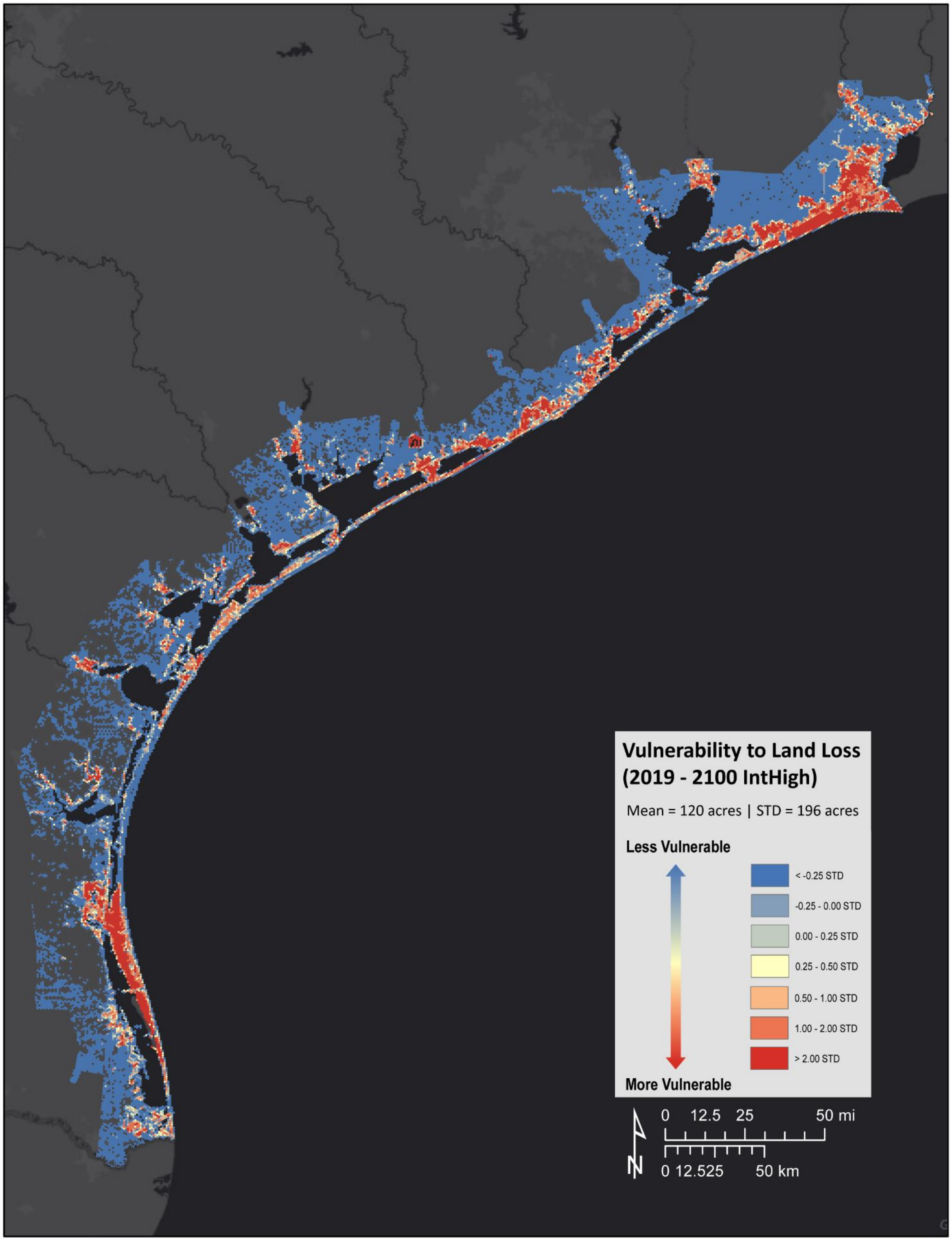


Figure 6-24. Map showing relative vulnerability to land loss, where land loss signifies any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in intermediate-high SLR scenario. The map is symbolized by standard deviations (STD) from the mean.

Texas Coast vs. Regions

Each region along the Texas coast has unique characteristics that cause the landscape to change differently than the average trend of the coast. **Figure 6-25** - **Figure 6-26** and **Table 6-10** compare the percent change of each land cover class between the Texas coast and each region in the intermediate-low and intermediate-high scenario. In both SLR scenarios, all regions are predicted to loss developed dry land, undeveloped dry land, and freshwater wetlands, while all regions are predicted to gain salt and brackish wetlands, given that there will be migration space for the wetlands in the future.

Region 1 has a greater percent loss of undeveloped dry land and Region 2 has a greater percent loss of developed dry land in both SLR scenarios. Region 1 also has a greater precent loss of freshwater wetlands in the intermediate-low scenario, but it is greater for Region 2 in intermediate-high scenario. Region 4 is predicted to withstand greater gain in salt and brackish wetlands than all other regions and the coastwide average. The lower rates of RSLR and erosion in Region 3 and Region 4, compared to the upper coast, allow the low marsh environments to keep pace with SLR as upland habitats become tidally influenced. The Texas coast is predicted to see an overall loss in beaches and tidal flats, except for the upper coast which sees a net gain in tidal flat habitats as saltwater marshes are eroded. Region 1 and Region 2 contain a large area of salt and brackish wetland habitats than the lower coast, and the lower coast contains a larger area of tidal flats than the upper coast. The large area of tidal flat habitats in Region 4 that exist today are predicted to drown by 2100 which contributes to the largest percent gain of open water for any of the regions in both SLR scenarios.

Each region along the Texas coast has unique characteristics that cause the landscape to change differently than the average trend of the coast. **Figure 6-25** and **Figure 6-26** compare the percent change of each land cover class between the Texas coast and each region.

With Region 1 being the most developed region along the coast, a greater percent loss of both developed and undeveloped dry land is predicted to occur by 2100. All regions are predicted to sustain a loss of freshwater wetlands. Region 2 is the only region that is predicted to endure a net loss of salt and brackish wetlands. Regions 3 and 4 are predicted to withstand greater gain in salt and brackish wetlands than the coastwide average, Region 4 especially. The lower rates of RSLR and erosion in these two regions, compared to the upper coast, allow the low marsh environments to keep pace with SLR as upland habitats become tidally influenced. The Texas coast is predicted to see an overall loss in beaches and tidal flats, except for the upper coast which sees a net gain in tidal flat habitats as saltwater marshes are eroded. Regions 1 and 2 contain a larger area of salt and brackish wetland habitats than the lower coast, and the lower coast contains a larger area of tidal flats than the upper coast. The large area of tidal flat habitats in region 4 that exist today are predicted to drown by 2100 which contributes to the largest percent gain of open water for any of the regions

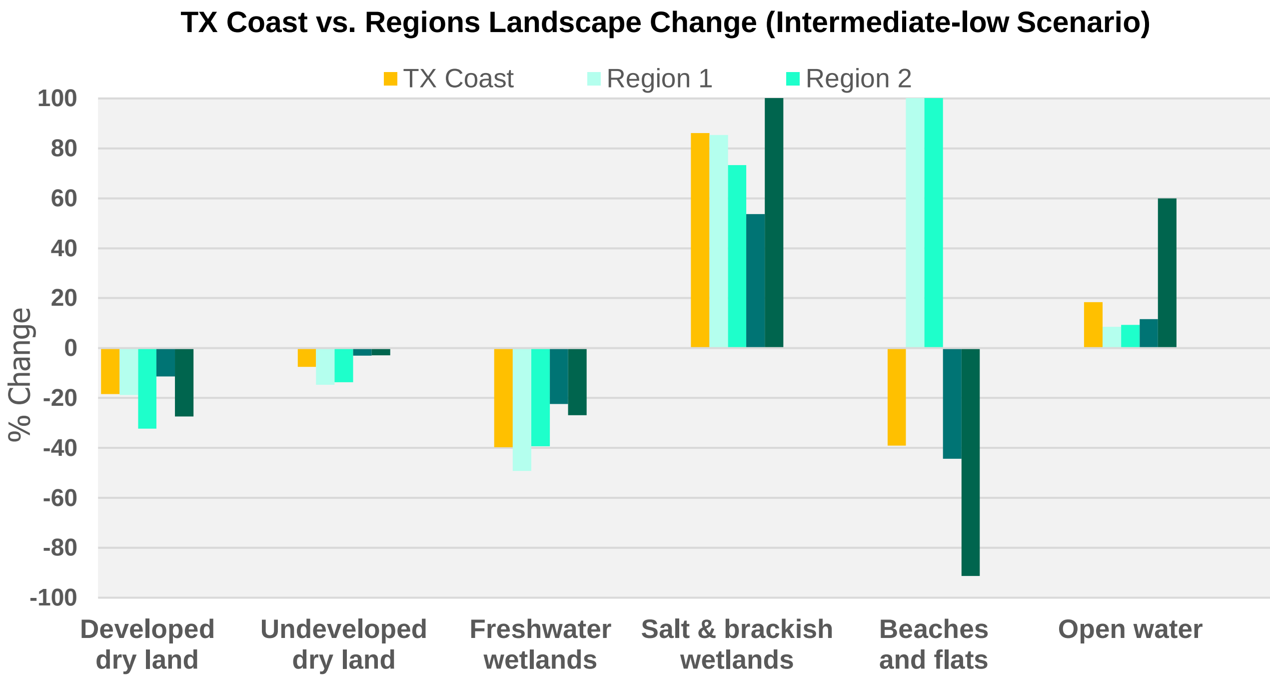


Figure 6-25. Graph showing the percent change of various land cover types from 2019 to 2100 in the intermediate-low SLR scenario for each region compared to the total change on the entire Texas coast.

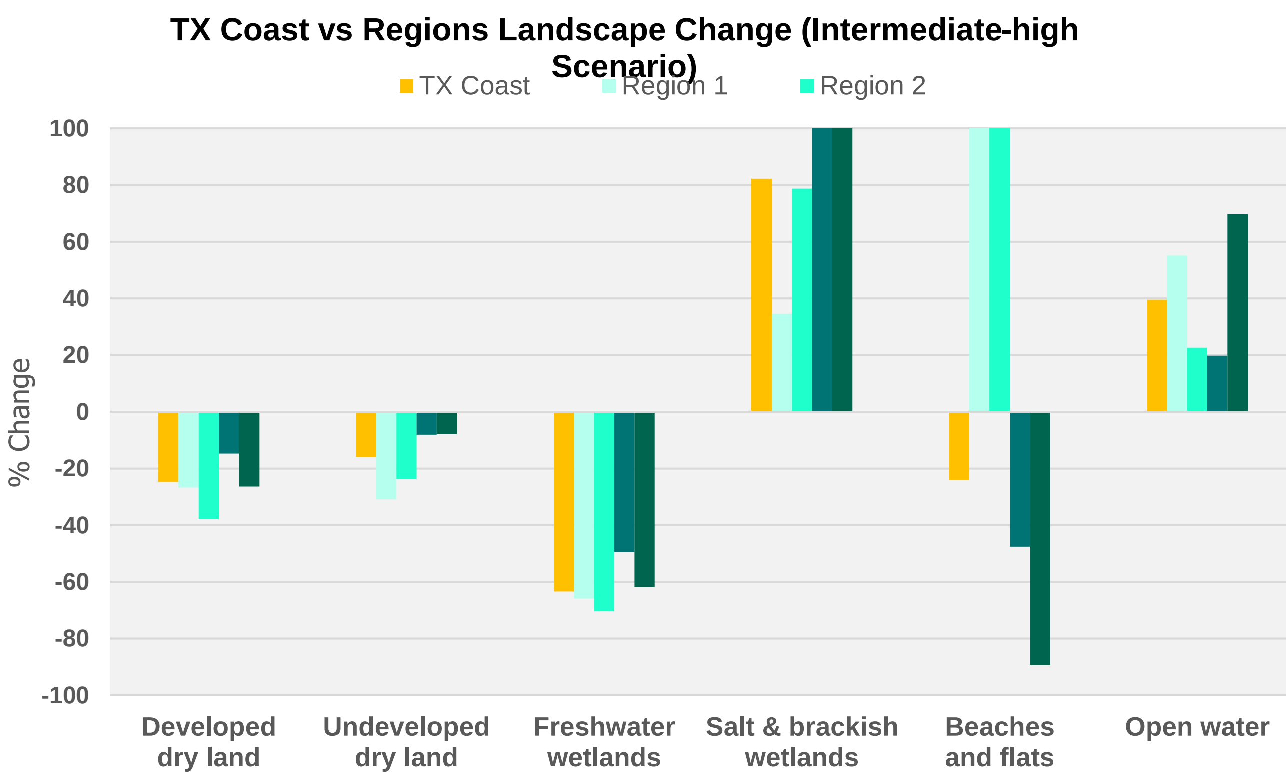


Figure 6-26. Graph showing the percent change of various land cover types from 2019 to 2100 in the intermediate-high SLR scenario for each region compared to the total change on the entire Texas coast.

Table 6-10. The percent change of various land cover types from 2019 to 2100 in both intermediate-low and intermediate-high SLR scenarios for each region compared to the total change on the entire Texas coast.

	% Change									
Land cover class	TX Coast		Region 1		Region 2		Region 3		Region 4	
	IntLow	IntHigh	IntLow	IntHigh	IntLow	IntHigh	IntLow	IntHigh	IntLow	IntHigh
Developed dry land	-18.37	-24.63	-18.76	-26.73	-32.31	-37.89	-11.36	-14.75	-27.44	-26.36
Undeveloped dry land	-7.57	-15.94	-14.71	-30.89	-13.67	-23.75	-3.04	-8.05	-2.86	-7.80
Freshwater wetlands, non-tidal	-39.71	-63.36	-49.24	-65.86	-39.28	-70.42	-22.41	-49.36	-26.83	-61.77
Salt & brackish emergent wetlands, tidal	86.18	82.20	85.31	34.60	73.31	78.69	53.71	144.18	257.70	503.75
Beaches and flats	-39.07	-24.14	355.23	533.21	140.00	172.71	-44.40	-47.58	-91.26	-89.26
Open water	18.44	39.51	8.49	55.11	9.23	22.64	11.57	19.84	59.91	69.73

Region 1

Anticipated consequences of SLR are expected to substantially alter the landscape of Region 1 by 2100. **Figure 6-27** displays the current landscape of Region 1 and the projected future landscapes under 0.5m and 1.5m SLR scenarios for 2100. **Table 6-11** and **Figure 6-28** illustrate alterations in each land cover class. **Figure 6-29** and **Figure 6-30** map individual losses and gains of freshwater and saltwater marshes in Region 1. These figures demonstrate where freshwater wetlands and salt and brackish wetlands that are currently present are predicted to either remain unchanged, be transformed into a different land cover type or open water, or experience growth by 2100 in both SLR scenarios.

Considering 0.5 or 1.5meters of SLR in addition to varying subsidence/uplift rates within Region 1 by 2100, substantial reductions in inland-fresh marshes and swamps are projected. In the 0.5m scenario, a little more than half of their original area is expected to persist by 2100, representing a combined loss of 49%, while in the 1.5m scenario, the combined loss is 66%. The model forecasts these habitats will transition into transitional scrub-shrub wetlands, regularly flooded marshes, or tidal flats. The majority of saltwater and brackish marshes in Region 1 are also predicted to be affected by SLR. Their initial area amounts to 308 square miles, but by 2100, only 166 square miles of their original area remains in the 0.5m SLR scenario, and even less in the 1.5m SLR scenario, at just 3 square miles. Alterations in salt and brackish marshes involve both expansion and contraction. On one hand, salt and brackish marshes will steadily migrate landward as the migration space becomes available, leading to an anticipated net gain of 85% in the 0.5m SLR scenario or 35% in the 1.5m SLR scenario by 2100. Conversely, Region 1 is also projected to experience a considerable increase in tidal flat habitats, from 29 square miles to 133 and 185 square miles in the 0.5m and 1.5m SLR scenarios by 2100, respectively. The gains of 355% and 533% result from the large areas of salt and brackish marshes being eroded into flats.

By 2100, the area of open water is projected to grow by 8% and 55% in the 0.5m and 1.5m SLR scenarios, respectively. The expansion of open water and the loss of crucial coastal habitats have the potential to heighten the region's susceptibility to future threats such as storm surges and nuisance flooding. **Figure 6-31** and **Figure 6-32** depict the relative vulnerability in both 0.5m and 1.5m SLR scenarios within this region. The maps display the areas that are converted into open water by 2100. On average, 125 acres of land are lost to open water within each hexagon in the 1.5m SLR scenario, while only an average of 23 acres become open water in the 0.5m SLR scenario. The areas most prone to land loss align with those experiencing the highest rates of subsidence. Marshes in these vulnerable areas are not vertically accreting quickly enough to match the rate of RSLR, leading to predictions of submersion by 2100.

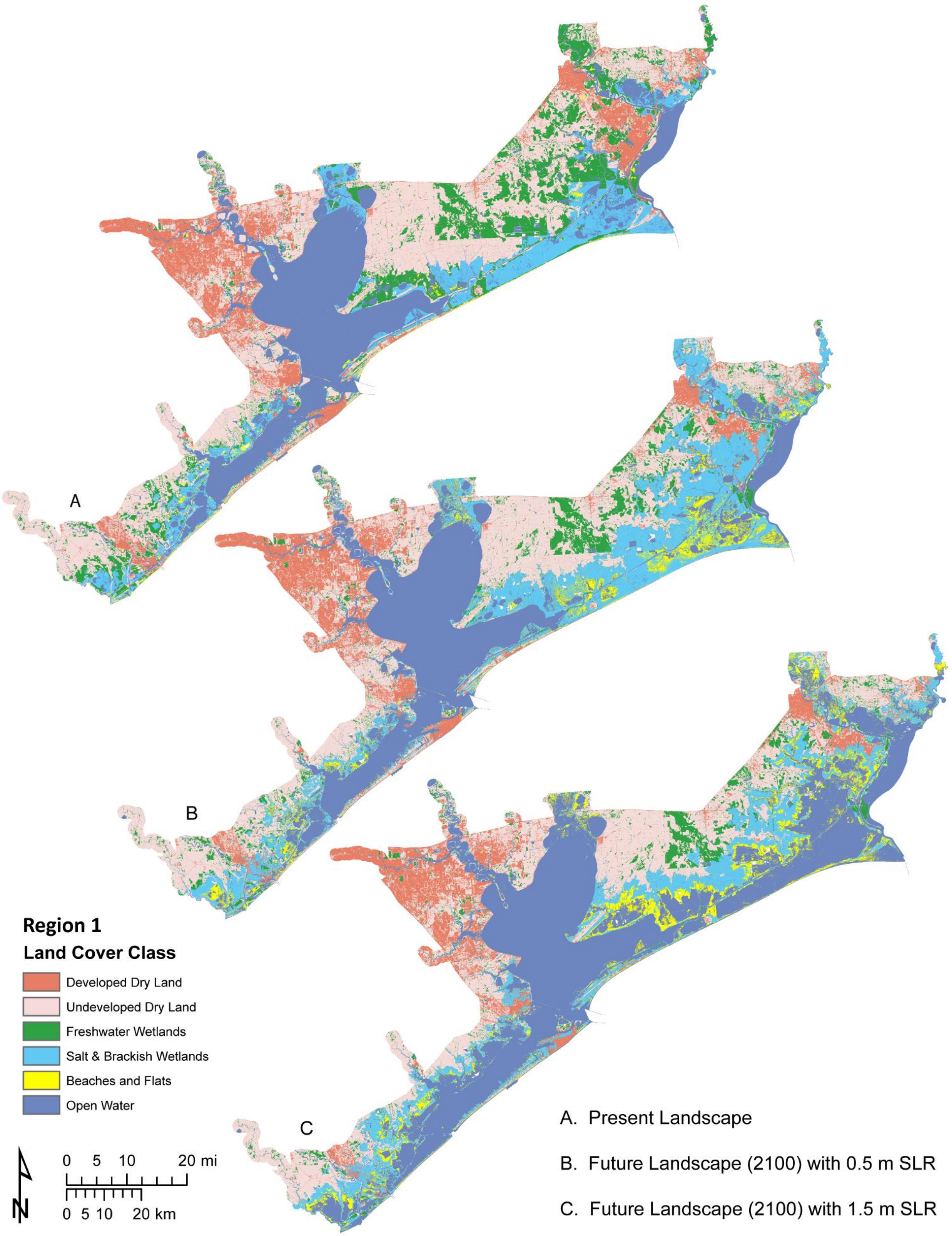
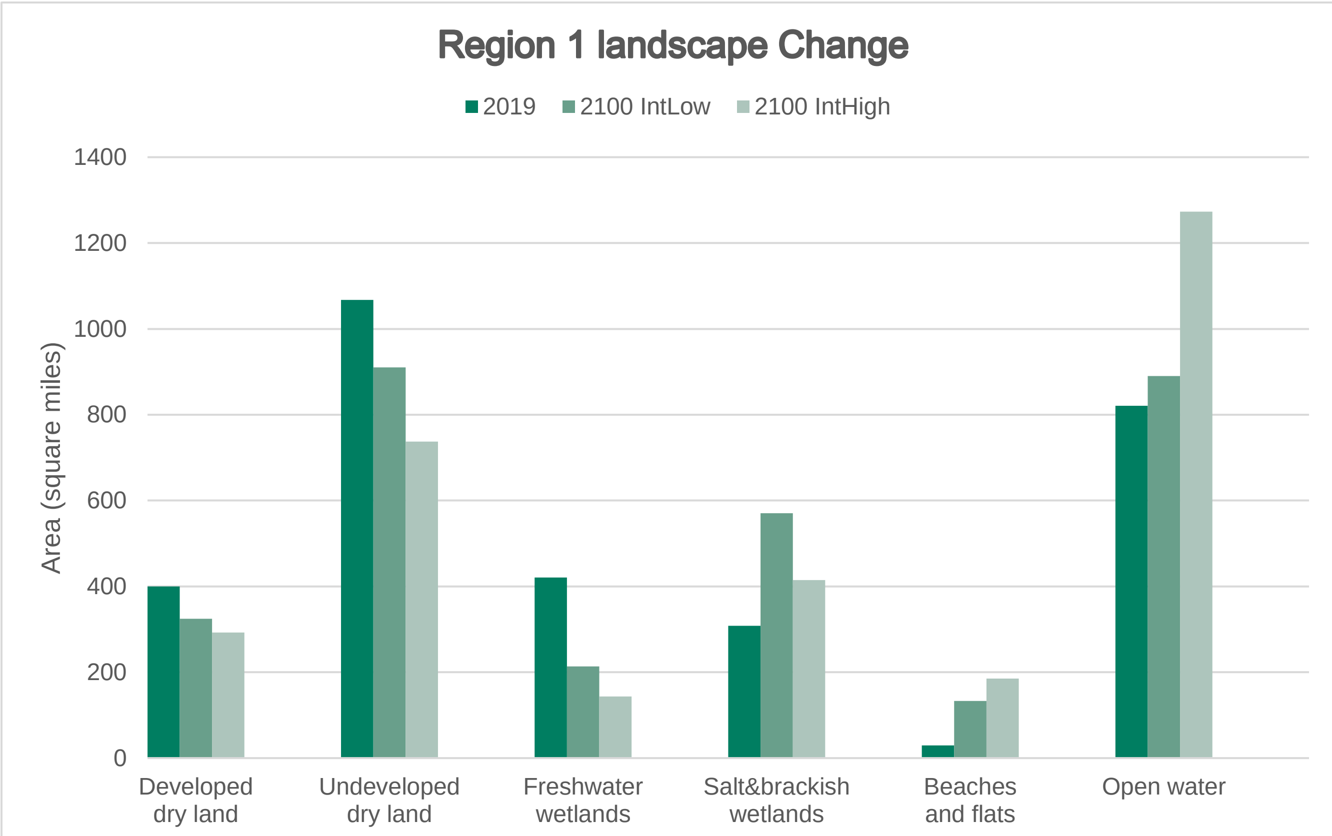


Figure 6-27 Map comparing the land cover distribution in Region 1 on the initial condition and 2100 conditions in both 0.5m and 1.5m SLR scenarios.



both 0.5m and 1.5m SLR scenarios.

Land cover class	2019 (sq. miles)	2100 IntLow (sq. miles)	% Diff	2100 IntHigh (sq. miles)	% Diff
Developed dry land	399.68	324.69	-18.76	292.85	-26.73
Undeveloped dry land	1067.38	910.36	-14.71	737.71	-30.89
Freshwater wetlands, non-tidal	420.48	213.42	-49.24	143.54	-65.86
Salt & brackish emergent wetlands, tidal	308.01	570.77	85.31	414.58	34.60
Beaches and flats	29.24	133.11	355.23	185.15	533.21
Open water	820.78	890.43	8.49	1273.09	55.11

Table 6-11 The percent difference between land cover types in Region 1 in 2019 and 2100.

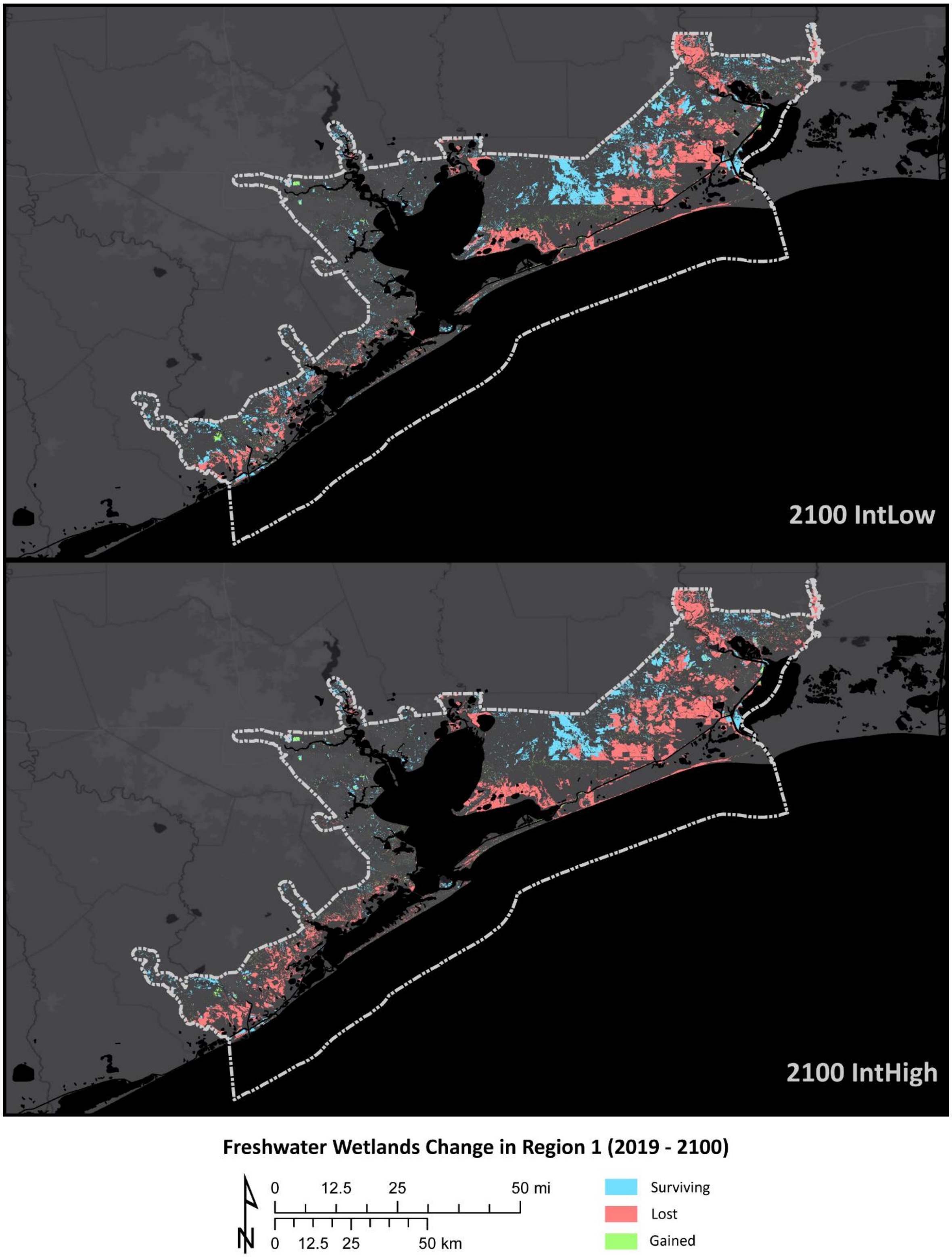


Figure 6-29 Map showing where freshwater wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

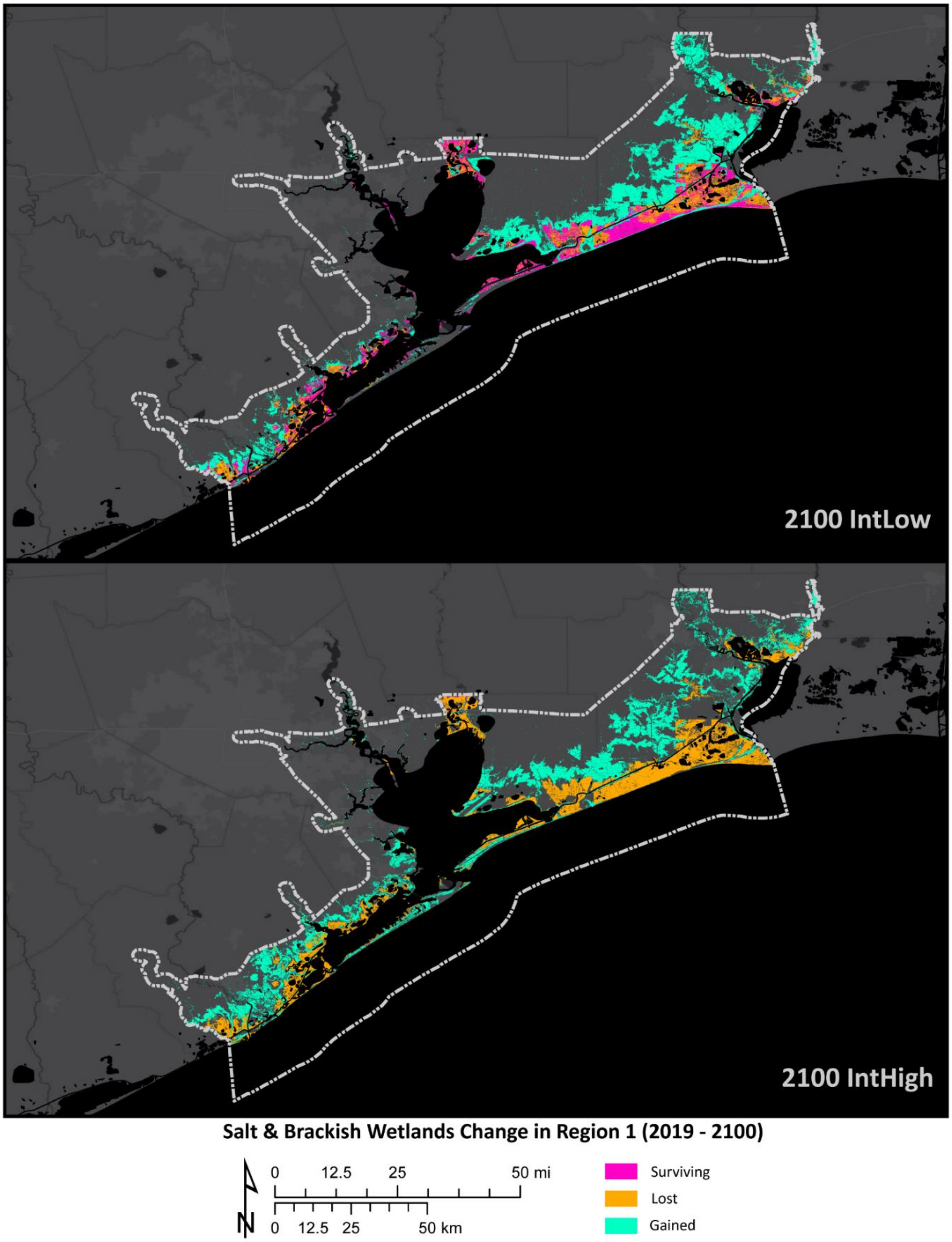


Figure 6-30 Map showing where brackish wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

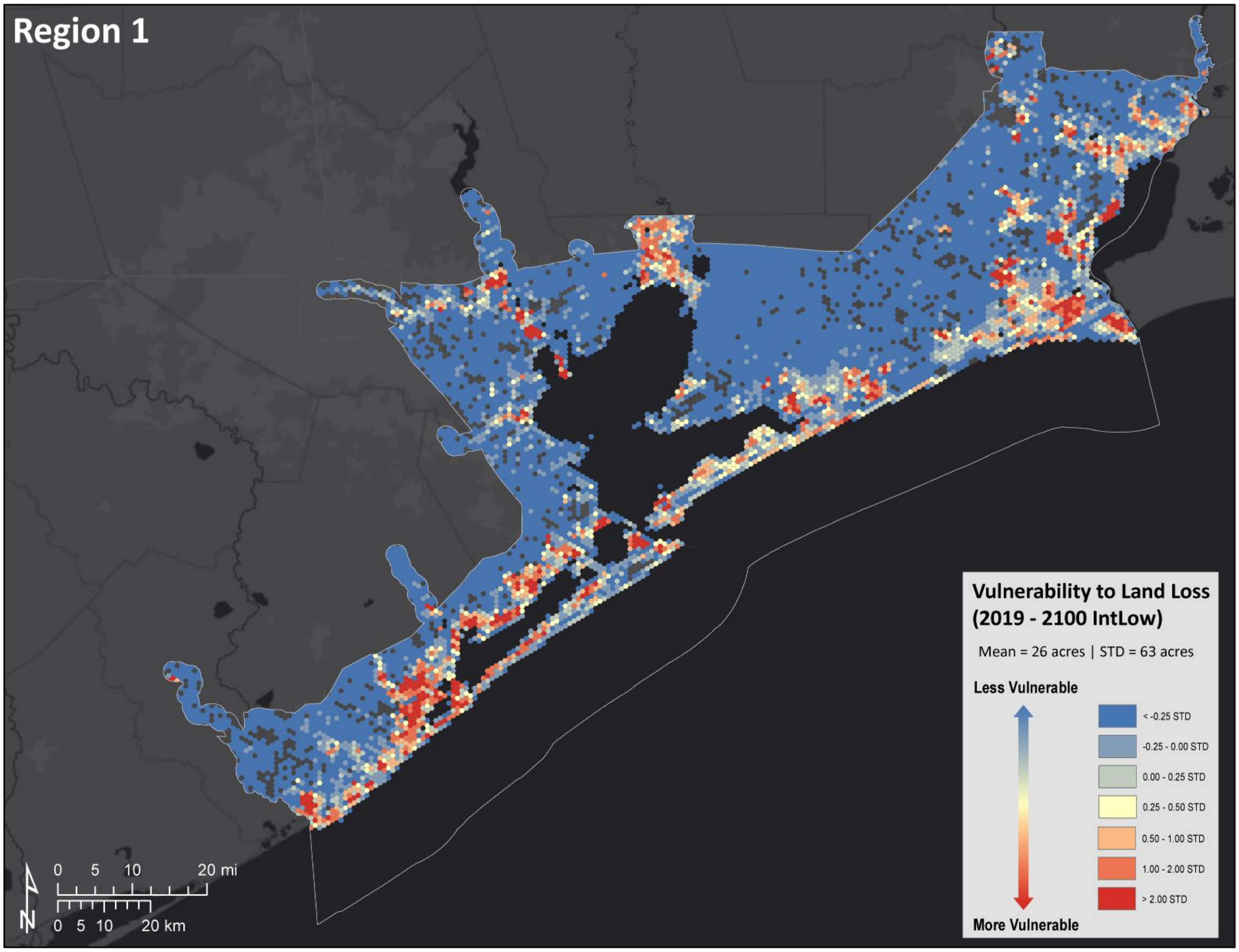


Figure 6-31 Map showing relative vulnerability to land loss in Region 1 where land loss means any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in 0.5m SLR scenario.

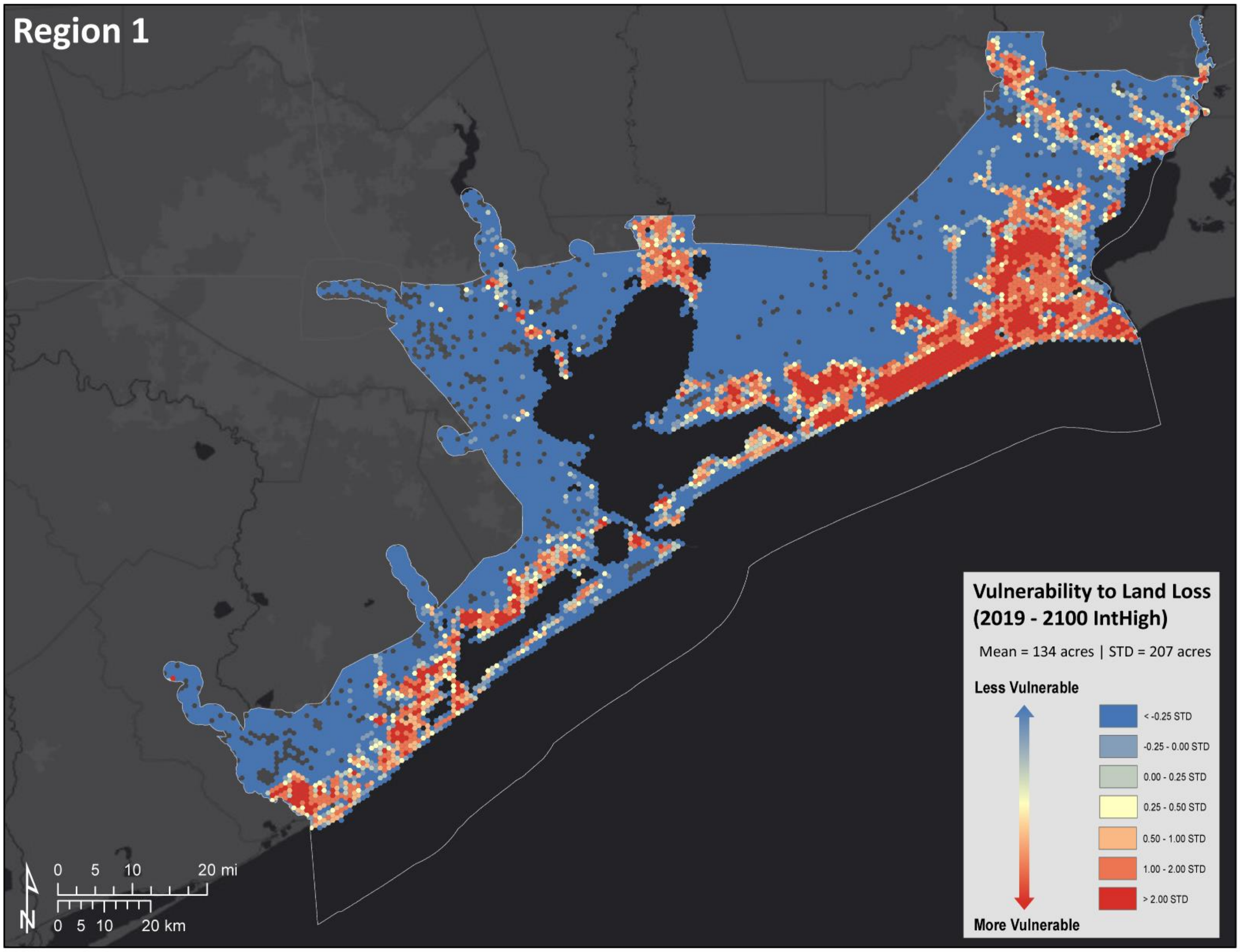


Figure 6-32 Map showing relative vulnerability to land loss in Region 1 where land loss means any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in 1.5m SLR scenario.

Region 2

Substantial effects of SLR are anticipated to influence Region 2, significantly transforming the landscapes by 2100. **Figure 6-33, Figure 6-34**, and **Table 6-12** present the current landscape of Region 2 and the projected future landscape in 2100**. Figure 6-43** and **Figure 6-44** display maps of individual losses and gains of freshwater and saltwater marshes in Region 2. These maps illustrate where freshwater wetlands and salt and brackish wetlands currently existing on the landscape are expected to either remain unchanged, be converted to a different land cover type or open water, or experience growth by 2100 in both 0.5m and 1.5m SLR scenarios.

Considering varying subsidence/uplift rates within this region by 2100, substantial reductions in inland-fresh marshes and swamps are projected. With the 0.5m scenario, a combined loss of 39% is anticipated, while the 1.5m scenario sees a dramatic shift to a 70% combined loss. The model forecasts these habitats will transition into transitional scrub-shrub wetlands, regularly flooded marshes, or tidal flats. The majority of saltwater and brackish marshes in Region 2 are also predicted to be affected by SLR. Their initial area amounts to 142 square miles, but by 2100, only 55 square miles of their original area remains in the 0.5m SLR scenario, and even less in the 1.5m SLR scenario, at just 3 square miles. Alterations in salt and brackish marshes involve both expansion and contraction. On one hand, salt and brackish marshes will steadily migrate landward as the migration space becomes available, leading to an anticipated net gain of 73% in the 0.5m SLR scenario or 79% in the 1.5m SLR scenario by 2100. Conversely, Region 2 is also projected to experience a considerable increase in tidal flat habitats, from 28 square miles to 68 and 77 square miles in the 0.5m and 1.5m SLR scenarios by 2100, respectively. The gains of 140% and 173% result from the large areas of salt and brackish marshes being eroded into flats.

The open water area is projected to increase by 9% and 23% by the year 2100 in the 0.5m and 1.5m SLR scenarios, respectively. The expansion of open water and loss of vital coastal habitats can potentially heighten this region's vulnerability to future hazards such as storm surges and nuisance flooding. **Figure 6-37** and **Figure 6-38** display the relative vulnerability in both 0.5m and 1.5m SLR scenarios within this region. The maps illustrate where land is converted to open water by 2100. Within each hexagon, an average of 87 acres of land is lost to open water in the 1.5m SLR scenario, while only an average of 31 acres becomes open water in the 0.5m SLR scenario. The most vulnerable areas are the salt and brackish water wetlands bordering the bays, indicating that they are not accreting rapidly enough to keep up with RSLR.

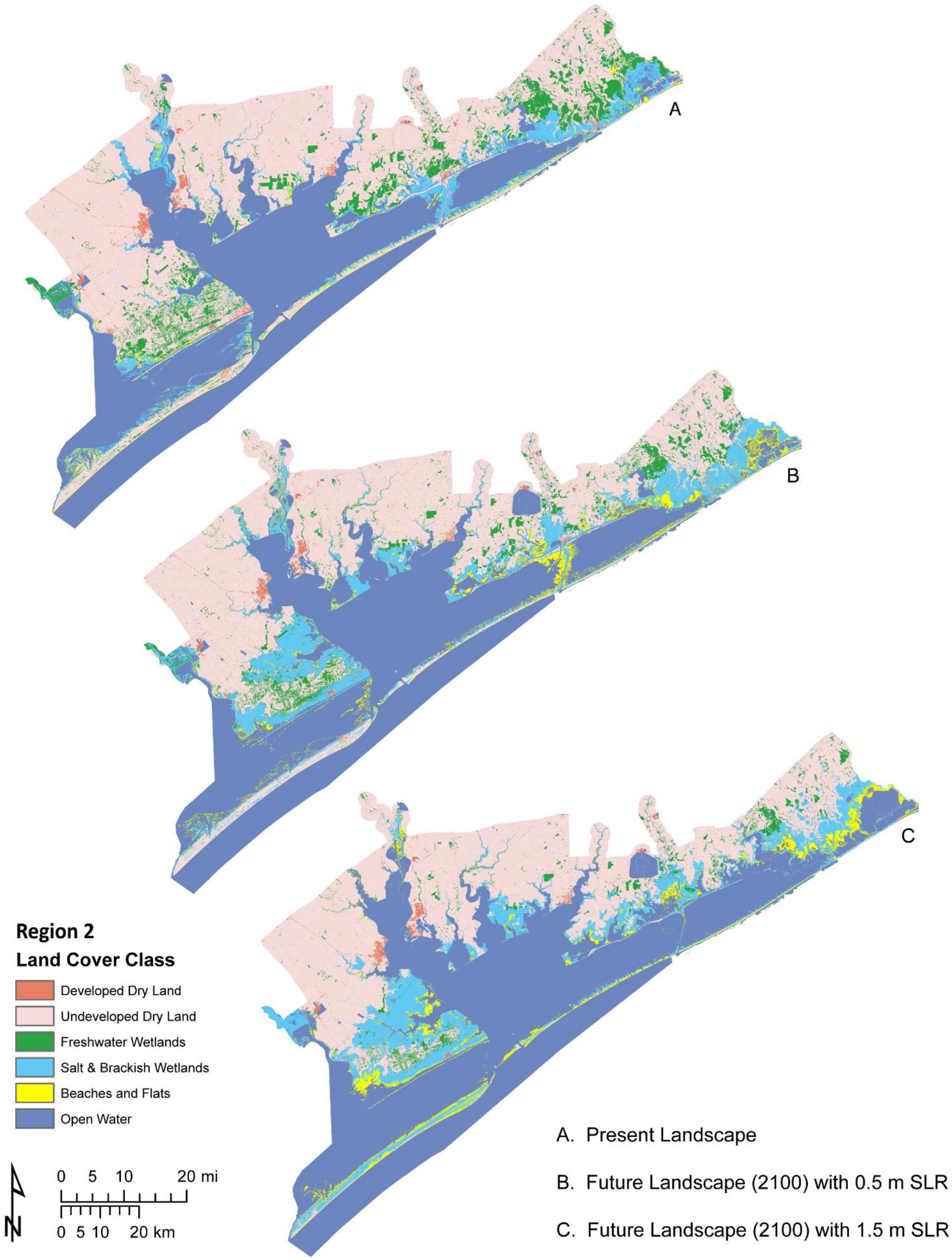


Figure 6-33 Map comparing the land cover distribution in Region 2 on the initial condition and 2100 conditions in both 0.5m and 1.5m SLR scenarios.

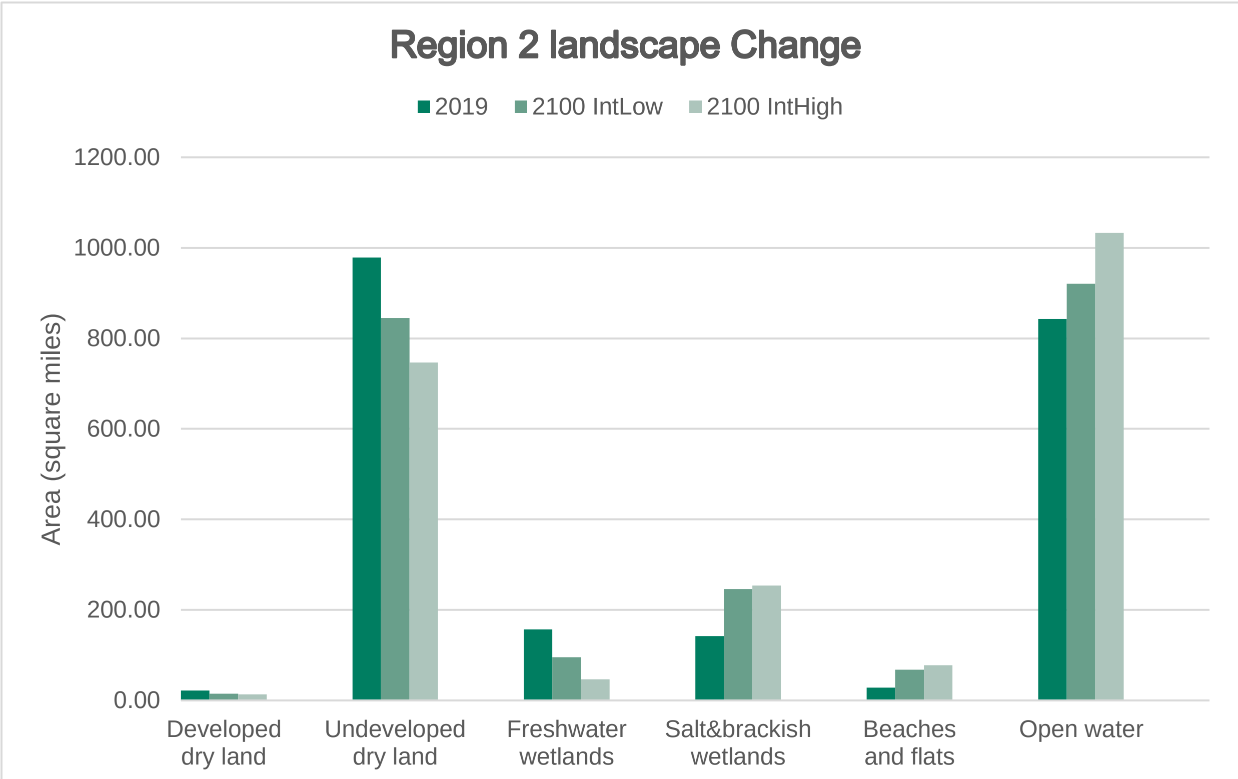


Figure 6-34 Graph comparing the land cover distribution in Region 2 on the initial condition (2019) and the 2100 conditions in both 0.5m and 1.5m SLR scenarios.

Table 6-12 The percent difference between land cover types in Region 2 in 2019 and 2100.

Land cover class	2019 (sq. miles)	2100 IntLow (sq. miles)	% Diff	2100 IntHigh (sq. miles)	% Diff
Developed dry land	21.85	14.79	-32.31	13.57	-37.89
Undeveloped dry land	978.77	844.94	-13.67	746.34	-23.75
Freshwater wetlands, non-tidal	157.09	95.39	-39.28	46.47	-70.42
Salt & brackish emergent wetlands, tidal	141.94	246.00	73.31	253.63	78.69
Beaches and flats	28.40	68.16	140.00	77.45	172.71
Open water	842.56	920.32	9.23	1033.28	22.64

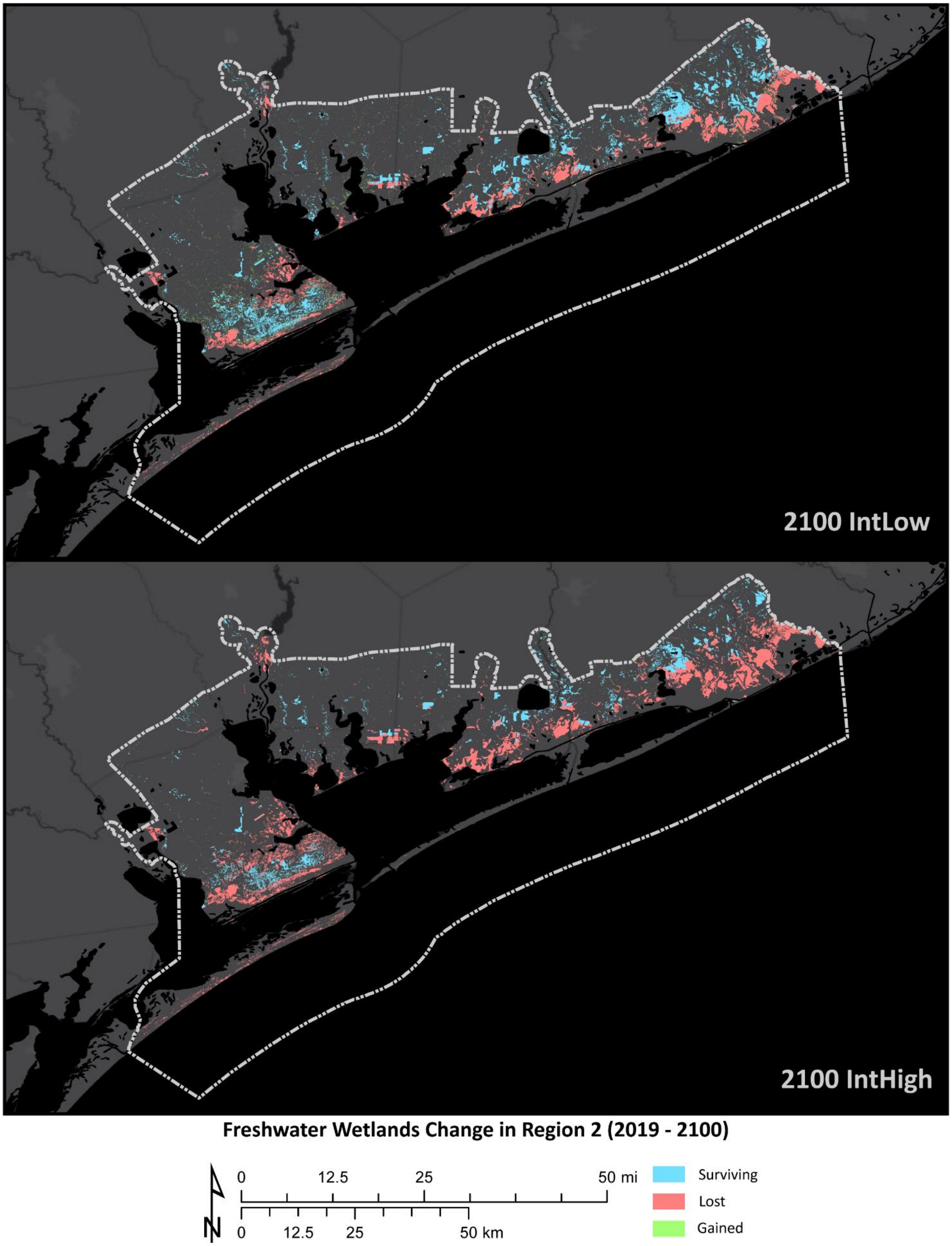


Figure 6-35 Map showing where freshwater wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

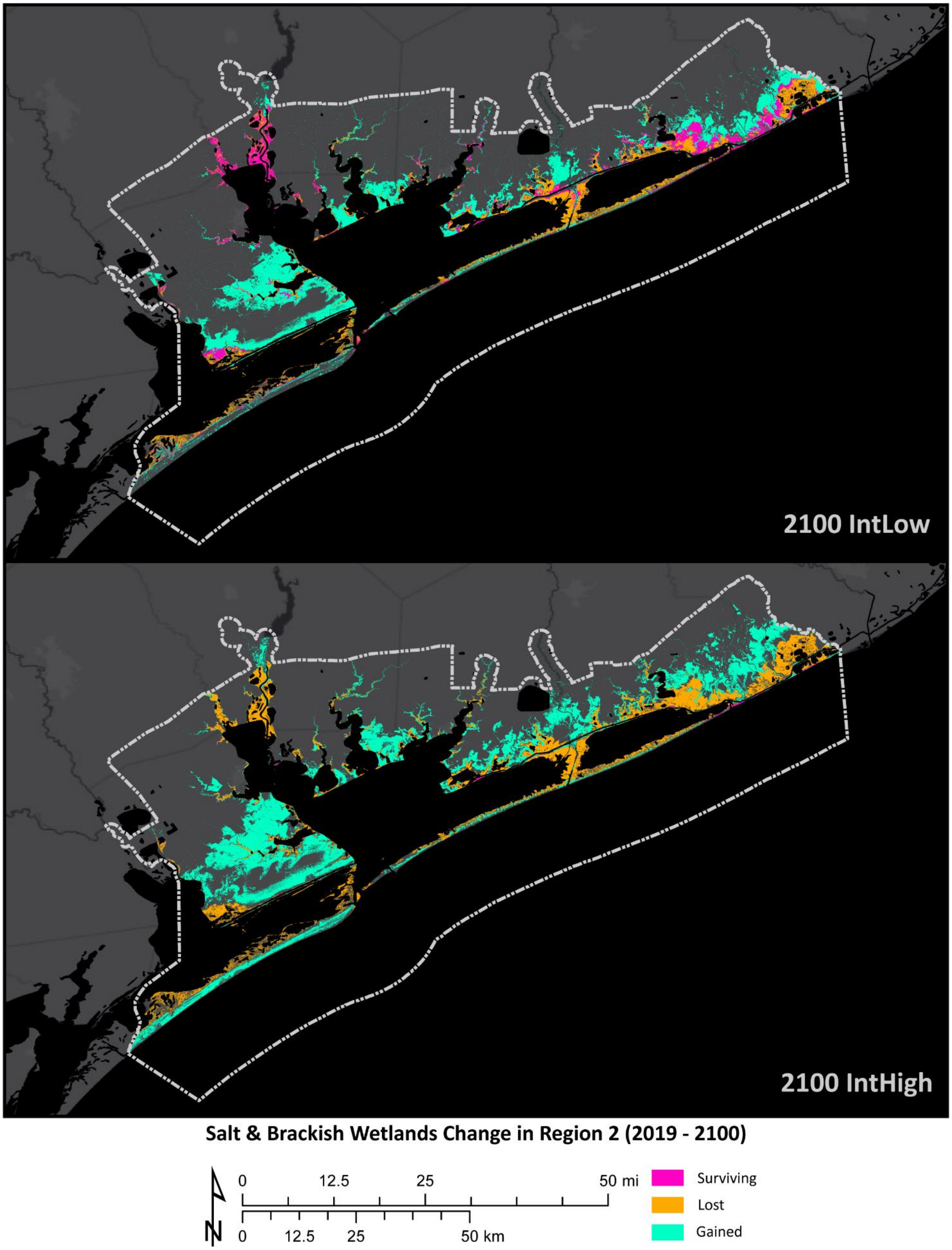


Figure 6-36 Map showing where brackish wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

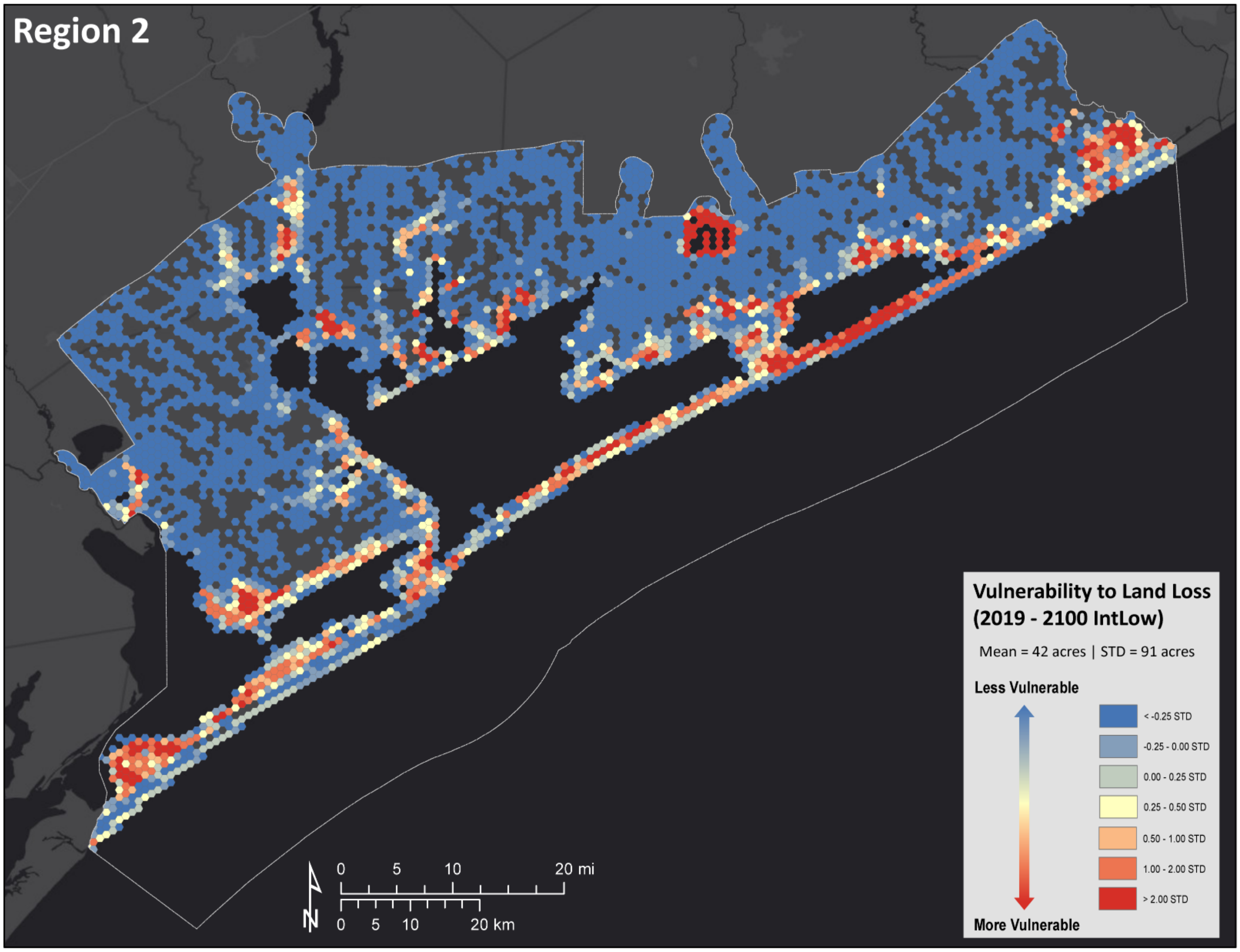


Figure 6-37 Map showing relative vulnerability to land loss in Region 2 where land loss means any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in 0.5m SLR scenario.

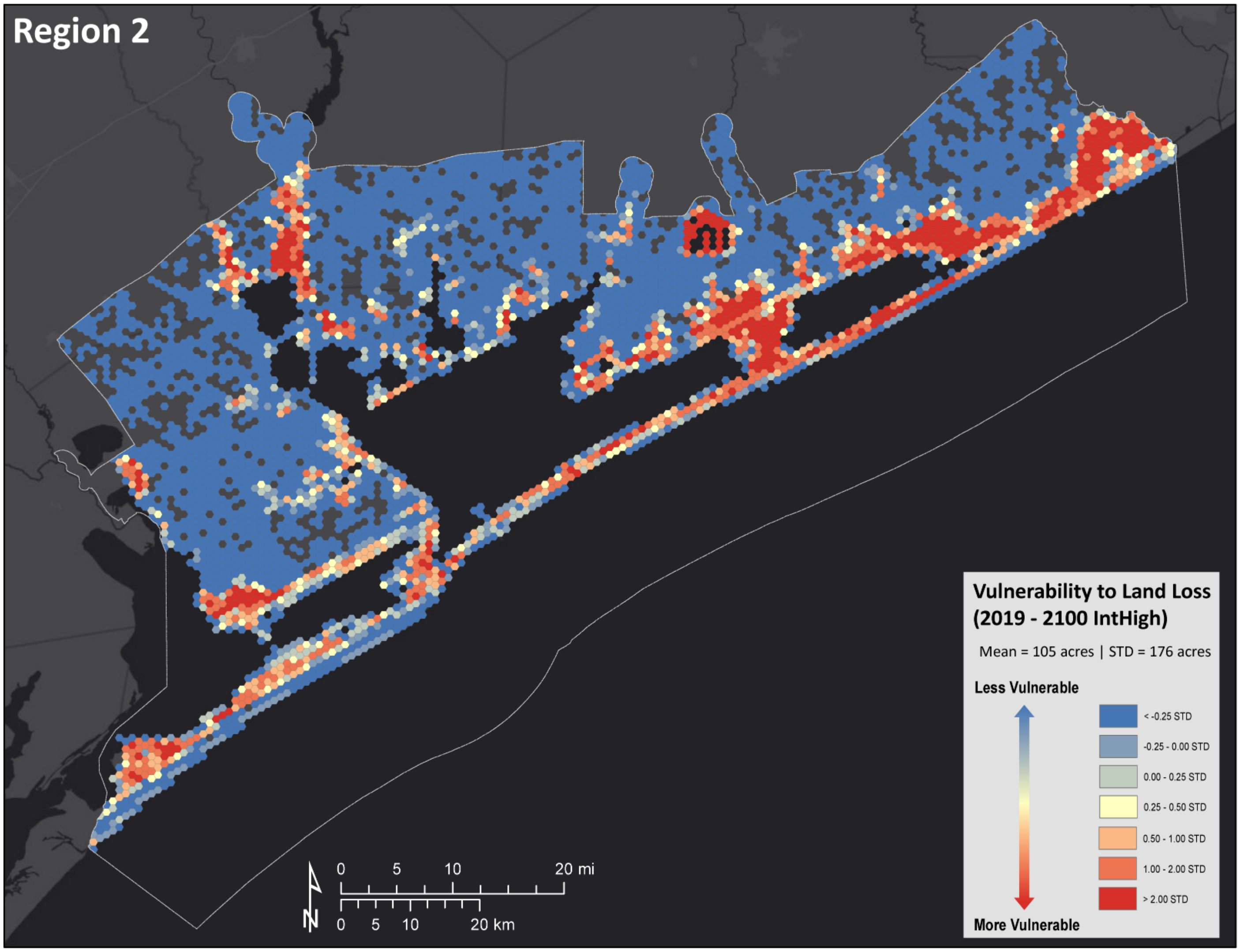


Figure 6-38 Map showing relative vulnerability to land loss in Region 2 where land loss means any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in 1.5m SLR scenario.

Region 3

Considerable effects of SLR are forecasted to influence Region 3, drastically altering the landscapes by 2100. Figure **6-39**, **Figure 6-40,** and **Table 6-13** present the current landscape of Region 3 and the model projections of the future landscape in 2100**. Figure 6-41** and **Figure 6-42** display maps of individual losses and gains of freshwater and saltwater marshes in Region 3. These maps depict where freshwater wetlands and salt and brackish wetlands currently on the landscape are predicted to either remain unchanged, be converted to another land cover type or open water, or experience growth by 2100 in both 0.5m and 1.5m SLR scenarios.

Notable reductions in inland-fresh marshes and swamps are anticipated. With the 0.5m scenario, a combined loss of 22% is expected, while the 1.5m scenario sees a dramatic shift to a 49% combined loss. The model forecasts these habitats will transition into transitional scrub-shrub wetlands, regularly flooded marshes, or tidal flats. The majority of saltwater and brackish marshes in Region 3 are also projected to be affected by SLR. Their initial area amounts to 108 square miles, but by 2100, only 26 square miles of their original area remains in the 0.5m SLR scenario, and even less in the 1.5m SLR scenario, at just 4 square miles. Changes in salt and brackish marshes involve both expansion and contraction. On one hand, salt and brackish marshes will steadily migrate landward as the migration space becomes available, leading to an anticipated net gain of 54% in the 0.5m SLR scenario or 144% in the 1.5m SLR scenario by 2100. Conversely, the lost low marsh area is converted to either tidal flats or open water. Region 3 is expected to experience a significant decrease in tidal flat habitats, with losses of 44% and 48% in the 0.5m and 1.5m SLR scenarios by 2100, respectively. The loss is primarily observed in the arms of Baffin Bay and on the backside of the barrier islands.

The open water area is projected to increase by 12% and 20% by the year 2100 in the 0.5m and 1.5m SLR scenarios, respectively. The expansion of open water and loss of critical coastal habitats have the potential to heighten this region's vulnerability to future hazards, such as storm surges and nuisance flooding. Figure 6-43 and **Figure 6-44** display the relative vulnerability in both 0.5m and 1.5m SLR scenarios within this region. The maps illustrate where land is converted to open water by 2100. Within each hexagon, an average of 43 acres of land is lost to open water in the 1.5m SLR scenario, while only an average of 25 acres becomes open water in the 0.5m SLR scenario. The areas most vulnerable to land loss correspond with the areas experiencing the highest rates of subsidence, particularly the marshes on the backside of the barrier islands, especially San Jose Island, and around the bayhead deltas. Similar to other regions, this suggests RSLR is outpacing the vertical accretion rate of the salt and brackish water wetlands.

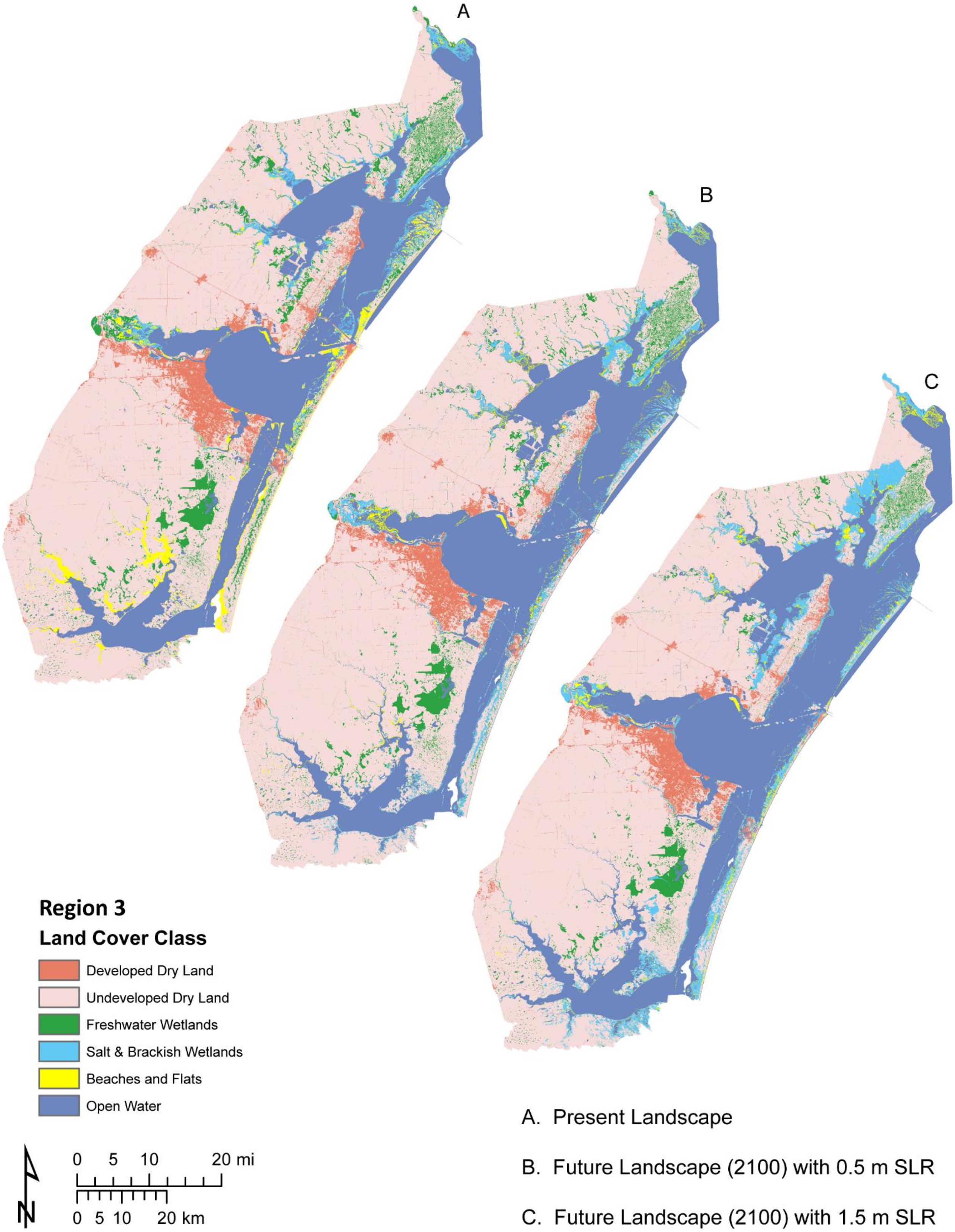


Figure 6-39 Map comparing the land cover distribution in Region 3 on the initial condition and 2100 conditions in both 0.5m and 1.5m SLR scenarios.

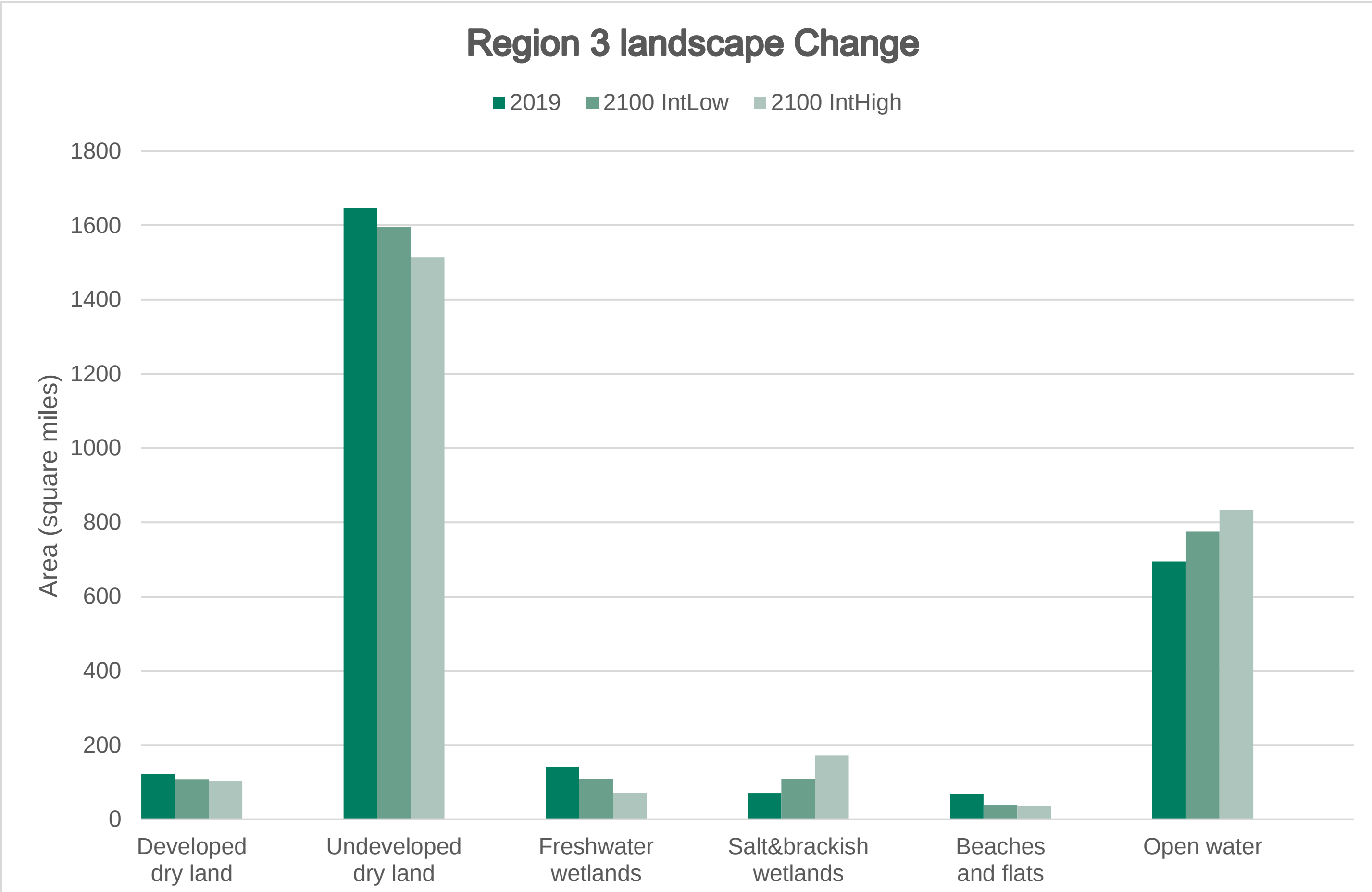


Figure 6-40 Map comparing the land cover distribution in Region 3 on the initial condition and 2100 conditions in both 0.5m and 1.5m SLR scenarios.

Table 6-13 The percent difference between land cover types in Region 3 in 2019 and 2100.

Land cover class	2019 (sq. miles)	2100 IntLow (sq. miles)	% Diff	2100 IntHigh (sq. miles)	% Diff
Developed dry land	122.10	108.23	-11.36	104.09	-14.75
Undeveloped dry land	1645.53	1595.49	-3.04	1513.14	-8.05
Freshwater wetlands, non-tidal	141.54	109.82	-22.41	71.67	-49.36
Salt & brackish emergent wetlands, tidal	70.58	108.49	53.71	172.34	144.18
Beaches and flats	69.10	38.42	-44.40	36.22	-47.58
Open water	695.24	775.66	11.57	833.20	19.84

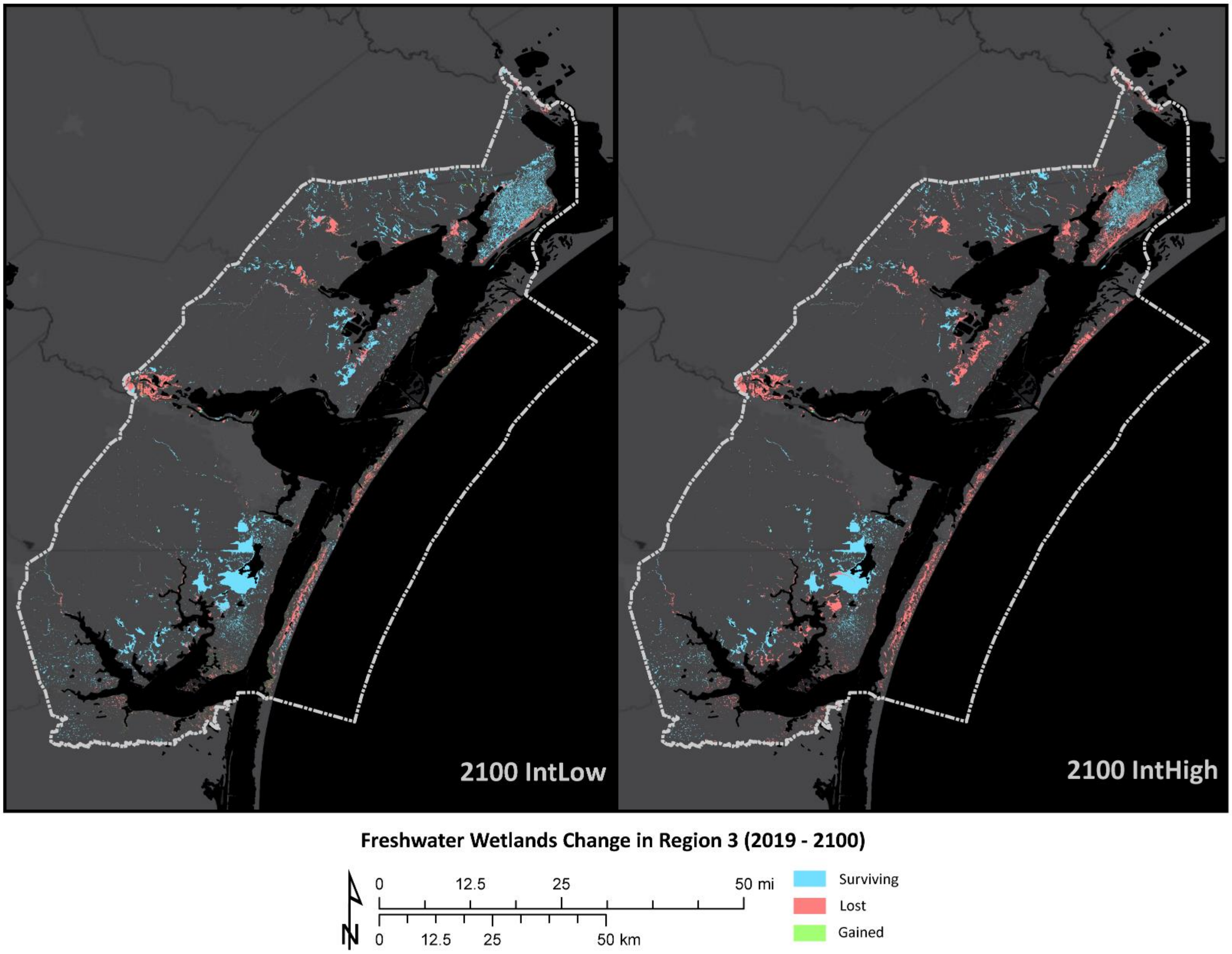


Figure 6-41 Map showing where freshwater wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

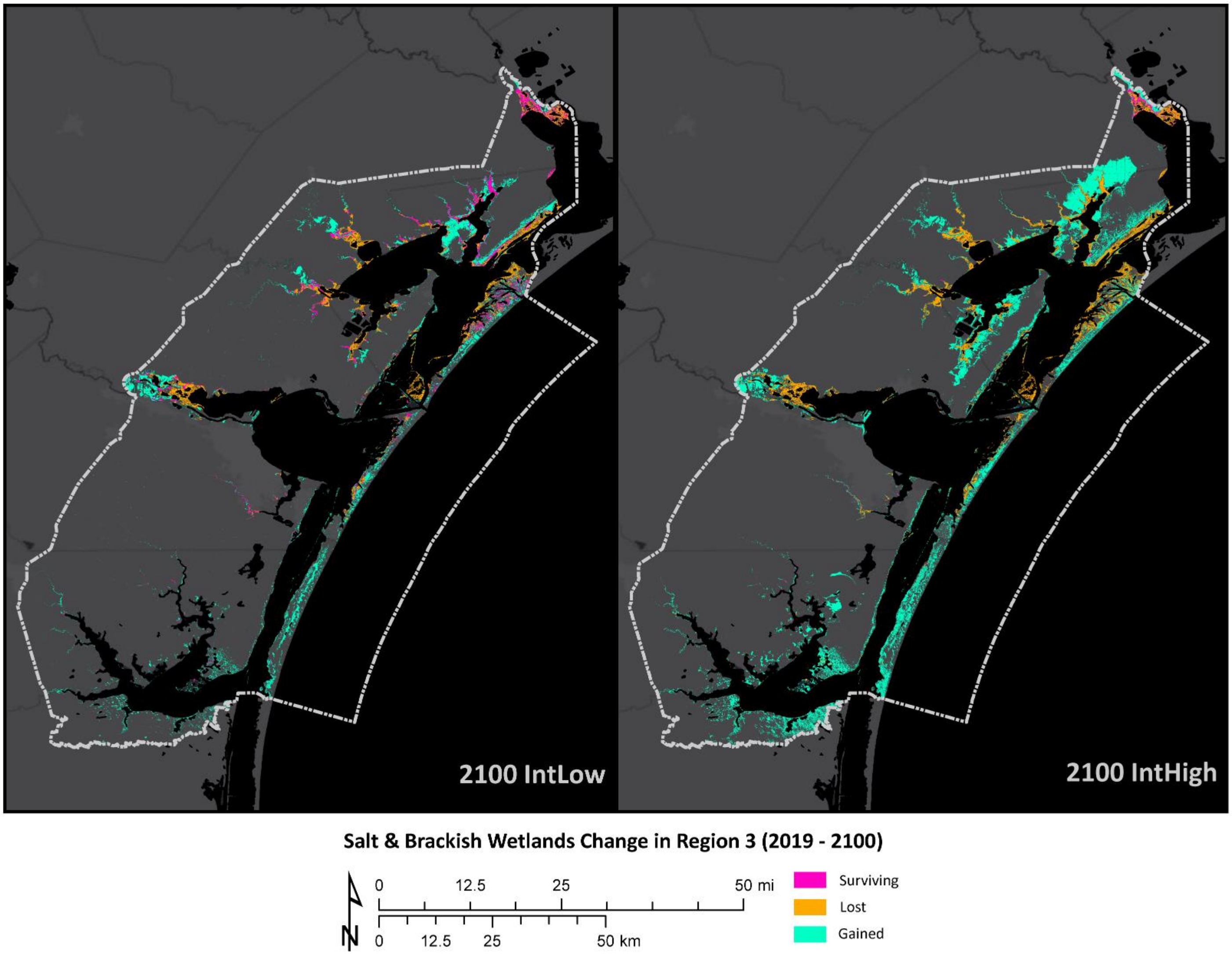


Figure 6-42 Map showing where brackish wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

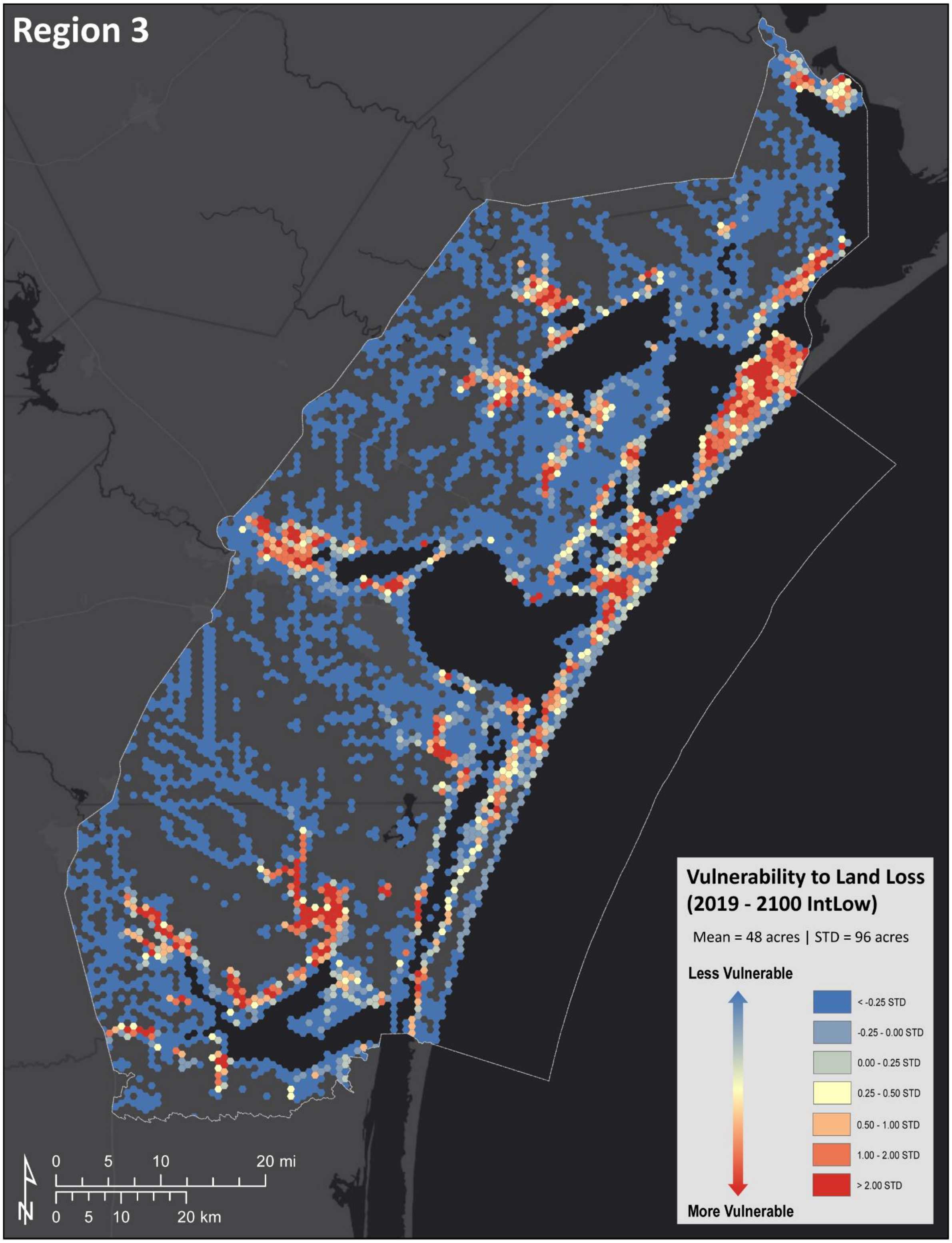


Figure 6-43 Map showing relative vulnerability to land loss in Region 3 where land loss means any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in 0.5m SLR scenario.

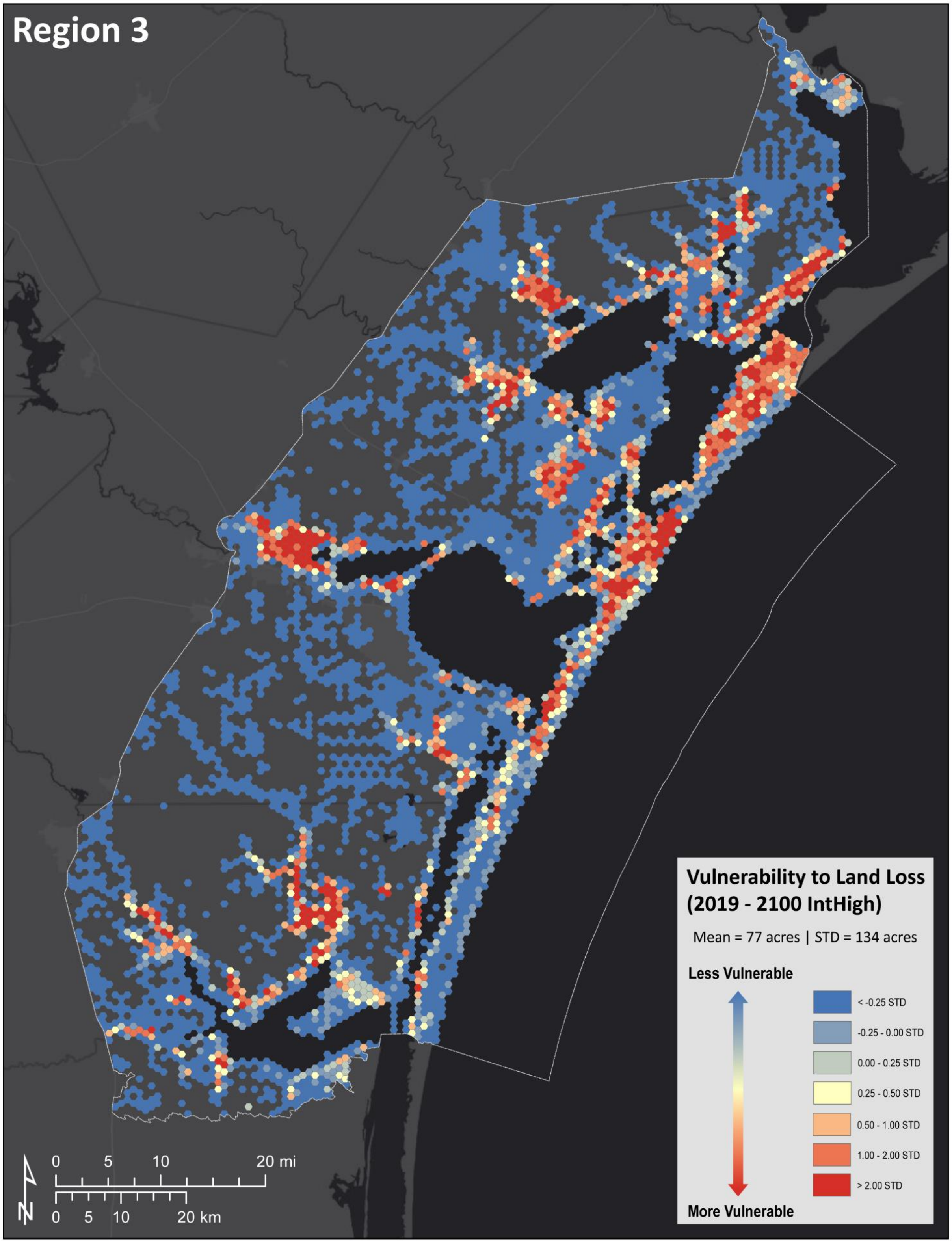


Figure 6-44 Map showing relative vulnerability to land loss in Region 3 where land loss means any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in 0.5m SLR scenario.

Region 4

Substantial effects of SLR are anticipated to impact Region 4, greatly transforming the landscapes by 2100. **Figure 6-45, Figure 6-46**, and **Table 6-14** present the current landscape of Region 4 and the model projections of the future landscape in 2100. **Figure 6-47** and **Figure 6-48** display maps of individual losses and gains of freshwater and saltwater marshes in Region 4. These maps show where freshwater wetlands and salt and brackish wetlands currently on the landscape are predicted to either remain unchanged, be converted to another land cover type or open water, or experience growth by 2100 in both 0.5m and 1.5m SLR scenarios.

Accounting for varying subsidence/uplift rates within this region by 2100, notable reductions in inland-fresh marshes and swamps are expected. With the 0.5m scenario, a combined loss of 27% is predicted, while the 1.5m scenario sees a dramatic shift to a 62% combined loss. The model forecasts these habitats will transition into transitional scrub-shrub wetlands, regularly flooded marshes, or tidal flats. The saltwater and brackish marshes in Region 4 are also anticipated to be affected by SLR. Their initial area amounts to 26 square miles, but by 2100, only 19 square miles of their original area remains in the 0.5m SLR scenario, and even less in the 1.5m SLR scenario, at just 4 square miles. Changes in salt and brackish marshes involve both expansion and contraction. On one hand, salt and brackish marshes will steadily migrate landward as the migration space becomes available, resulting in a predicted net gain of 258% in the 0.5m SLR scenario or 504% in the 1.5m SLR scenario by 2100. Conversely, the lost low marsh area is converted to either tidal flats or open water. Region 3 is expected to experience a significant decrease in tidal flat habitats, with losses of 91% and 89% in the 0.5m and 1.5m SLR scenarios by 2100, respectively.

The open water area is projected to increase by 60% and 70% by the year 2100 in the 0.5m and 1.5m SLR scenarios, respectively. The expansion of open water and loss of critical coastal habitats have the potential to heighten this region's vulnerability to future hazards, such as storm surges and nuisance flooding. **Figure 6-49** and **Figure 6-50** display the relative vulnerability in both 0.5m and 1.5m SLR scenarios within this region. The maps illustrate where land is converted to open water by 2100. Within each hexagon, an average of 92 acres of land is lost to open water in the 1.5m SLR scenario, while only an average of 78 acres becomes open water in the 0.5m SLR scenario. The backside of South Padre Island and the Laguna Atascosa National Wildlife Refuge are both highly susceptible to land loss driven by RSLR. The loss of the barrier island and the habitats in the refuge could greatly impact the communities and wildlife in this region.

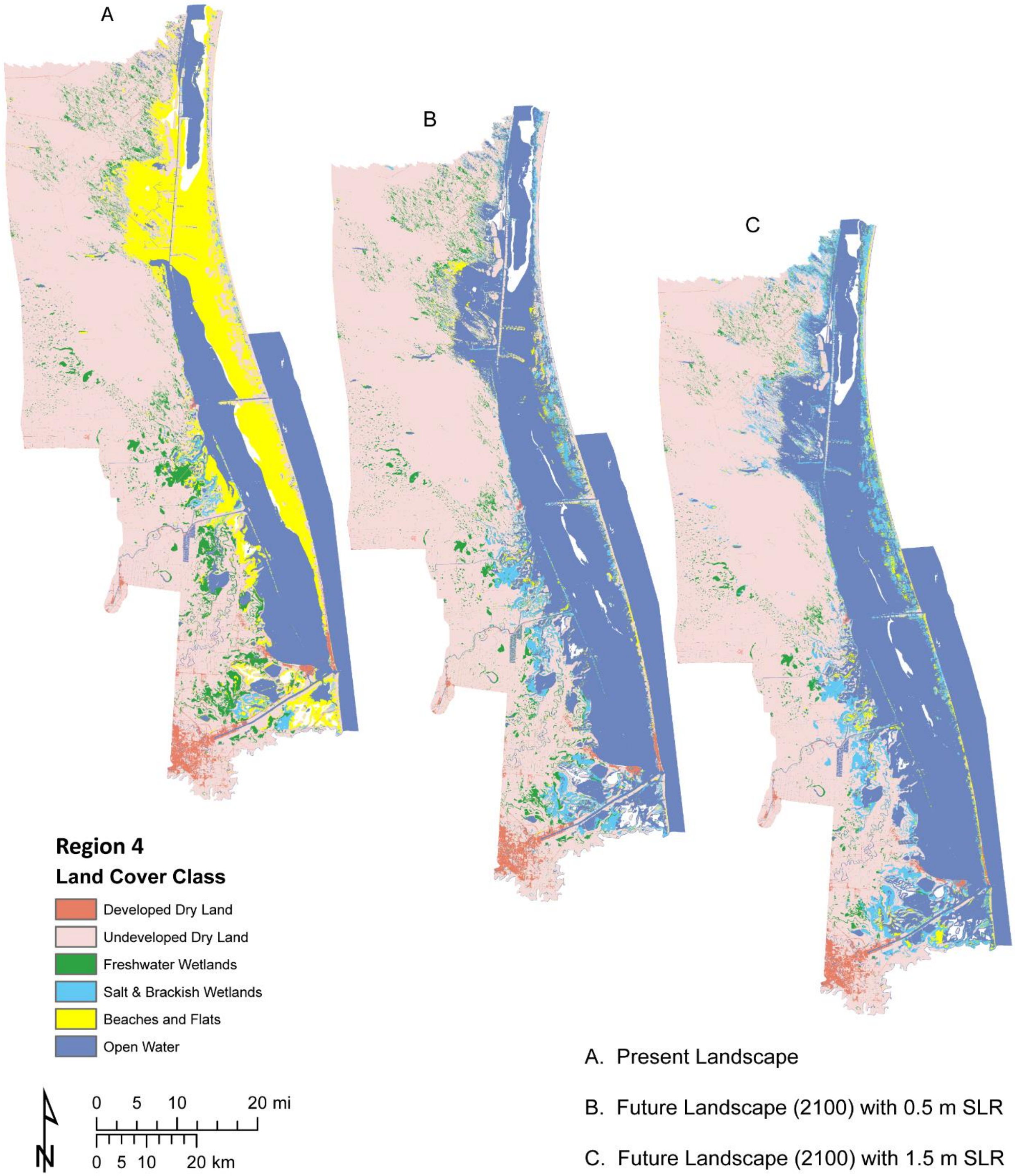


Figure 6-45 Map comparing the land cover distribution in Region 4 on the initial condition and 2100 conditions in both 0.5m and 1.5m SLR scenarios.

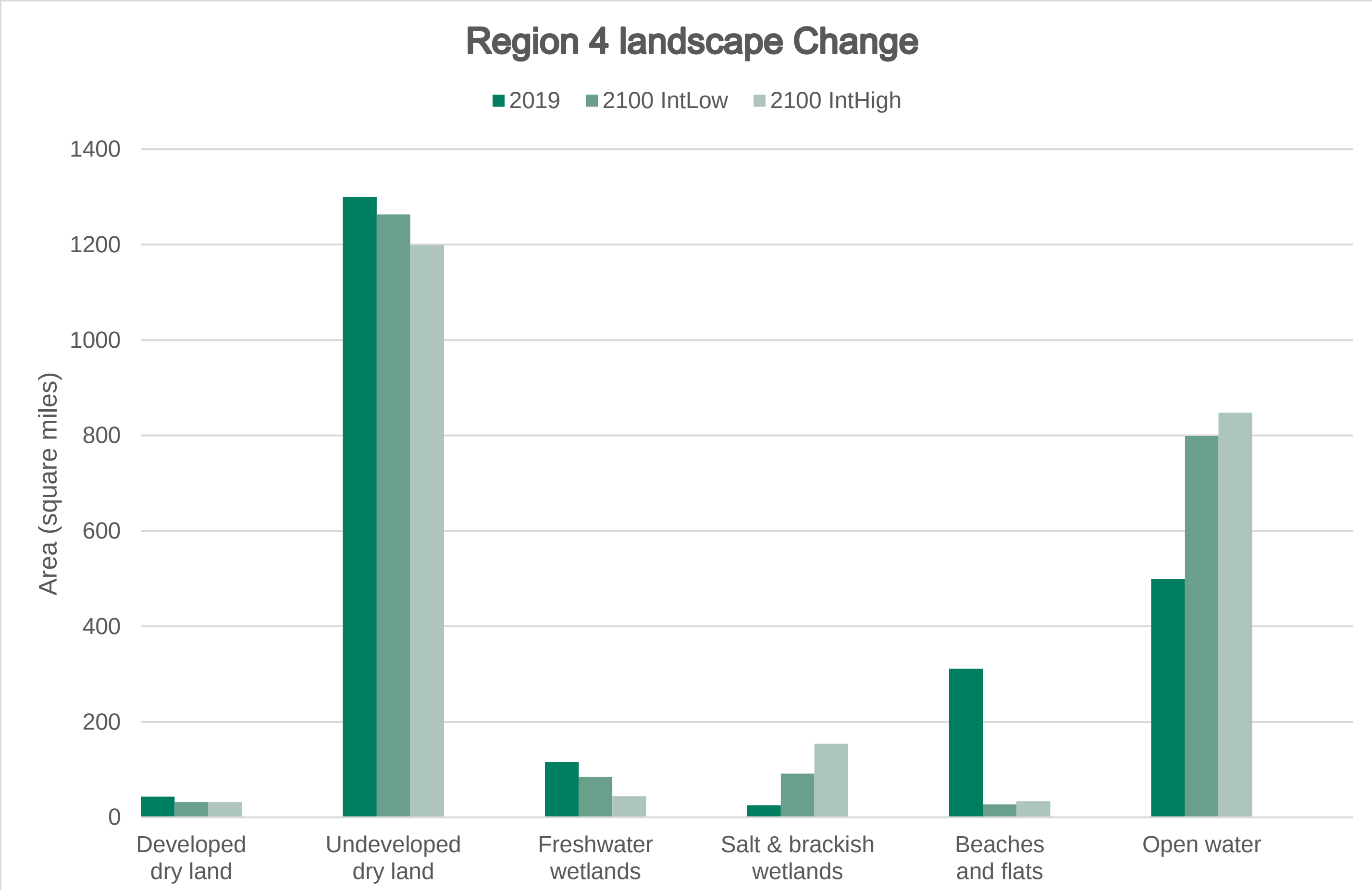


Figure 6-46 Graph comparing the land cover distribution in Region 4 on the initial condition (2019) and the 2100 conditions in both 0.5m and 1.5m SLR scenarios.

Table 6-14 The percent difference between land cover types in Region 4 in 2019 and 2100.

Land cover class	2019 (sq. miles)	2100 IntLow (sq. miles)	% Diff	2100 IntHigh (sq. miles)	% Diff
Developed dry land	43.36	31.46	-27.44	31.93	-26.36
Undeveloped dry land	1300.22	1262.99	-2.86	1198.83	-7.80
Freshwater wetlands, non-tidal	115.80	84.73	-26.83	44.27	-61.77
Salt & brackish emergent wetlands, tidal	25.58	91.50	257.70	154.44	503.75
Beaches and flats	311.27	27.19	-91.26	33.44	-89.26
Open water	499.62	798.93	59.91	848.02	69.73

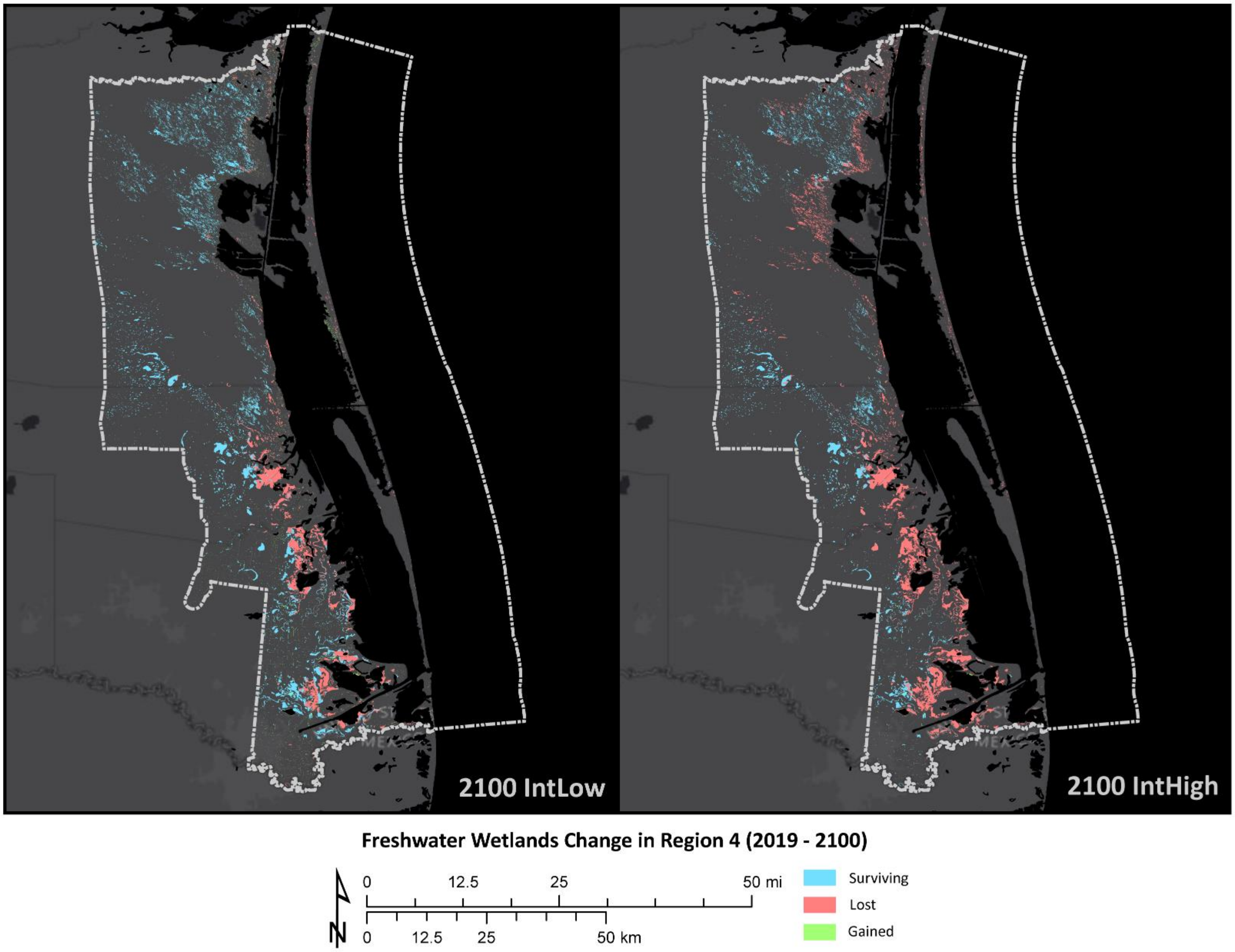


Figure 6-47 Map showing where freshwater wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

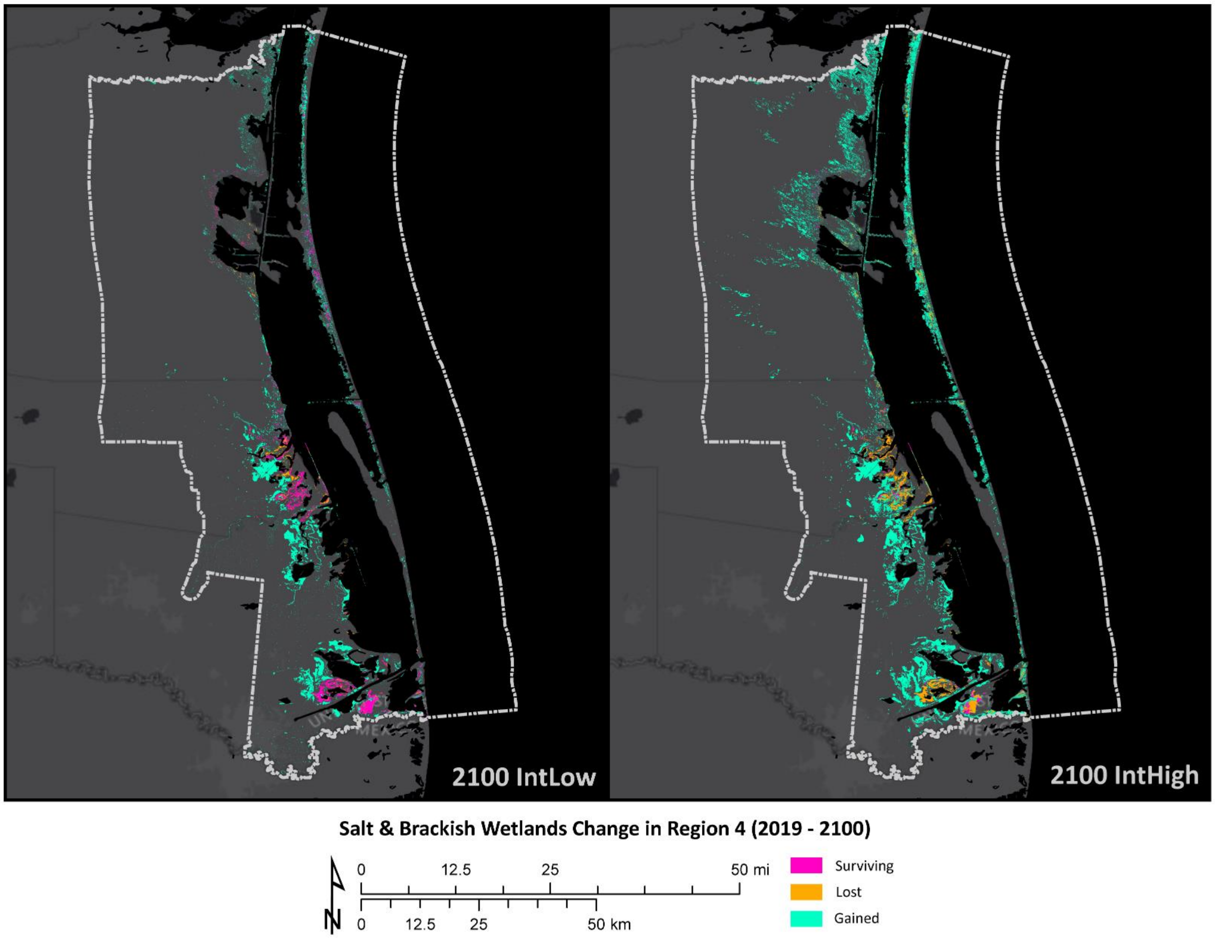


Figure 6-48 Map showing where brackish wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

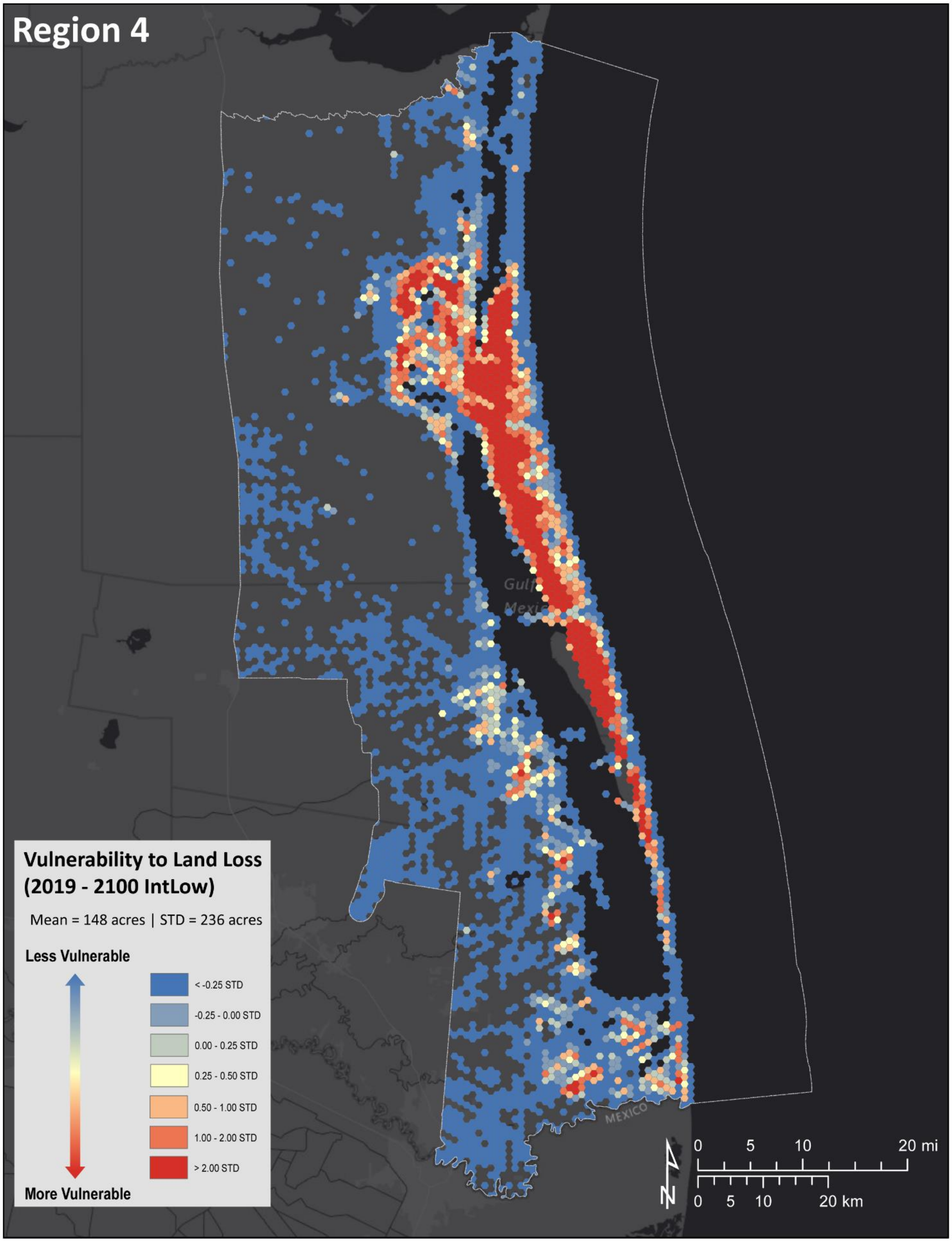


Figure 6-49 Map showing where brackish wetlands that exist on the present landscape are modeled to either survive, be converted to another land cover type or open water, or gain area by the year 2100 in both 0.5m and 1.5m SLR scenarios.

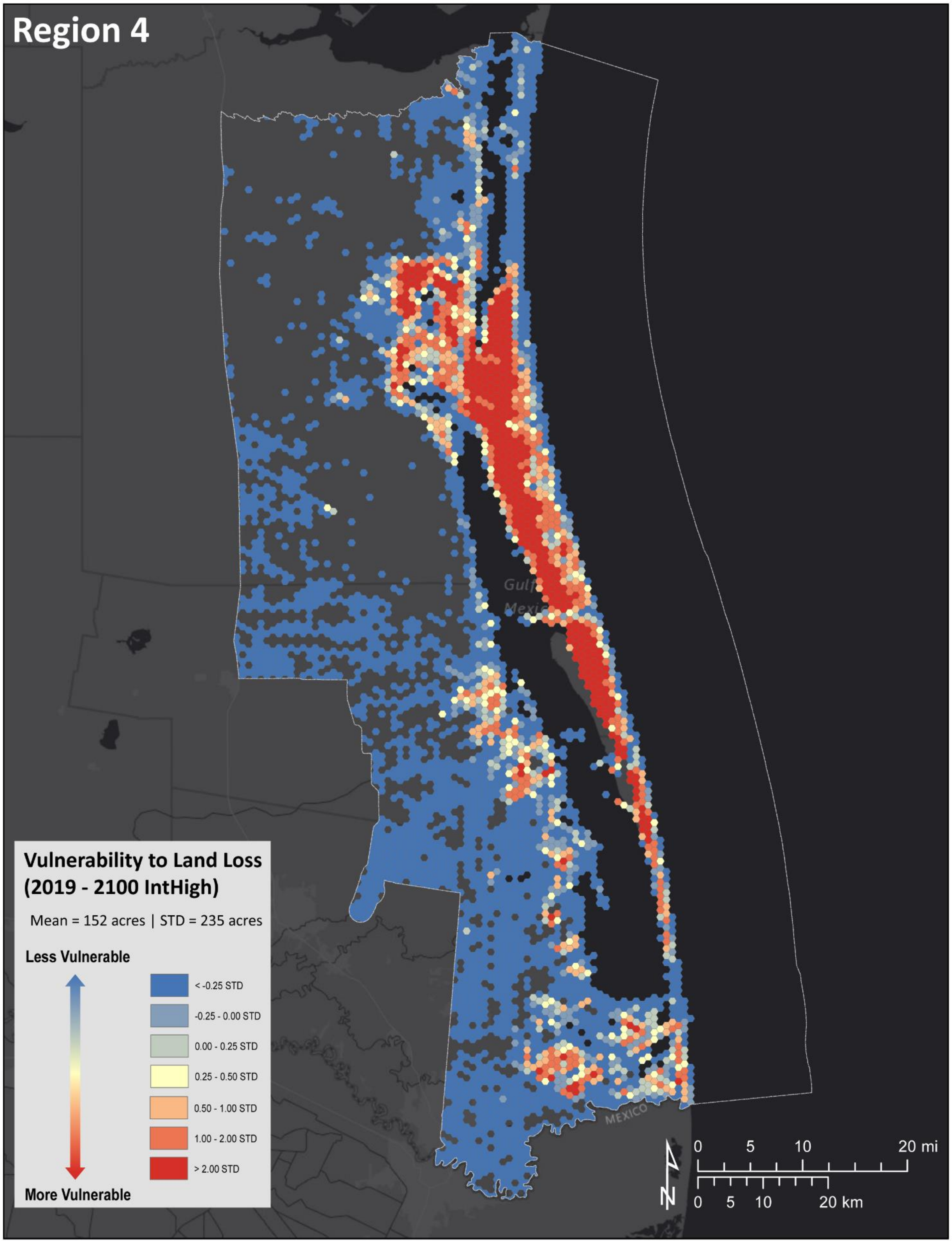


Figure 6-50 Map showing relative vulnerability to land loss in Region 4 where land loss means any type of land (excluding intertidal flats) that has converted to open water by the year 2100 in 1.5m SLR scenario.

6.3.2 Storm Surge Modeling

The following subsections present the maximum inundation extent for 19 synthetic storms in both the present and future landscapes with SLR. It also provides detail on the simulated maximum water surface elevation (MAXELE) analysis for a handful of storms. The MAXELE, also known as the maximum envelope of water (MEOW), is the maximum storm surge elevation computed at any point during the hurricane and provides information about the maximum inundation patterns. The maximum inundation extent maps illustrate the increased extent of maximum surge in the future landscape compared to the present landscape. To determine the amount of flooding caused by storm surge, the total inundated land area was calculated for each region where the storm made landfall.

In both the present and future landscapes, the right side (east) of the storm track experienced the highest storm surge impact due to the counterclockwise direction of the circulating winds during the hurricane, and the stronger winds passing on the right side (east) of the storm track. Most storms under the present landscape had a maximum storm surge elevation of 4-6 m, with a few storms having a MAXELE higher than 6 m, such as Storm 322, Storm 214, and Storm 216. In contrast, Storm 466, Storm 160, and Storm 240 had a MAXELE lower than 4 m under present conditions.

The future landscape simulations showed that the maximum storm surge elevation followed similar trends as observed in the present conditions. However, the water level was significantly higher under the future conditions than in the present condition, penetrating considerably farther inland. The intermediate-low scenario resulted in a 0.5m increase in maximum storm surge offshore, which was equivalent to the SLR value used in the model. The intermediate-high scenario led to a 1.5m increase in maximum storm surge offshore, which was the SLR value added to the model. It could be due to relatively deep water and low bottom friction offshore.

The increase in surge throughout the region ranged from 0.5-3 m in the future landscape simulations. However, it is important to note that storm surge flooding under SLR in the future landscape along the nearshore and complex coastlines was nonlinear. A significant variation in storm surge elevation between the present and future conditions was observed for all storm simulations. The increase in surge inland was higher by a factor of 1 m or more under the intermediate-low SLR scenario and 3 m or more under the intermediate-high scenario in many locations, which showed a nonlinear increase above the SLR value added to the model. Some locations showed an increment of less than the added SLR value, possibly due to the additional SLR allowing water to go farther inland and exposing new areas to inundation, which decreased water levels in the newly exposed flooded area.

The study also found that the higher sea level enabled an early arrival of the peak surge in the future condition compared to the present condition and significantly increased the time of inundation along the barrier islands and inland regions. The surge driven inland took longer to recede back to the Gulf of Mexico due to the increased sea level, significantly prolonging the timing of inundation in future condition.

Region 1

The study analyzed a total of 9 storms that made landfall in Region 1 under the present condition and two future conditions – Storm 466, Storm 160, Storm 363, Storm 262, Storm 358, Storm 154, Storm 587, Storm 449, and Storm 524. Among these storms, four were Category 1 storms, 4 were Category 2 and the remaining 1 storm was a Category 3 storm. Storm 466 and Storm 154 were also modeled for the 2019 Plan. Each storm possesses unique characteristics, such as forward speed, a RMW, central pressure, orientation, and more (refer to **Table 6-15**). Therefore, their storm surge impacts differed from one another.

Table 6-15. Selected storms that made landfall in Region 1 and their characteristics

Storm	Wind Speed (kt)	RMW (Nmi)	Forward Speed (kt)	Central Pressure (mb)	Heading (deg)	Landfall Location
Storm 466	63.14	37.33	6.5	963.7	-20	High Island
Storm 160	86.99	7.29	8.6	927.3	-80	Bolivar Peninsula
Storm 363	76.84	20.17	6.2	927.3	-40	Anahuac Wildlife Refuge
Storm 262	84.21	22.86	5.9	921.3	-60	Galveston
Storm 358	86.91	10.08	9.5	955.4	-40	Galveston Island

Storm	Wind Speed (kt)	RMW (Nmi)	Forward Speed (kt)	Central Pressure (mb)	Heading (deg)	Landfall Location
Storm 154	87.77	34.71	10.3	940.4	-80	Follets Island
Storm 587	96.55	17.33	7.9	910.2	20	Galveston Island
Storm 449	74.67	34.9	19.5	947.7	-20	Freeport
Storm 524	81.35	23.58	13.1	940.4	0	Freeport (Brazos River)

In order to measure the extent of flooding caused by a more intense storm surge in the future landscape, the study computed the total area of inundated land within Region 1 for both present and future landscapes in the intermediate-low and intermediate-high scenarios. Based on the landscape change modeling, it was discovered that in the intermediate-low scenario, approximately 68 square miles of land in Region 1 were lost and converted to open water due to RSLR. This area significantly increased to 457 square miles in the intermediate-high scenario.

Storm 466

Figure 6-51 shows the MAXELE resulting from Storm 466 in four distinct landscape and sea-level scenarios. In addition to two future scenarios modeled, it includes the MAXELE resulting from the intermediate SLR scenario modeled for the 2019 Plan as a point of reference. An area with 1 – 2.5 m of inundation observed on the right side of the landfall along the McFaddin National Wildlife Refuge in the present landscape increased to more than 4 m in the future landscapes. Additionally, the water level was significantly higher in the future scenarios, causing a significant area to the west of the landfall to become flooded and extended considerably farther inland compared to the present landscape.

Within the Region 1 area, Storm 466 caused a total land inundated area of 626 square miles in the present landscape. In the future landscape, the total area of inundation resulting from Storm 466 in Region 1 was 1,036 square miles in the intermediate-low scenario, which represents a 65% increase. In the intermediate-high scenario, the total area of inundation resulting from Storm 466 in Region 1 was 1,376 square miles, representing a 120% increase. **Figure 6-52** shows the extent of the inundation (inundation envelope) due to Storm 466 in the present landscape compared to two future landscapes.

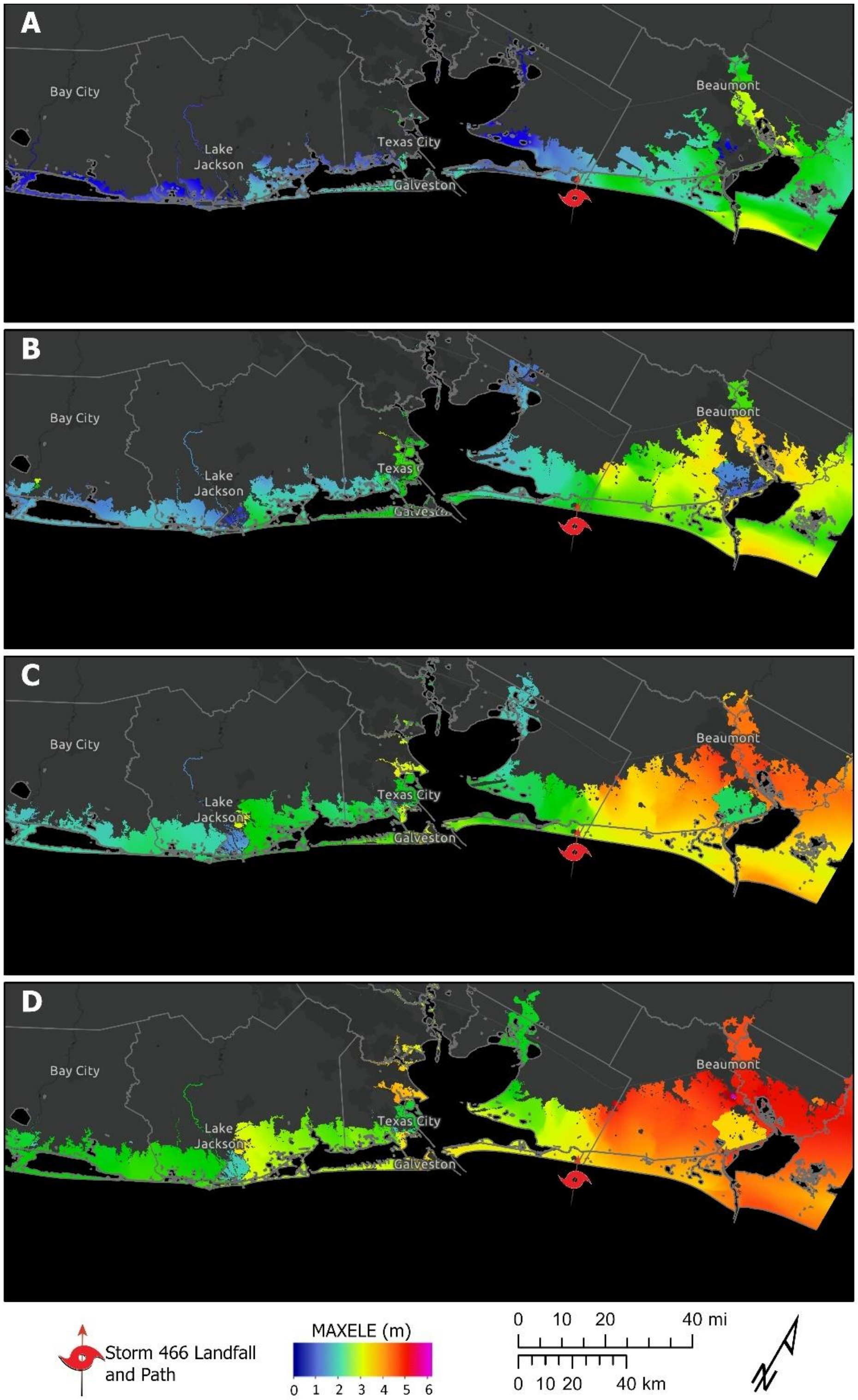


Figure 6-51. Maximum water surface elevation (MAXELE) due to Storm 466 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, (C) Future landscape - Intermediate SLR scenario (from 2019 Plan), and (D) Future landscape - Intermediate-high SLR scenario.

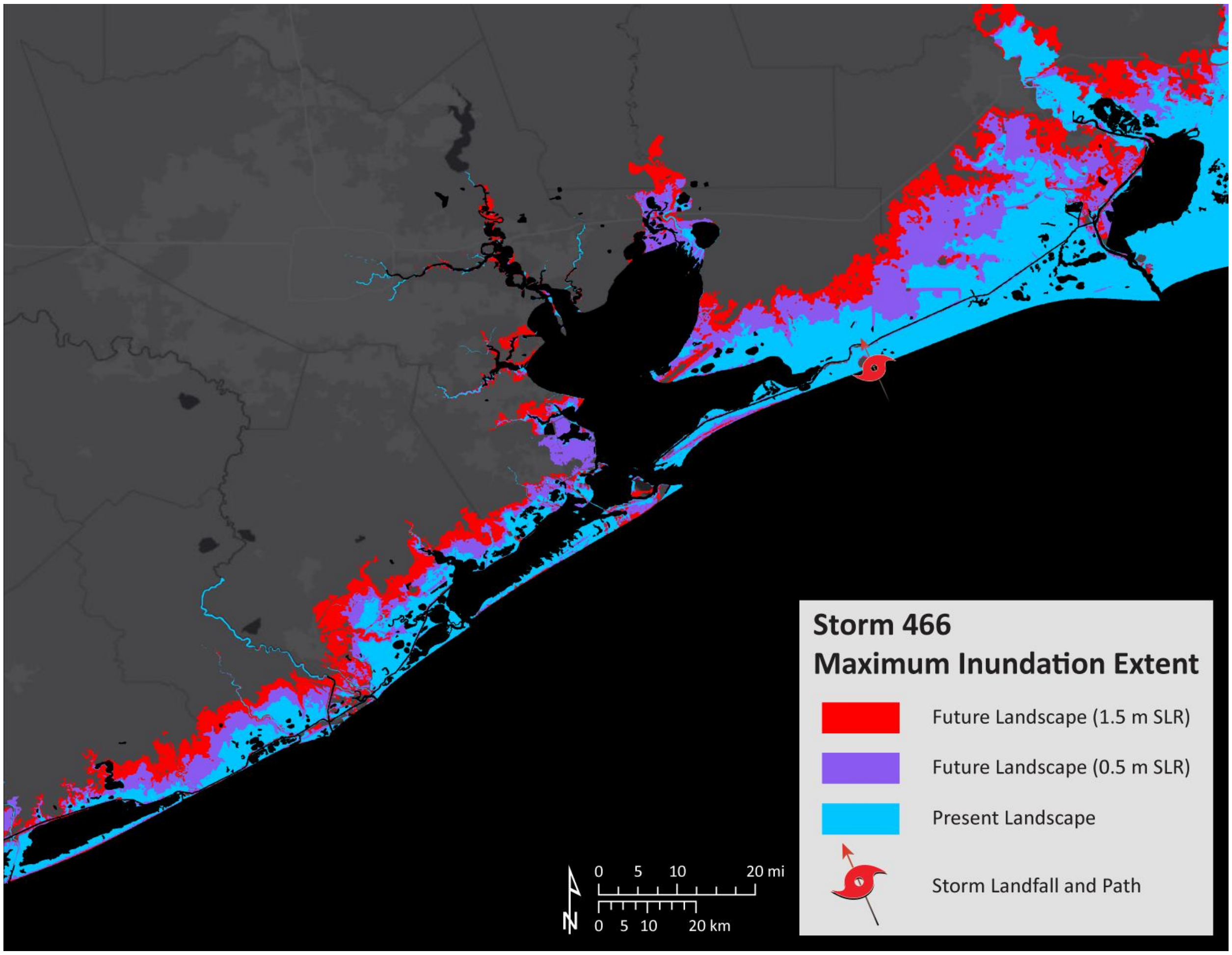


Figure 6-52. Maximum extent of inundation due to Storm 466

Storm 160

Figure 6-53 displays the maximum water surface elevation resulting from Storm 160 in the present landscape and two future landscapes modeled for the 2023 Plan. Despite being a Category 2 hurricane with a wind speed of 100 miles per hour at landfall, Storm 160 has the smallest RMW (8.4 miles at landfall) among the modeled 19 storms. The surge height caused by the storm was the smallest among all modeled storms, with a general surge height of 1-2 meters on the east side of the landfall location. The increase in surge height nearshore was consistent with the added SLR value in the future landscape. However, the storm surge was able to penetrate much farther inland in the future landscape compared to the present landscape. A significant increase in storm surge inundation was observed on the west side of the landfall in the future landscape, resulting in a considerable increase in the inundation area in future scenarios.

Figure 6-54 shows the maximum extent of inundation resulting from Storm 160 in the present landscape and two future landscapes. The total inundated land area within Region 1 in the present landscape was 273 square miles. In future landscapes, the total area of inundation was 698 square miles in the intermediate-low scenario and 1,052 square miles in the intermediate-high scenario, which is a 156% and 285% increase from the present landscape, respectively.

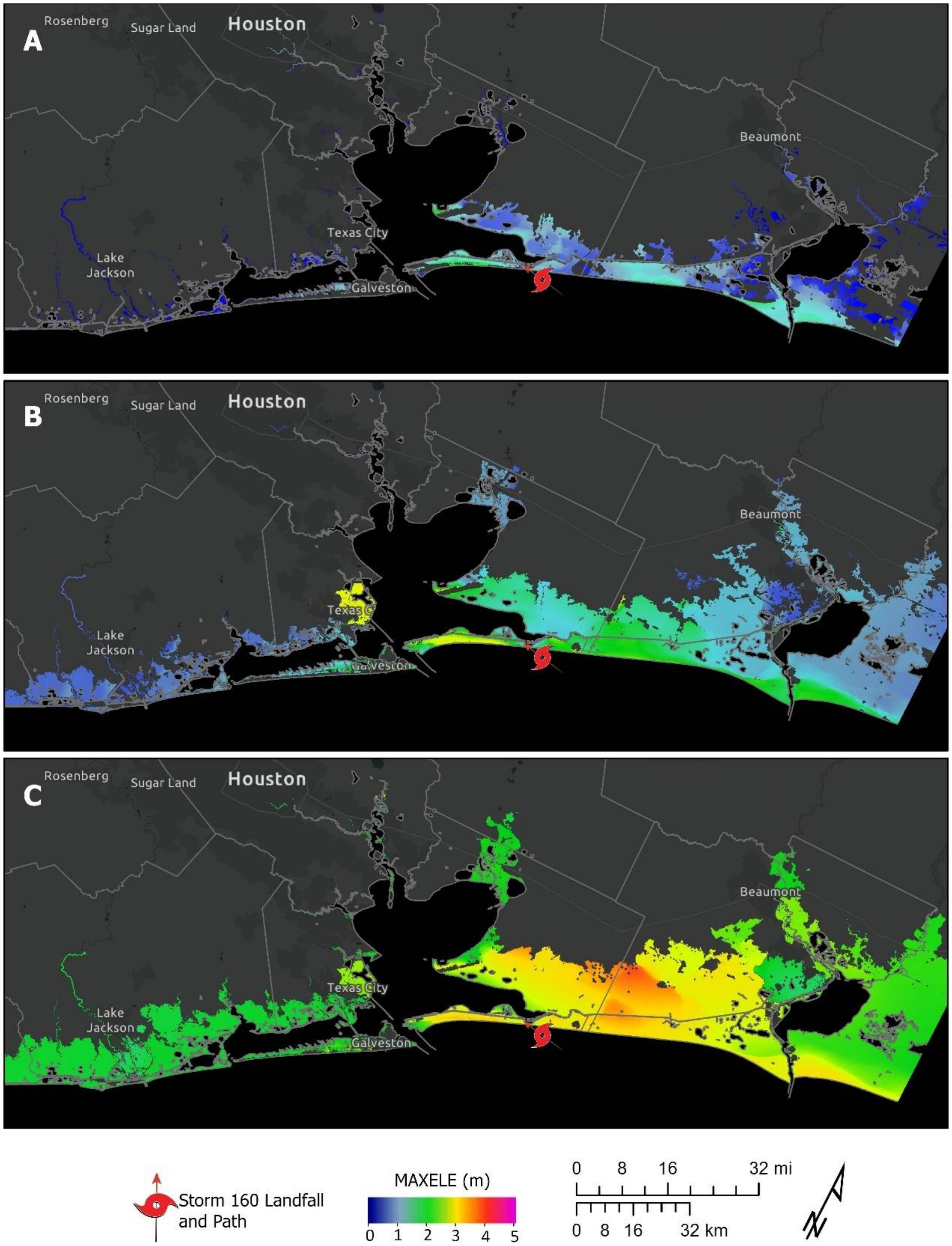


Figure 6-53. Maximum water surface elevation (MAXELE) due to Storm 160 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

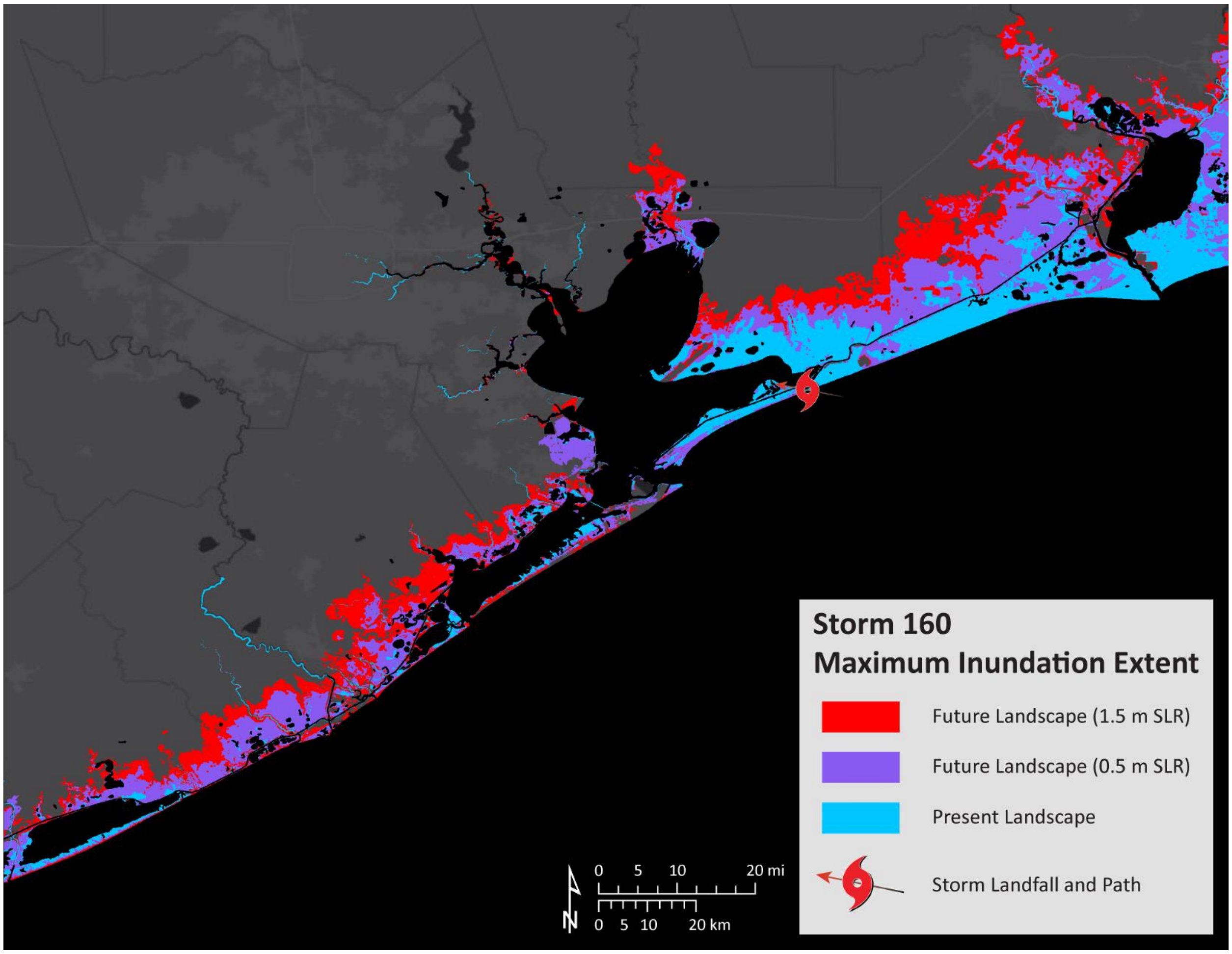


Figure 6-54. Maximum extent of inundation due to Storm 160.

Storm 363

Figure 6-55 shows the maximum water surface elevation resulting from Storm 363 in the present landscape and two future landscapes modeled for the 2023 Plan. In the present landscape, an area with 2.5 – 4 m of inundation is visible on the right side of the landfall along the McFaddin National Wildlife Refuge, which escalates to more than 5 m in the future landscapes. The storm surge impact was found to be similar to Storm 466 (Figure 6-51) which made landfall just 3 miles east of Storm 363. However, the water level was considerably higher in the future scenarios, causing a significant area to the west of the landfall to become flooded and extended considerably farther inland compared to the present landscape.

In the Region 1 area, Storm 363 caused a total land inundated area of 689 square miles in the present landscape which was very similar to the inundation area due to Storm 466. In the intermediate-low scenario of the future landscape, the total area of inundation resulting from Storm 363 in Region 1 was 1,063 square miles, representing a 54% increase. In the intermediate-high scenario, the total area of inundation resulting from Storm 363 in Region 1 was 1,395 square miles, representing a 102% increase. **Figure 6-56** shows the extent of the inundation due to Storm 363 in the present landscape compared to two future landscapes.

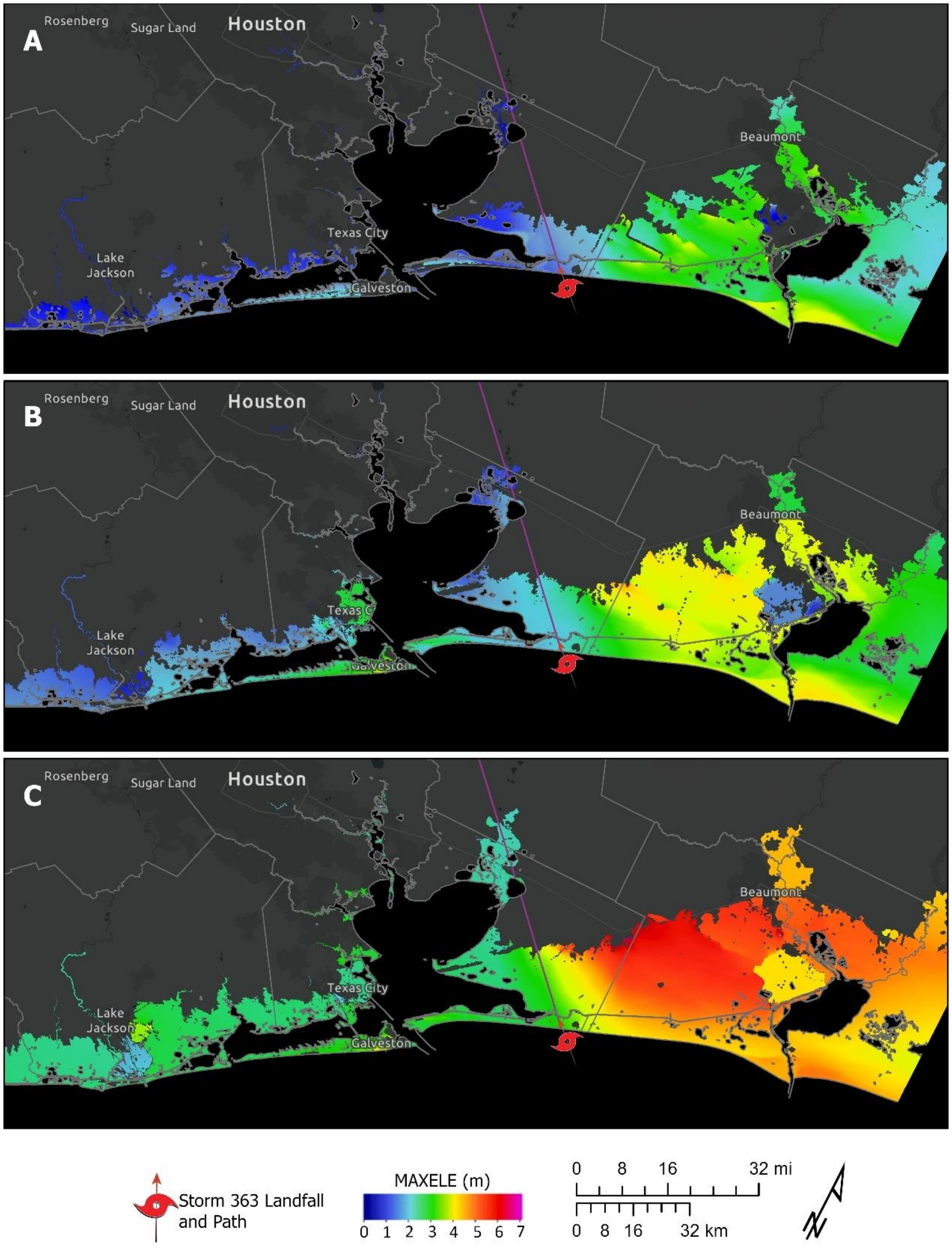


Figure 6-55. Maximum water surface elevation (MAXELE) due to Storm 363 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

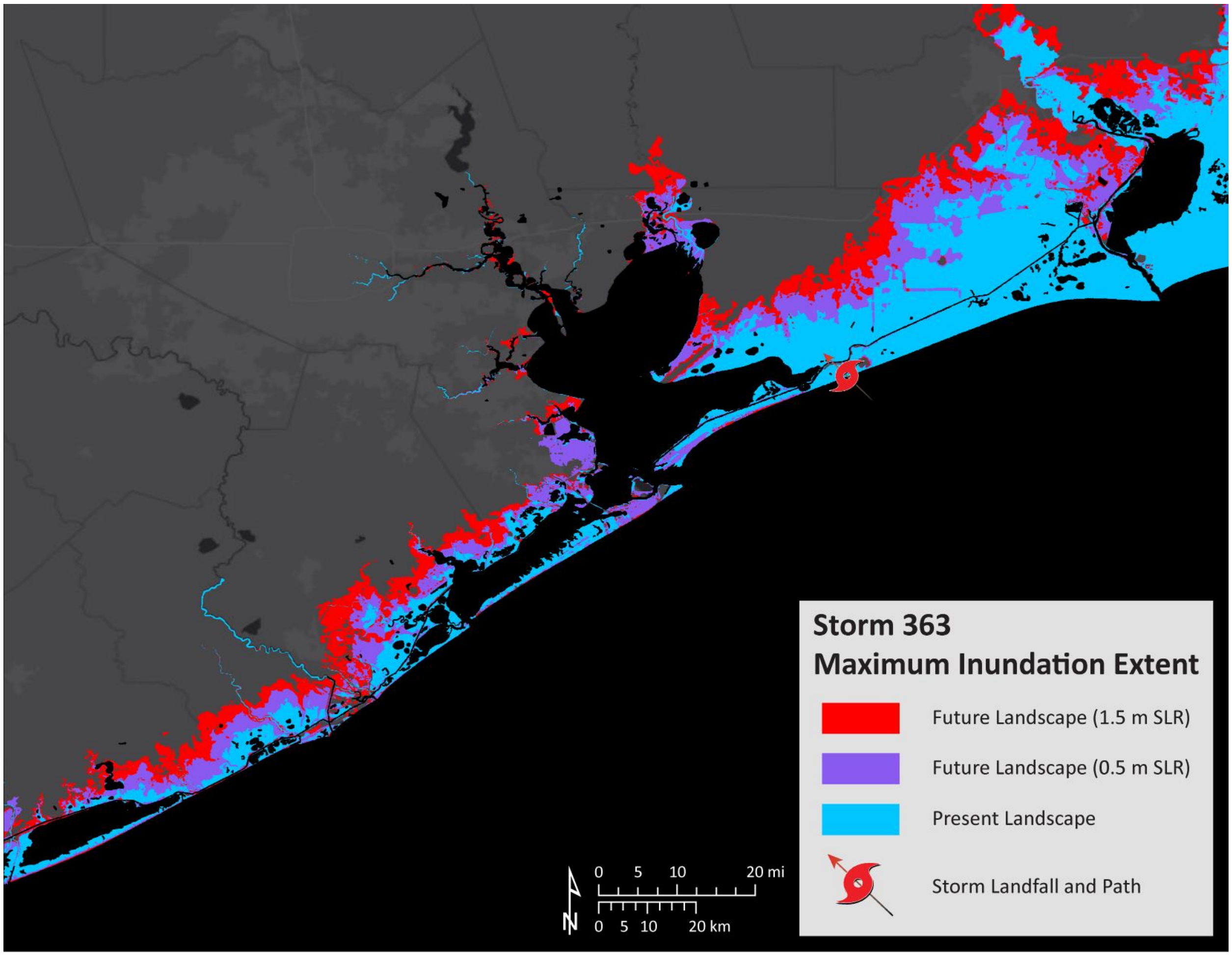


Figure 6-56. Maximum extent of inundation due to Storm 363.

Storm 262

Figure 6-57 shows the maximum water surface elevation resulting from Storm 262 in the present landscape and two future landscapes with SLR. This slow moving, relatively large Category 2 storm made landfall in Galveston, causing a storm surge of 2 – 3 m in the Galveston Island under the present landscape. In the future landscapes, the surge height increased to 4 -5 m in the island. The storm surge was able to penetrate much farther inland in the future landscapes causing a significant impact in the west side of Galveston Bay as well as in Houston.

In the present landscape, Storm 262 caused a total inundated land area of 851 square miles within Region 1. In the intermediate-low and intermediate-high scenarios of future landscapes, the total inundation areas resulting from Storm 262 were 1,174 and 1,526 square miles, respectively, representing a 38% and 79% increase from the present landscape. Figure 6-58 shows the maximum extent of inundation resulting from Storm 262 in the present landscape and two future landscapes.

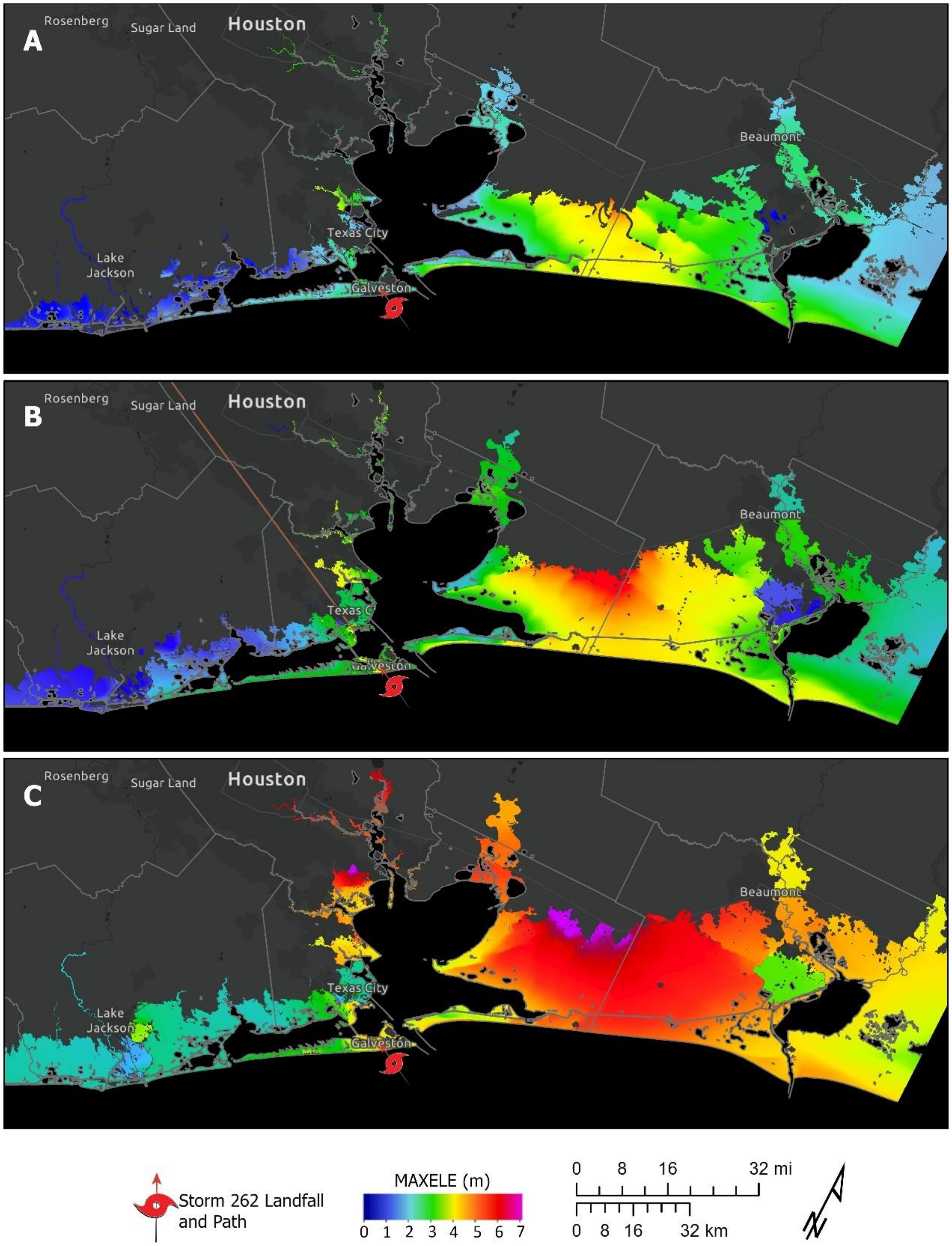


Figure 6-57. Maximum water surface elevation (MAXELE) due to Storm 262 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

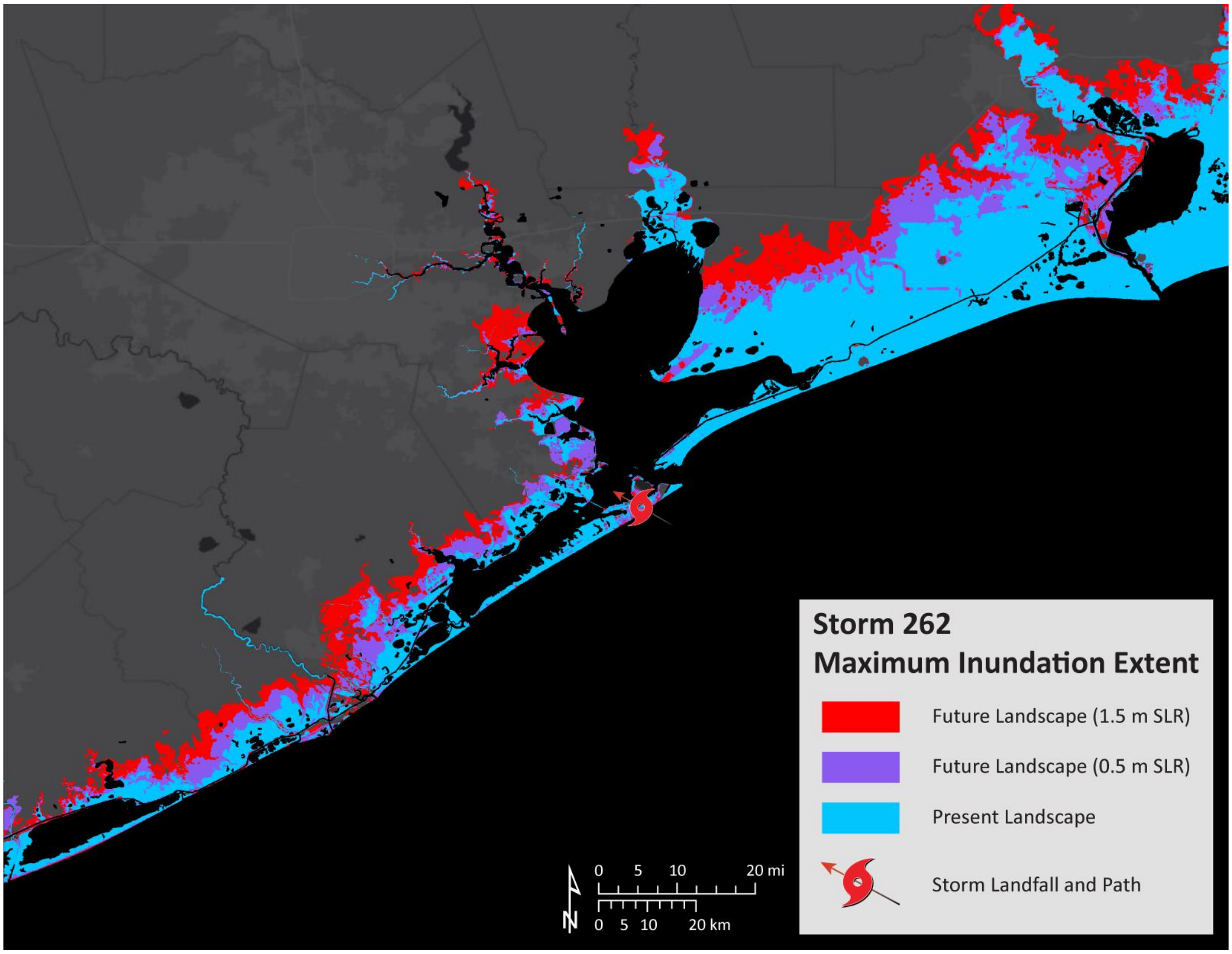


Figure 6-58. Maximum extent of inundation due to Storm 262.

Storm 358

Figure 6-59 shows the maximum water surface elevation resulting from Storm 358 in the present and two future landscapes modeled for the 2023 Plan. Storm 358 made landfall 7 miles west of Storm 262 in Galveston Island and was also a Category 2 hurricane with wind speeds similar to Storm 262. However, Storm 358 has a relatively small RMW compared to Storm 262 but has higher central pressure. Despite these differences, the storm surge impact between the two storms was significantly different.

In the present landscape, Storm 358's storm surge penetration was considerably less than that of Storm 262, with a surge height of less than 1 meter in most areas except for Galveston Island, Bolivar Peninsula, and Texas City. The future landscape showed that the storm surge was able to penetrate further inland, but the surge height and inundation area were still significantly less than that of Storm 262.

In the Region 1 area, Storm 358 caused a total land inundation area of 246 square miles in the present landscape, which was 71% less than that caused by Storm 262. In the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 358 in Region 1 was 744 and 1,157 square miles, representing a 202% and 370% increase from the present landscape, respectively. Although the percentage increase from the present to future landscapes was higher than that of Storm 262, the total inundation area within Region 1 in the future landscapes was still 37% and 24% less than that due to Storm 262 in the intermediate-low and intermediate-high scenarios. **Figure 6-60** shows the extent of the inundation due to Storm 363 in the present landscape compared to two future landscapes.

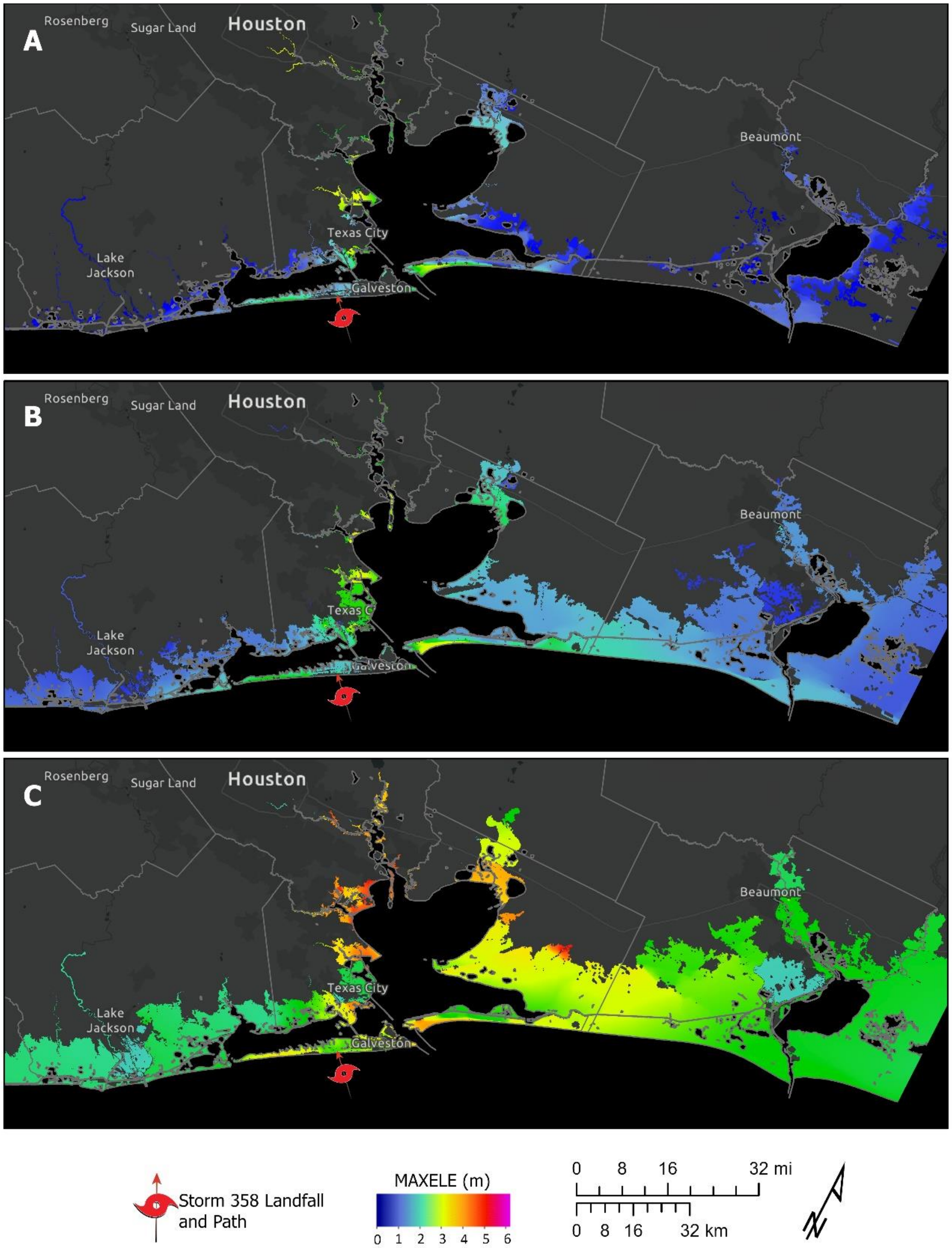


Figure 6-59. Maximum water surface elevation (MAXELE) due to Storm 358 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

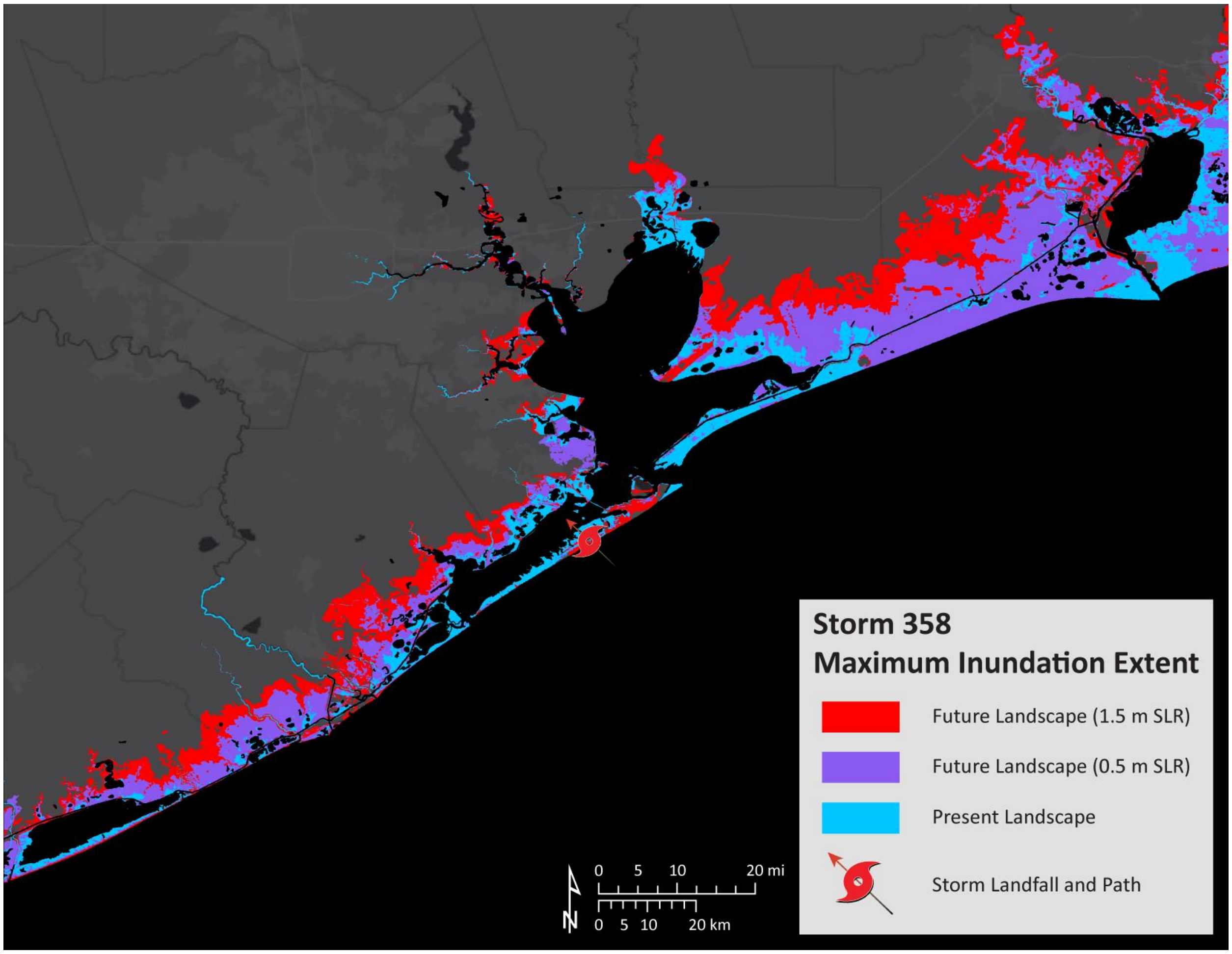


Figure 6-60. Maximum extent of inundation due to Storm 358.

Storm 154

Figure 6-61 shows the maximum water surface elevation resulting from Storm 154 in four distinct landscape and sea-level scenarios. In addition to two future scenarios modeled, it includes the MAXELE resulting from the intermediate SLR scenario modeled for the 2019 Plan as a point of reference. The storm surge impact due to Storm 154 in the present landscape looked similar to Storm 262 (**Figure 6-57**). An area with 2 - 4 m of inundation was observed in Galveston Island, Bolivar Peninsula, and McFaddin National Wildlife Refuge area in the present landscape, which increased to more than 4 m in the future landscapes. Additionally, the storm surge was significantly higher in all three future landscape scenarios, causing a significant area in Galveston, Chambers, and Jefferson County to become flooded, and extended considerably farther inland to Harris and Orange County compared to the present landscape.

In the present landscape, Storm 154 caused a total inundated land area of 805 square miles within Region 1, which is very similar to Storm 262. In the future landscape, the total area of inundation resulting from Storm 154 in Region 1 was 1,114 square miles in the intermediate-low scenario, which represents a 39% increase. In the intermediate-high scenario, the total area of inundation resulting from Storm 154 in Region 1 was 1,439 square miles, representing a 79% increase from the present landscape. **Figure 6-62** shows the maximum extent of the inundation due to Storm 154 in the present landscape compared to two future landscapes.

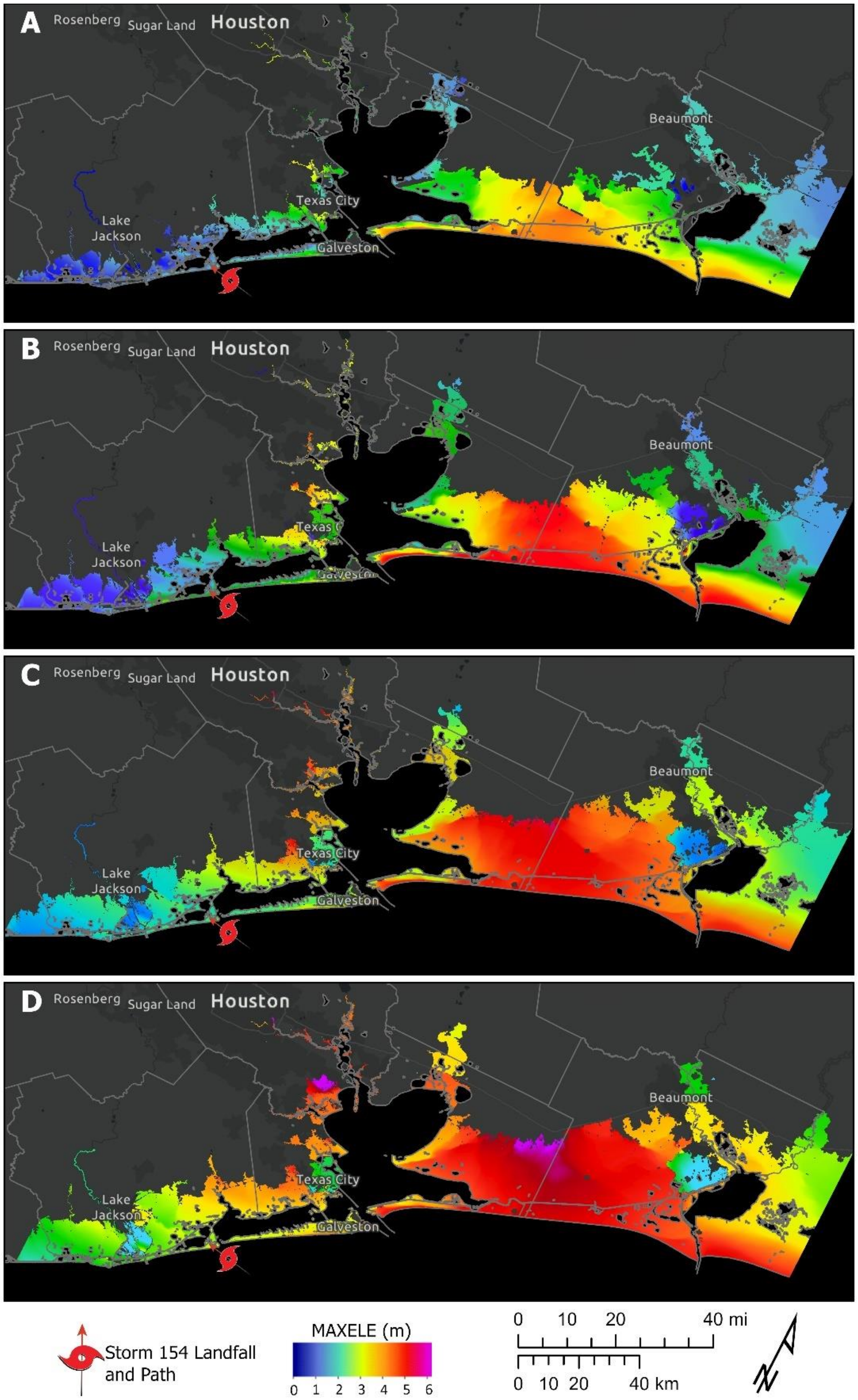


Figure 6-61. Maximum water surface elevation (MAXELE) due to Storm 154 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, (C) Future landscape - Intermediate SLR scenario (from 2019 Plan), and (D) Future landscape - Intermediate-high SLR scenario

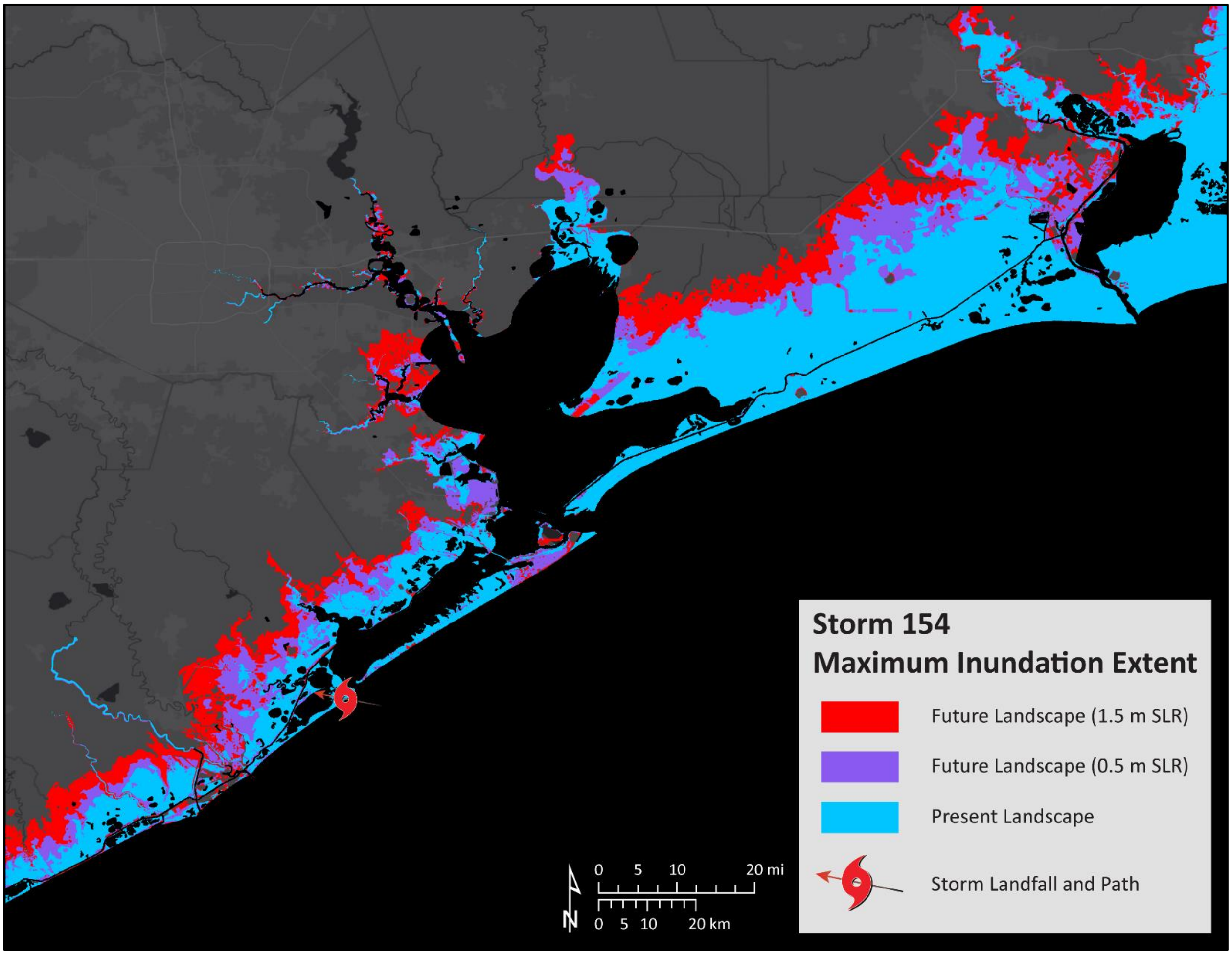


Figure 6-62. Maximum extent of inundation due to Storm 154

Storm 587

Figure 6-63 presents the maximum water surface elevation resulting from Storm 587 in the present landscape and two future landscapes with SLR. This slow-moving and relatively large storm has made landfall on the western end of Galveston Island and is the only Category 3 hurricane modeled in Region 1. The amount of storm surge impact seen in the Texas City and Seabrook area in the present landscape was not observed in any other storms modeled for Region 1. Additionally, the inland penetration observed due to this powerful storm was significantly higher than any other storms modeled in Region 1. The storm surge was able to reach much farther inland in the future landscapes, causing a massive increase in the flooding area. In the intermediate-high scenario, more than 5 m of surge height was observed throughout the region.

Figure 6-64 shows the maximum extent of inundation resulting from Storm 587 in the present landscape and two future landscape scenarios. The total inundated land area within Region 1 in the present landscape is 939 square miles. In future landscapes, the total area of inundation was 1,260 square miles in the intermediate-low scenario and 1,654 square miles in the intermediate-high scenario, which is a 34% and 76% increase from the present landscape, respectively.

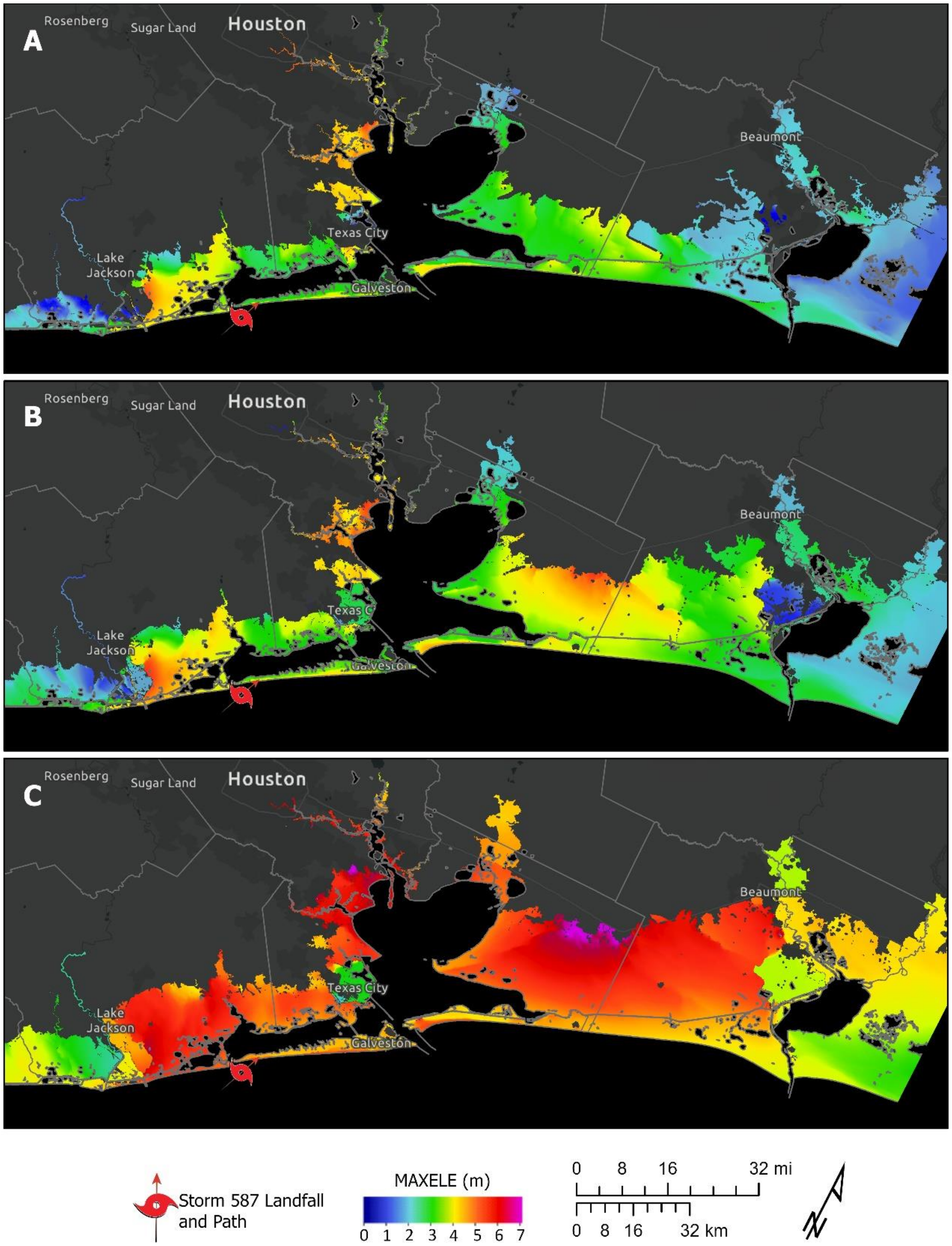


Figure 6-63. Maximum water surface elevation (MAXELE) due to Storm 587 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

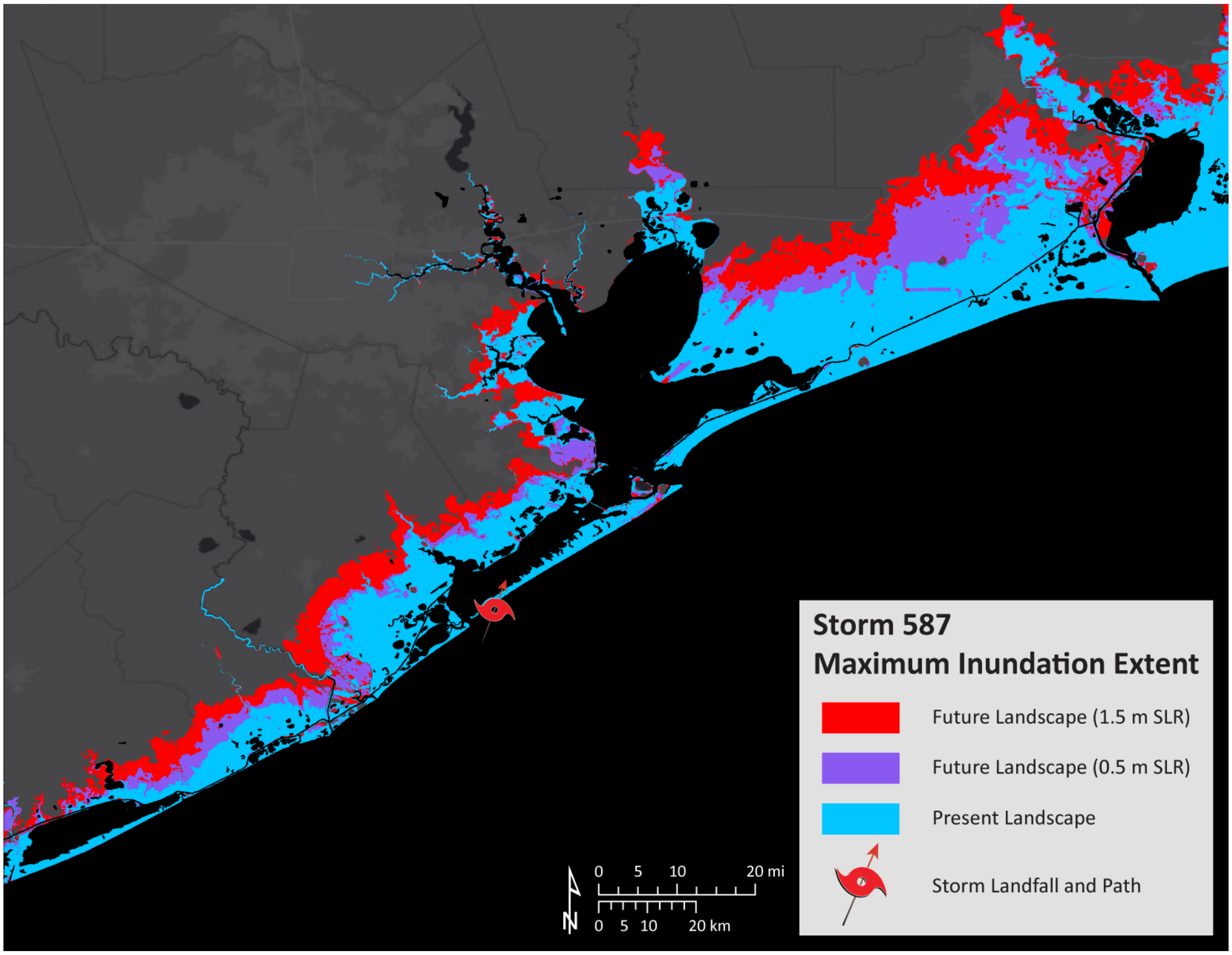


Figure 6-64. Maximum extent of inundation due to Storm 587.

Storm 449

Figure 6-65 shows the maximum water surface elevation resulting from Storm 449 in the present landscape and two future landscapes with SLR. This Category 1 hurricane has the highest forward speed among the 19 modeled storms for the 2023 Plan and is a relatively large RMW. The large wind field of Storm 449 generated strong currents that caused a significant buildup of water, leading to widespread flooding in the region. The storm surge impact in the region was even greater than that of the Category 3 hurricane, Storm 587 (see **Figure 6-63**). Despite making landfall near Freeport, the present landscape experienced 3.5 – 4.5 m of inundation in the Bolivar Peninsula and the McFaddin National Wildlife Refuge area. In the future landscape, an additional 2-3 m of surge height was observed throughout the region. The storm surge reached considerably farther inland compared to the present landscape causing massive widespread flooding of 6 m and more.

In the present landscape, Storm 449 caused a total inundated land area of 980 square miles in Region 1, which is 4% more than that caused by Category 3 Storm 587. In the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 449 in Region 1 was 1,249 and 1,655 square miles, representing a 27% and 69% increase from the present landscape, respectively. These inundation areas in the future landscapes were similar to those caused by Storm 587. Figure 6-66 shows the extent of the inundation due to Storm 449 in the present landscape compared to two future landscapes.

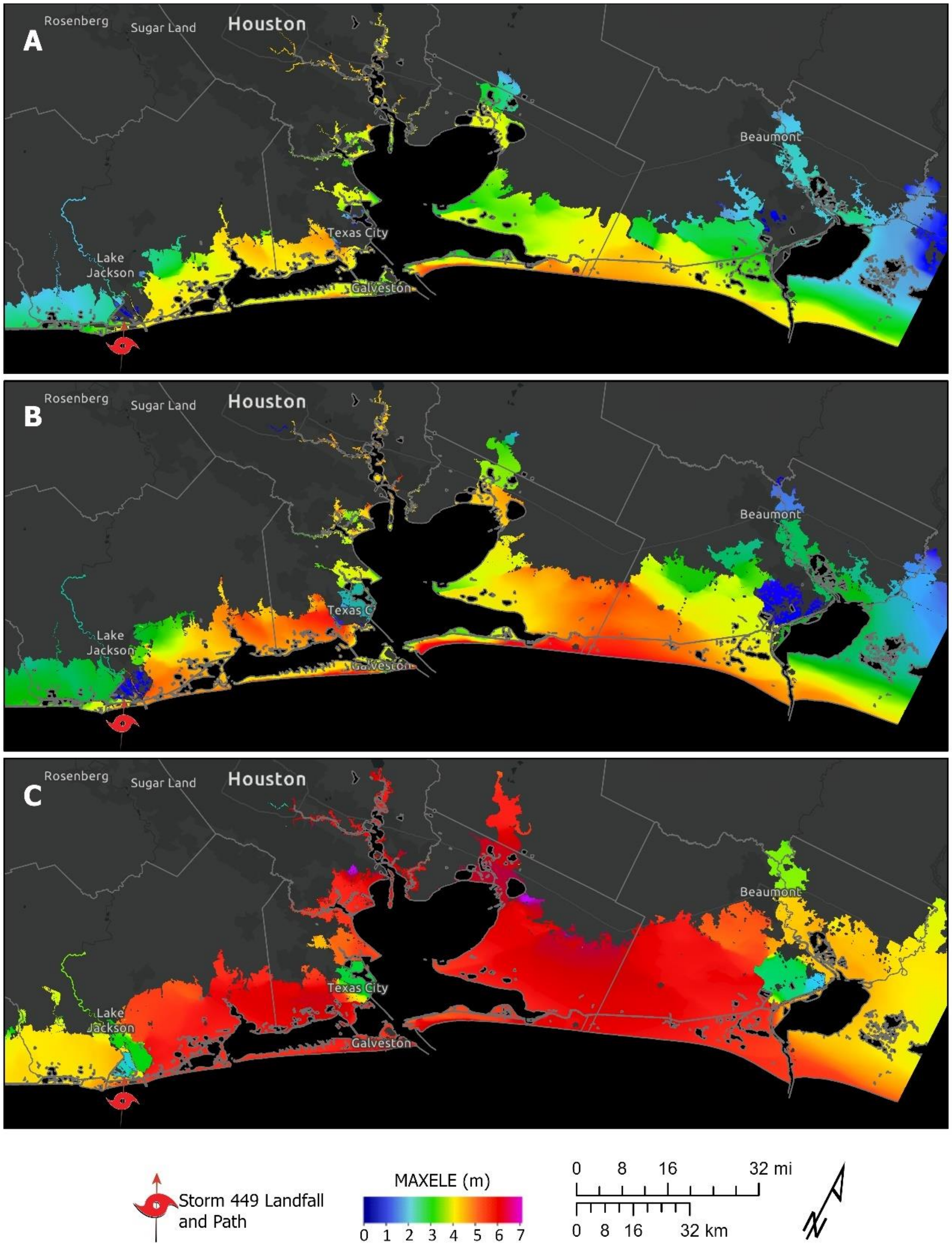


Figure 6-65. Maximum water surface elevation (MAXELE) due to Storm 449 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

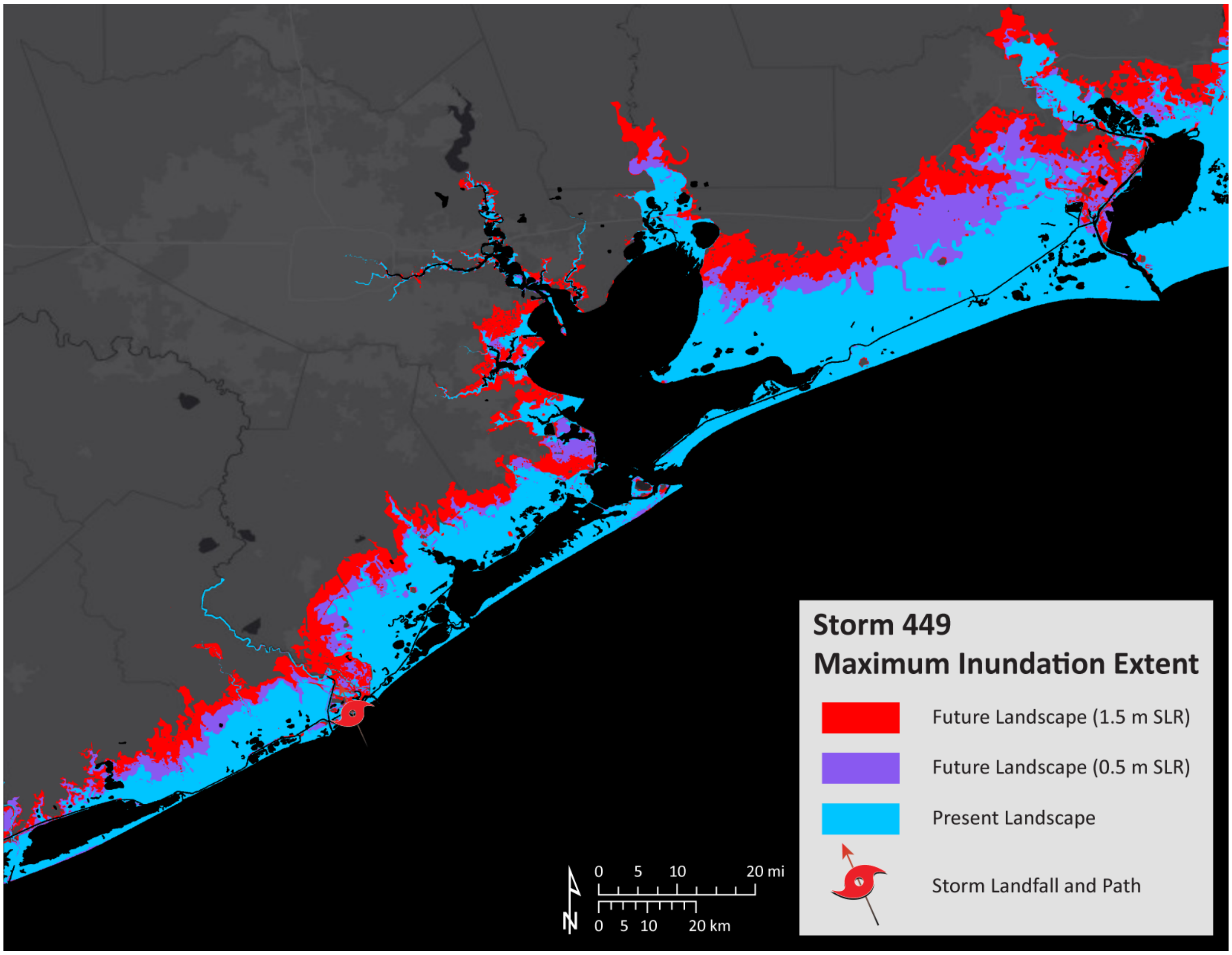


Figure 6-66. Maximum extent of inundation due to Storm 449.

Storm 524

Figure 6-67 presents the maximum water surface elevation caused by Storm 524 in the present landscape and two future landscapes with SLR. This Category 1 hurricane made landfall 7 miles west of Storm 449 near the mouth of the Brazos River, with higher wind speed and a smaller RMW compared to Storm 449. While the storm surge impact due to Storm 524 was similar to Storm 449 along the west side of Galveston Bay, Storm 449 had a greater impact on the east side of the bay due to its larger wind field. Both future landscape scenarios exhibited significantly higher storm surge impacts, causing extensive flooding throughout the region and extending much farther inland to Harris County and Orange County compared to the present landscape.

In the present landscape, Storm 524 caused a total inundated land area of 894 square miles within Region 1 and also caused a significant impact in Region 2 as it made landfall near the border of these two regions. In the future landscape, the total area of inundation resulting from Storm 524 in Region 1 was 1,124 square miles in the intermediate-low scenario, which represents a 25% increase. In the intermediate-high scenario, the total area of inundation resulting from Storm 524 in Region 1 was 1,607 square miles, representing an 80% increase from the present landscape. **Figure 6-68** shows the maximum extent of the inundation due to Storm 524 in the present landscape compared to two future landscapes.

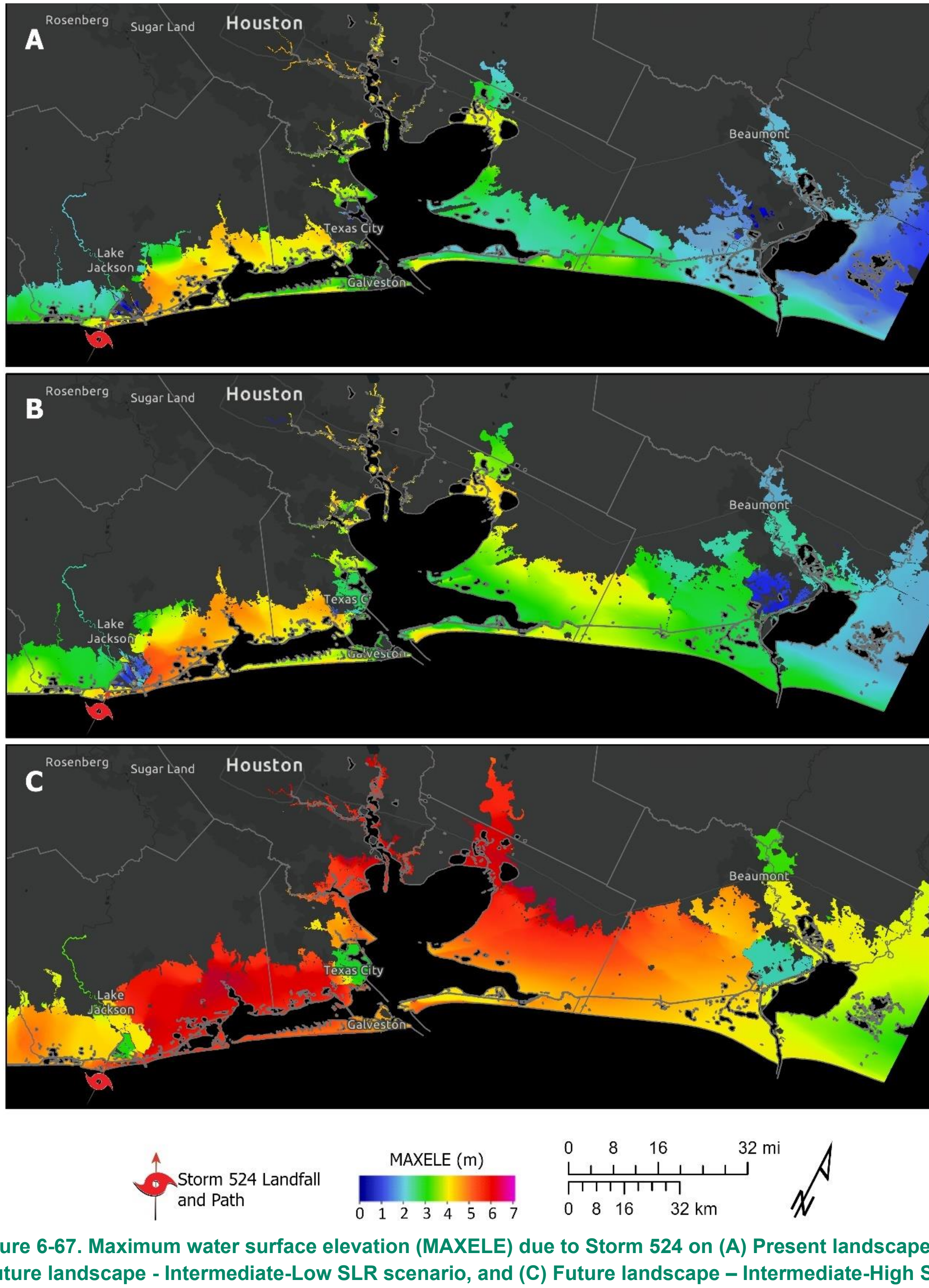


Figure 6-67. Maximum water surface elevation (MAXELE) due to Storm 524 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

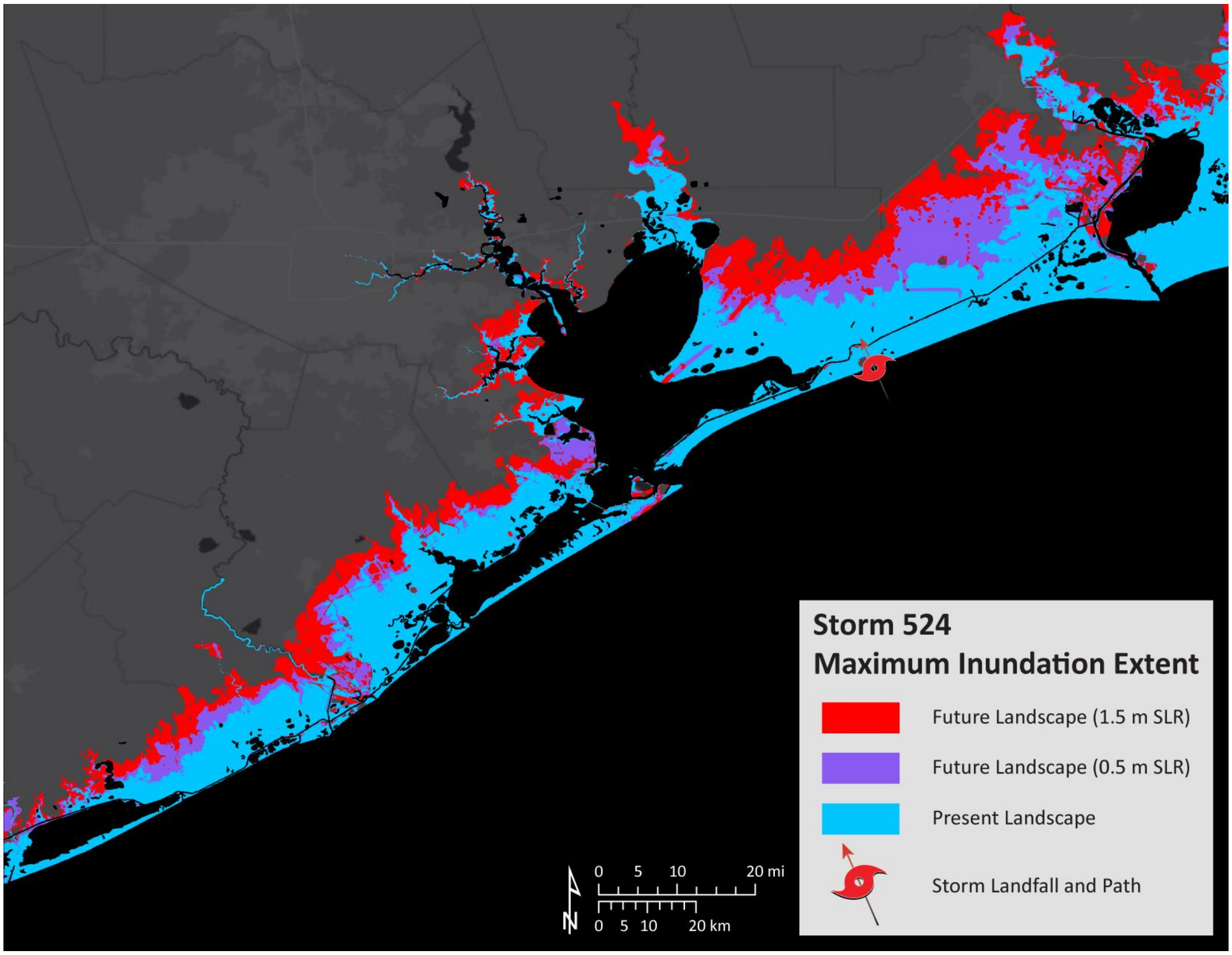


Figure 6-68. Maximum extent of inundation due to Storm 524.

Region 2

The study examined the impact of two Category 2 storms, Storm 146 and Storm 240, that made landfall in Region 2 under present and future conditions. These storms were also analyzed in the 2019 Plan, and their characteristics, including forward speed, the RMW, central pressure, orientation, and landfall location, are presented in **Table** .

To estimate the extent of flooding caused by intensified storm surges in the future landscape, the study calculated the total inundated land area in Region 2 for both present and future landscapes under the intermediate-low and intermediate-high scenarios. The landscape change modeling showed that in the intermediate-low scenario, around 68 square miles of land in Region 2 were lost and converted to open water due to RSLR. This area increased to 191 square miles in the intermediate-high scenario.

Table 6-16. Selected storms that made landfall in Region 2 and their characteristics

Storm	Wind Speed (kt)	RMW (Nmi)	Forward Speed (kt)	Central Pressure (mb)	Heading (deg)	Landfall Location
Storm 146	83.83	34.89	18.3	927.3	-80	Matagorda Peninsula
Storm 240	84.61	23.26	17.7	947.7	-60	Matagorda Island

Storm 146

Figure 6-69 shows the MAXELE resulting from Storm 146 in four distinct landscape and sea-level scenarios, including the MAXELE resulting from the intermediate SLR scenario modeled for the 2019 Plan for reference. Storm 146, a Category 2 hurricane with a large wind field, was able to fill in the bays and inland lakes hours before making landfall in the present landscape. In the future landscapes, higher water levels and more inland penetration of surge completely inundated the barrier islands with 2-5 m of water well before the storm's landfall. During landfall, there was an extensive surge buildup that penetrated farther inland in both the present and future conditions as the bays and inland lakes were already filled with extra water from the forerunner surge.

The impact of Storm 146 was significantly higher in Region 1 all the way to Chambers County compared to Region 2. In the present landscape, an area with 2 – 4 m of inundation was observed on the right side of the landfall along the Freeport area to the West Bay region, which increased to more than 5 m in the future landscapes. Additionally, the water level was significantly higher in the future scenarios, causing a significant area to the west of the landfall along Matagorda Bay region to become flooded and extended considerably farther inland compared to the present landscape.

Within the Region 2 area, Storm 146 caused a total land inundated area of 245 square miles in the present landscape. In the future landscape, the total area of inundation resulting from Storm 146 in Region 2 was 375 square miles in the intermediate-low scenario, which represents a 53% increase. In the intermediate-high scenario, the total area of inundation resulting from Storm 146 in Region 2 was 588 square miles, representing a 140% increase. However, the storm surge impact within Region 1 was significantly greater than that of Region 2 as higher inundation was observed on the right side of the landfall. For example, the total area of inundation within Region 1 in the present landscape due to Storm 146 was 884 square miles and it increased by 65% in the intermediate-high scenario. Figure 6-70 shows the extent of the inundation (inundation envelope) due to Storm 146 in the present landscape compared to two future landscapes.

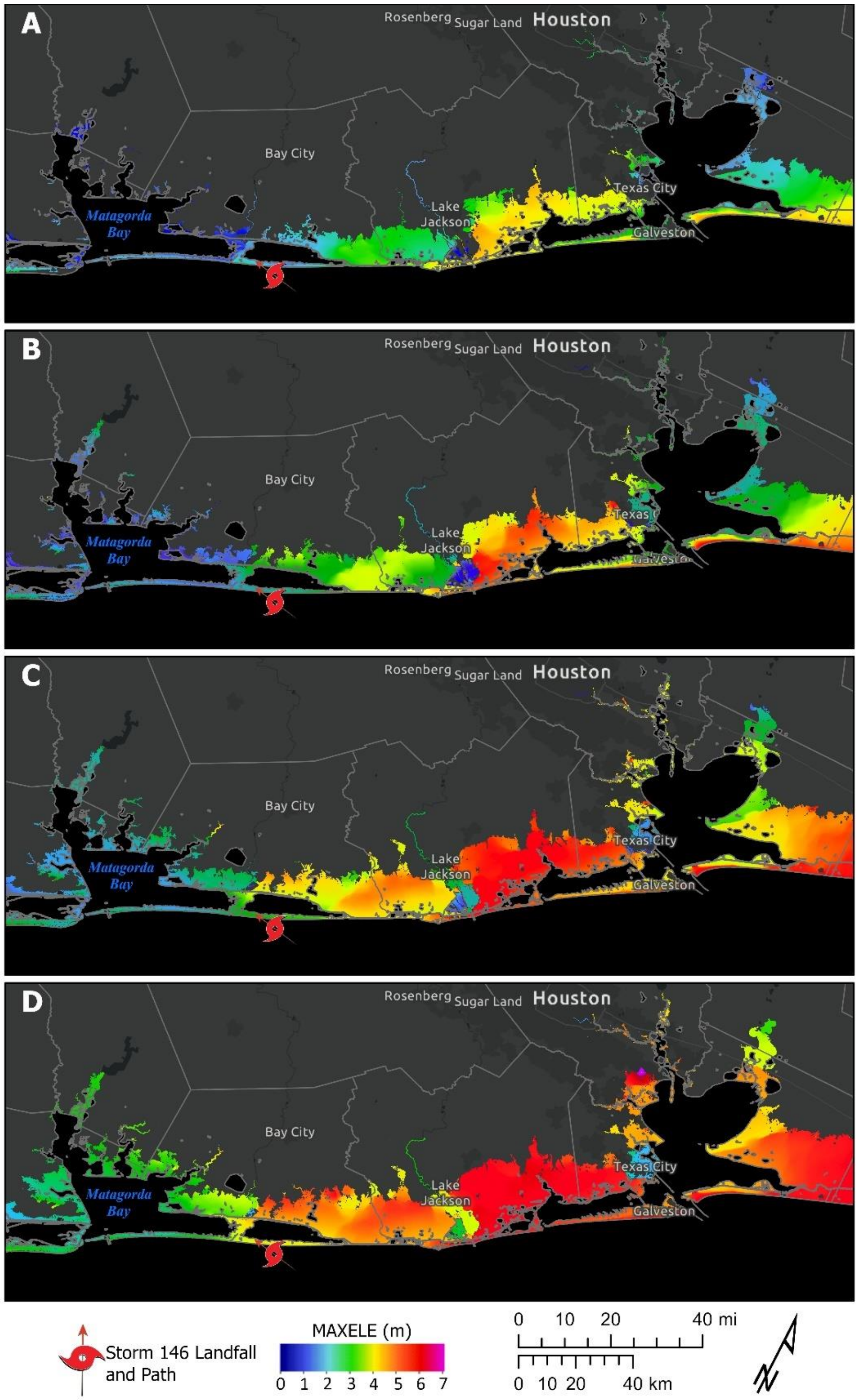


Figure 6-69. Maximum water surface elevation (MAXELE) due to Storm 146 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, (C) Future landscape - Intermediate SLR scenario (from 2019 Plan), and (D) Future landscape - Intermediate-high SLR scenario.

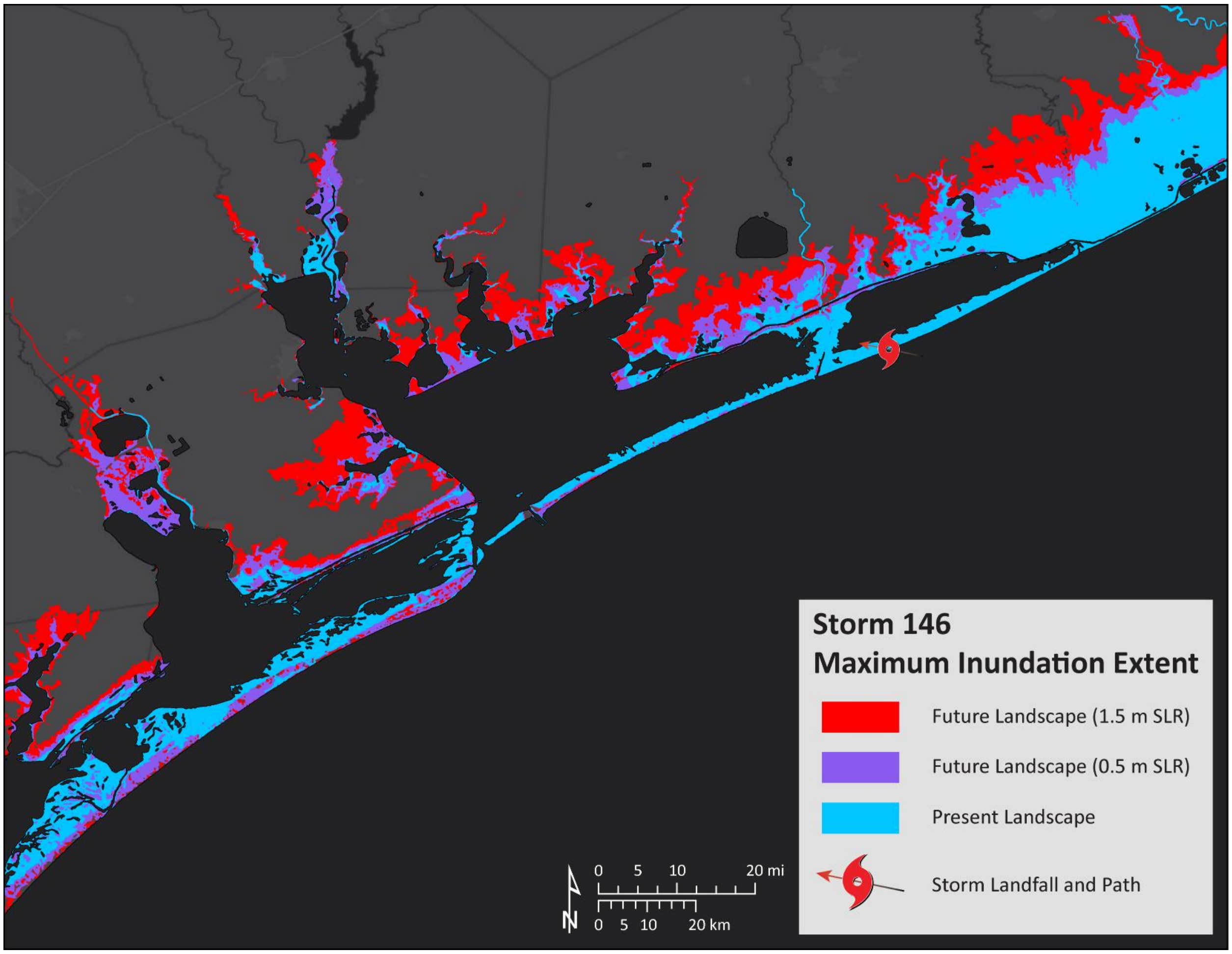


Figure 6-70. Maximum extent of inundation due to Storm 146.

Storm 240

Figure 6-71 shows the maximum water surface elevation resulting from Storm 240 in four distinct landscape and sea-level scenarios. In addition to two future scenarios modeled, it includes the MAXELE resulting from the intermediate SLR scenario modeled for the 2019 Plan for a reference. Despite Storm 146 and Storm 240 having very similar characteristics and making landfall 40 miles apart from each other at the two end of Matagorda Bay, they had different surge height and extent of water pushed inland. Storm 240, for instance, caused more inundation and higher surge height in Matagorda Peninsula than Storm 146, even though the latter made landfall on the peninsula. Similarly, Storm 240 had a more significant impact in and around the Matagorda Bay system in both the present and future landscape than Storm 146.

In the Region 2 area, Storm 240 caused a total land inundation area of 339 square miles in the present landscape, which is 38% higher than that caused by Storm 146. In the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 240 in Region 2 was 504 and 731 square miles, representing a 49% and 116% increase from the present landscape, respectively. Although the percentage increase from the present to future landscapes was higher than that of Storm 146, the total inundation area within Region 2 in the future landscapes was still 37% and 24% higher than that due to Storm 146 in the intermediate-low and intermediate-high scenarios. **Figure 6-72** shows the extent of the inundation due to Storm 240 in the present landscape compared to two future landscapes.

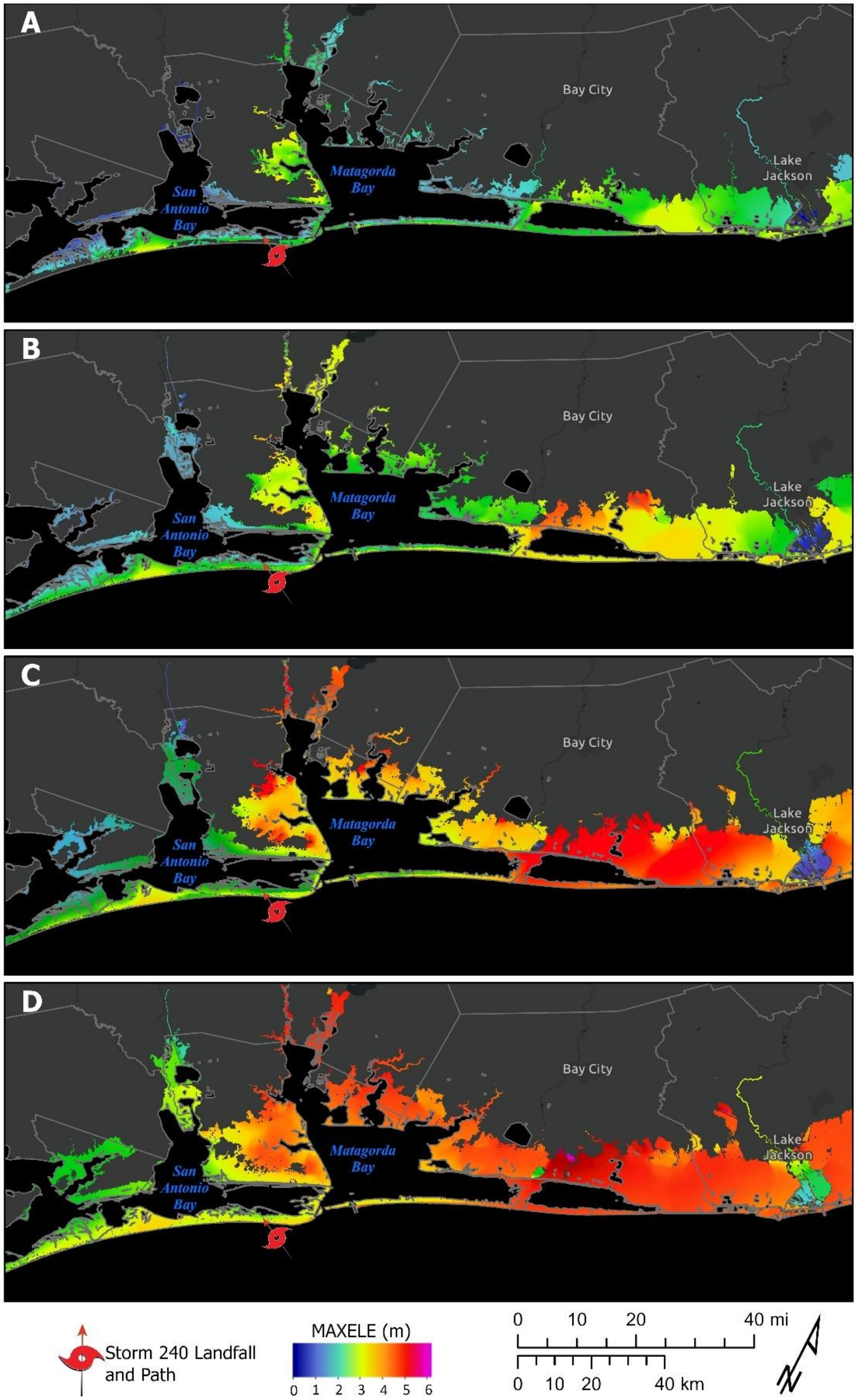


Figure 6-71. Maximum water surface elevation (MAXELE) due to Storm 240 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, (C) Future landscape - Intermediate SLR scenario (from 2019 Plan), and (D) Future landscape - Intermediate-high SLR scenario.

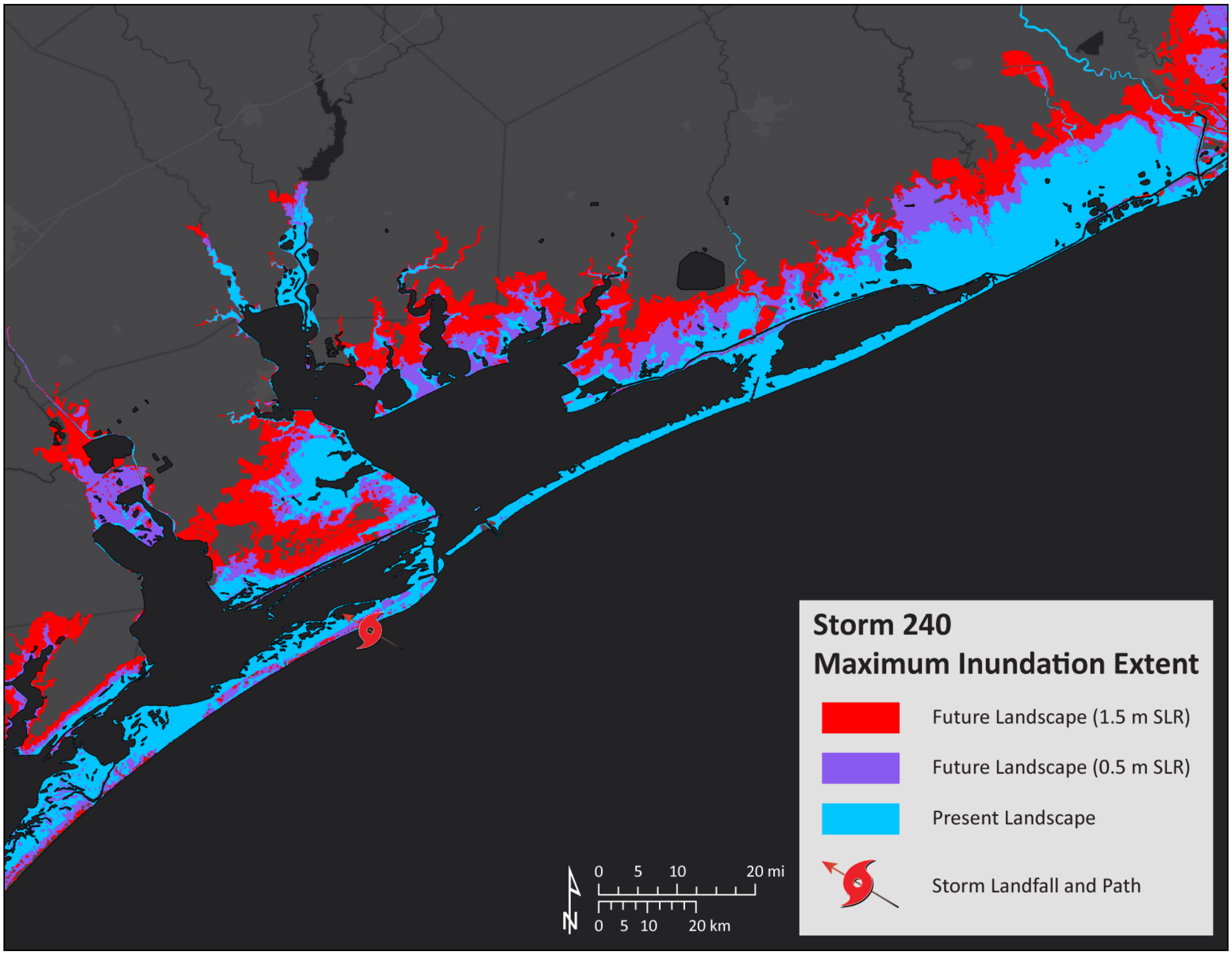


Figure 6-72. Maximum extent of inundation due to Storm 240.

Region 3

This study analyzed four storms that made landfall in Region 3 under the present condition and two future conditions – Storm 328, Storm 322, Storm 222, and Storm 416. Of these storms, three were Category 2, and the remaining Storm 222 was a Category 3 storm. Storm 416 was also modeled for the 2019 Plan. Each storm had unique characteristics, such as forward speed, a RMW, central pressure, orientation, and more (see **Table 6-17**), which resulted in different storm surge impacts.

Table 6-17. Selected storms that made landfall in Region 3 and their characteristics

Storm	Wind Speed (kt)	RMW (Nmi)	Forward Speed (kt)	Central Pressure (mb)	Heading (deg)	Landfall Location
Storm 328	95	15.12	10.4	927.3	-40	San Jose Island
Storm 322	86.77	30.28	4.6	940.4	-40	Padre Balli Park
Storm 222	96.68	18.98	8.4	921.3	-60	North Padre Island
Storm 416	87	16.86	11	933.7	-20	Malaquite Beach

To quantify the extent of flooding caused by a more intense storm surge in the future landscape, the total area of inundated land within Region 3 was calculated for both present and future landscapes in the intermediate-low and intermediate-high scenarios. Based on the landscape change modeling, it was found that in the intermediate-low scenario, approximately 83 square miles of land in Region 3 were lost and converted to open water due to RSLR. This area increased significantly to 143 square miles in the intermediate-high scenario.

Storm 328

Figure 6-73 shows the maximum water surface elevation resulting from Storm 328 in the present landscape and two future landscapes with SLR. This strong Category 2 storm made landfall in San Jose Island, causing a storm surge of 2 – 3 m in the Matagorda Island and Mustang Island under the present landscape. In the future landscapes, the surge height increased to 4 -6 m in the islands. The storm surge penetrated much farther inland in the future landscapes around Matagorda and San Antonio Bay systems, causing a significant impact in the Port Lavaca area.

In the present landscape, Storm 328 caused a total inundated land area of 144 square miles within Region 1. However, the storm surge impact was higher in Region 2 than in Region 3, as higher inundation was observed on the right side of the landfall. Therefore, the total area of inundation within Region 2 in the present landscape due to Storm 328 was 266 square miles. In the intermediate-low and intermediate-high scenarios of future landscapes, the total inundation areas in Region 3 resulting from Storm 328 were 209 and 395 square miles, respectively, representing a 45% and 174% increase from the present landscape. **Figure 6-74** shows the maximum extent of inundation resulting from Storm 328 in the present landscape and two future landscapes.

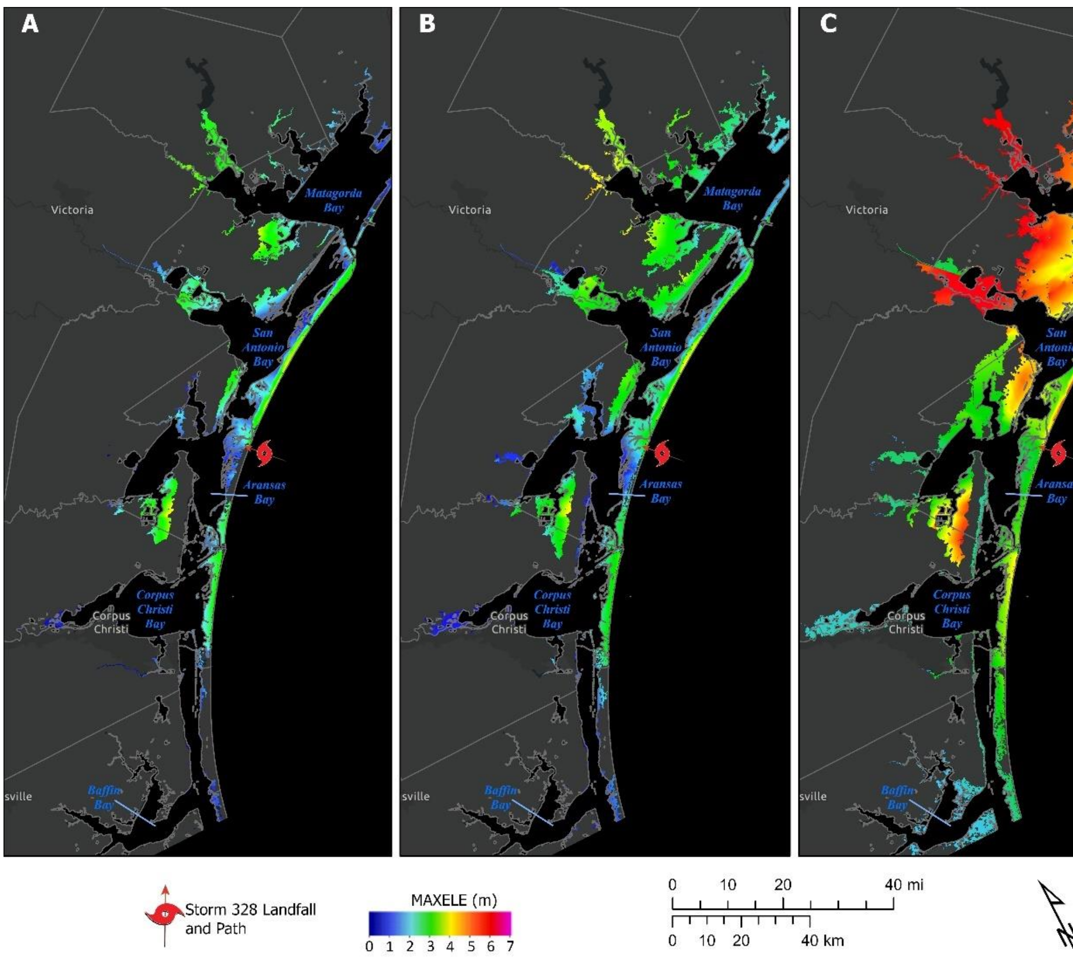


Figure 6-73. Maximum water surface elevation (MAXELE) due to Storm 328 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

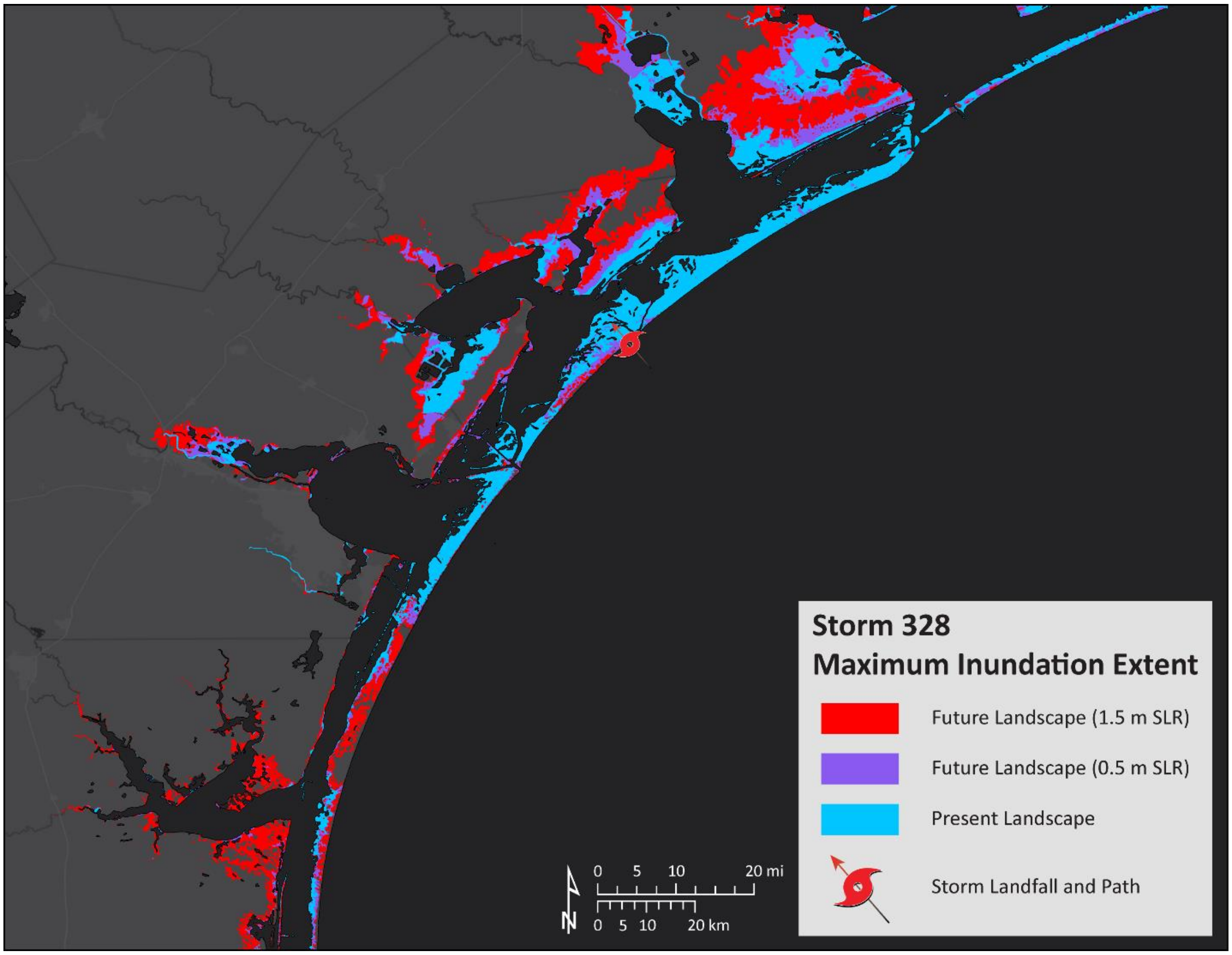


Figure 6-74. Maximum extent of inundation due to Storm 328.

Storm 322

Storm 322, the slowest storm among nineteen storms modeled with a forward speed of 5.3 miles per hour, made landfall in Padre Balli Park at the northern end of North Padre Island and. **Figure 6-75** shows the maximum water surface elevation resulting from Storm 322 in the present landscape and two future landscapes with SLR. In the present landscape, the barrier islands throughout the region experienced 2 – 3.5 m of inundation, and a significant surge penetrated inland around the Aransas Bay and Nueces River Delta area. In future landscapes, the water level rose significantly higher in the barrier island systems, reaching up to 6 m. Additionally, widespread inundation was observed, extending considerably farther inland and reaching a wide area in the City of Corpus Christi.

Storm 322 caused a total land inundation area of 372 square miles within Region 3 in the present landscape. In the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 322 in Region 3 was 519 and 794 square miles, representing a 40% and 113% increase from the present landscape, respectively. Figure 6-76 shows the maximum extent of inundation resulting from Storm 322 in the present landscape and two future landscapes.

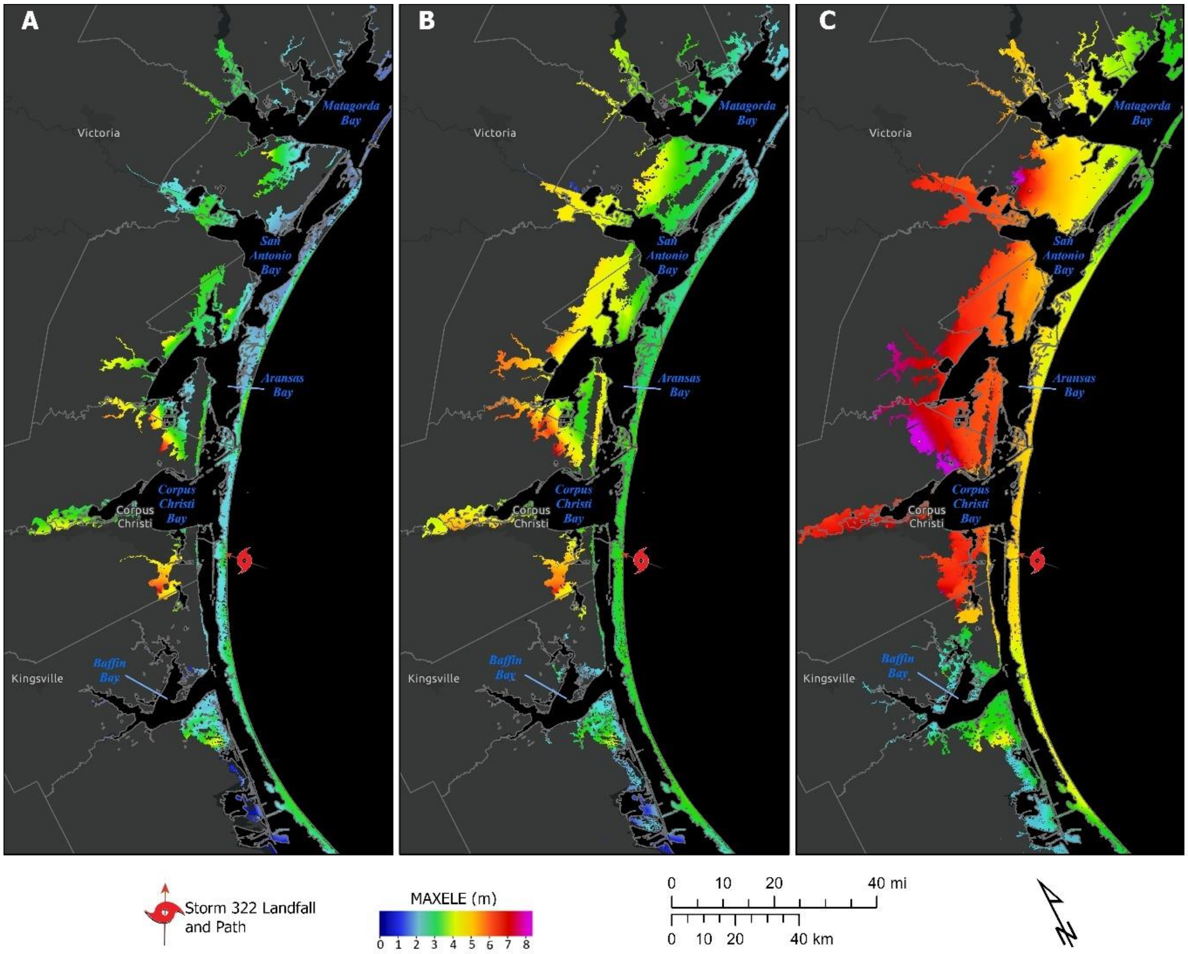


Figure 6-75. Maximum water surface elevation (MAXELE) due to Storm 322 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

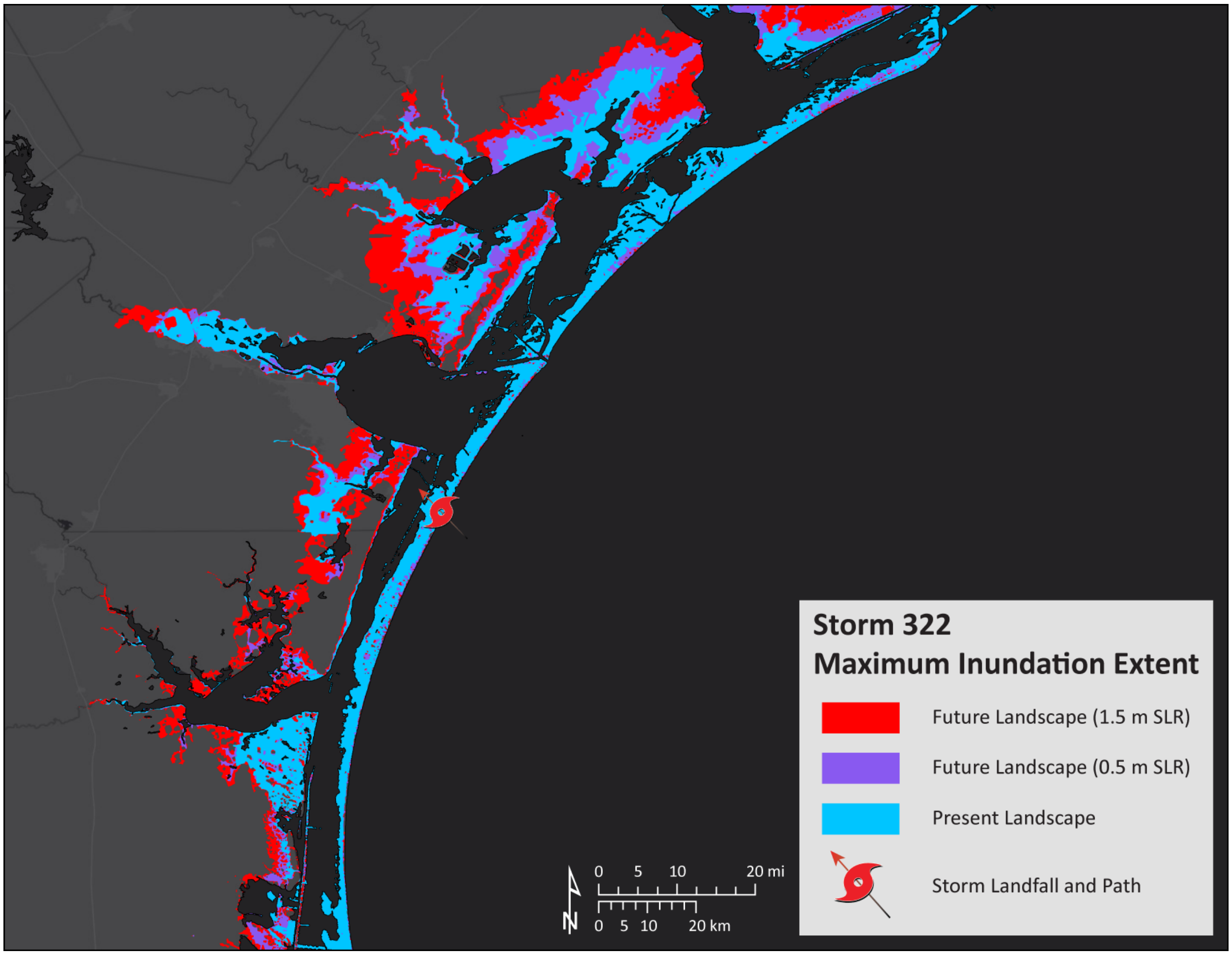


Figure 6-76. Maximum extent of inundation due to Storm 322.

Storm 222

Storm 222 is a slow-moving and relatively large storm that made landfall 9 miles south of Storm 322 at North Padre Island and is the only Category 3 hurricane modeled in Region 3. **Figure 6-77** displays the maximum water surface elevation resulting from Storm 222 in the present landscape and two future landscapes with SLR. Despite being a Category 3 hurricane, Storm 222 did not cause widespread storm surge inundation as seen in Storm 322. However, the barrier islands throughout the region experienced 2 – 3 m of inundation, and up to 4 m of surge was seen along the Nueces River Delta area and south of Aransas Bay in the present landscape. The storm surge was able to reach much farther inland in the future landscapes, causing a significant increase in the flooding area. In the intermediate-high scenario, the region experienced more than 4.5 m of surge height.

Storm 222 caused a total land inundation area of 240 square miles in the present landscape within Region 3, which is 36% less than that caused by Storm 322, a Category 2 storm that made landfall near it. In the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 222 in Region 3 was 346 and 579 square miles, representing a 44% and 141% increase from the present landscape, respectively. Figure 6-78 shows the extent of the inundation due to Storm 222 in the present landscape compared to two future landscapes.

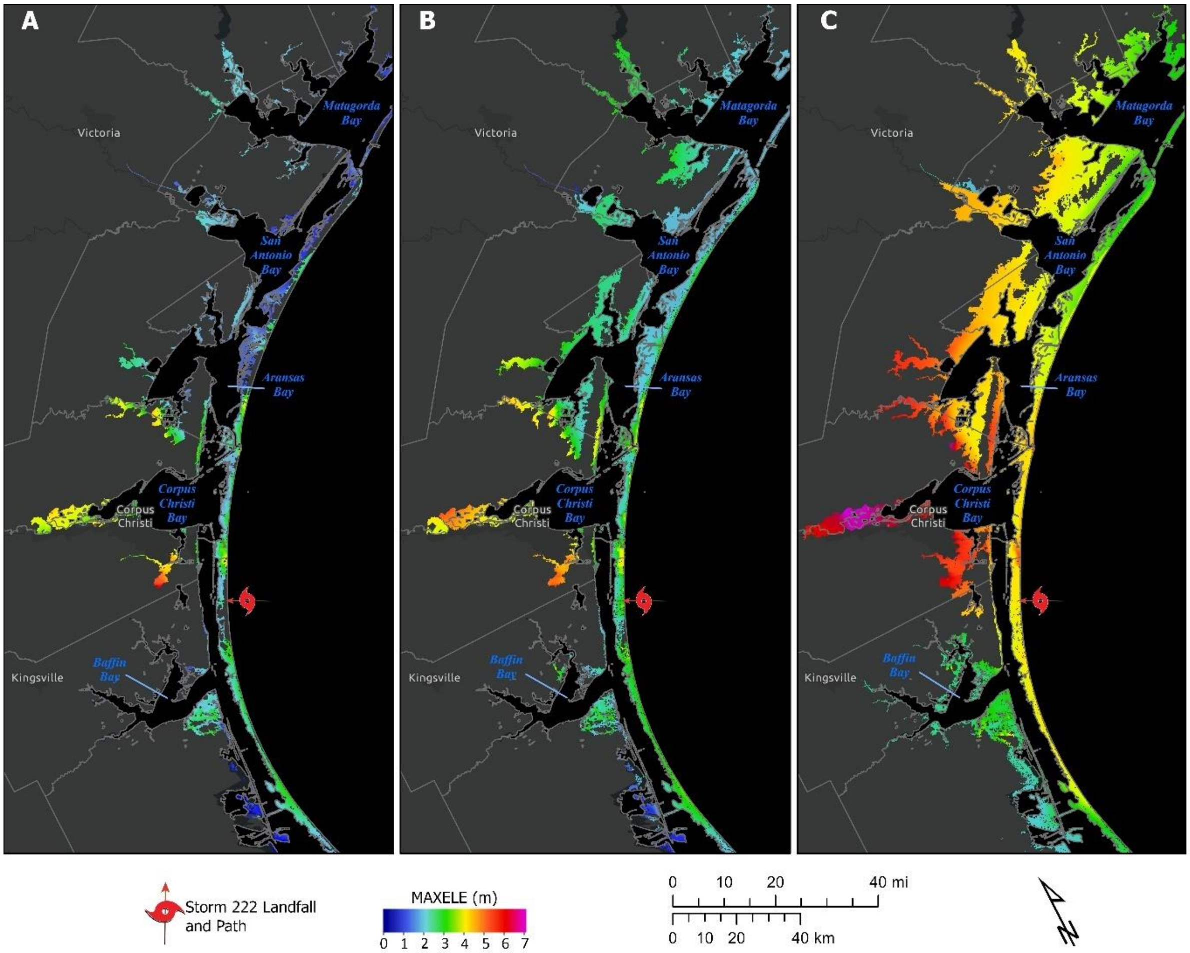


Figure 6-77. Maximum water surface elevation (MAXELE) due to Storm 222 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

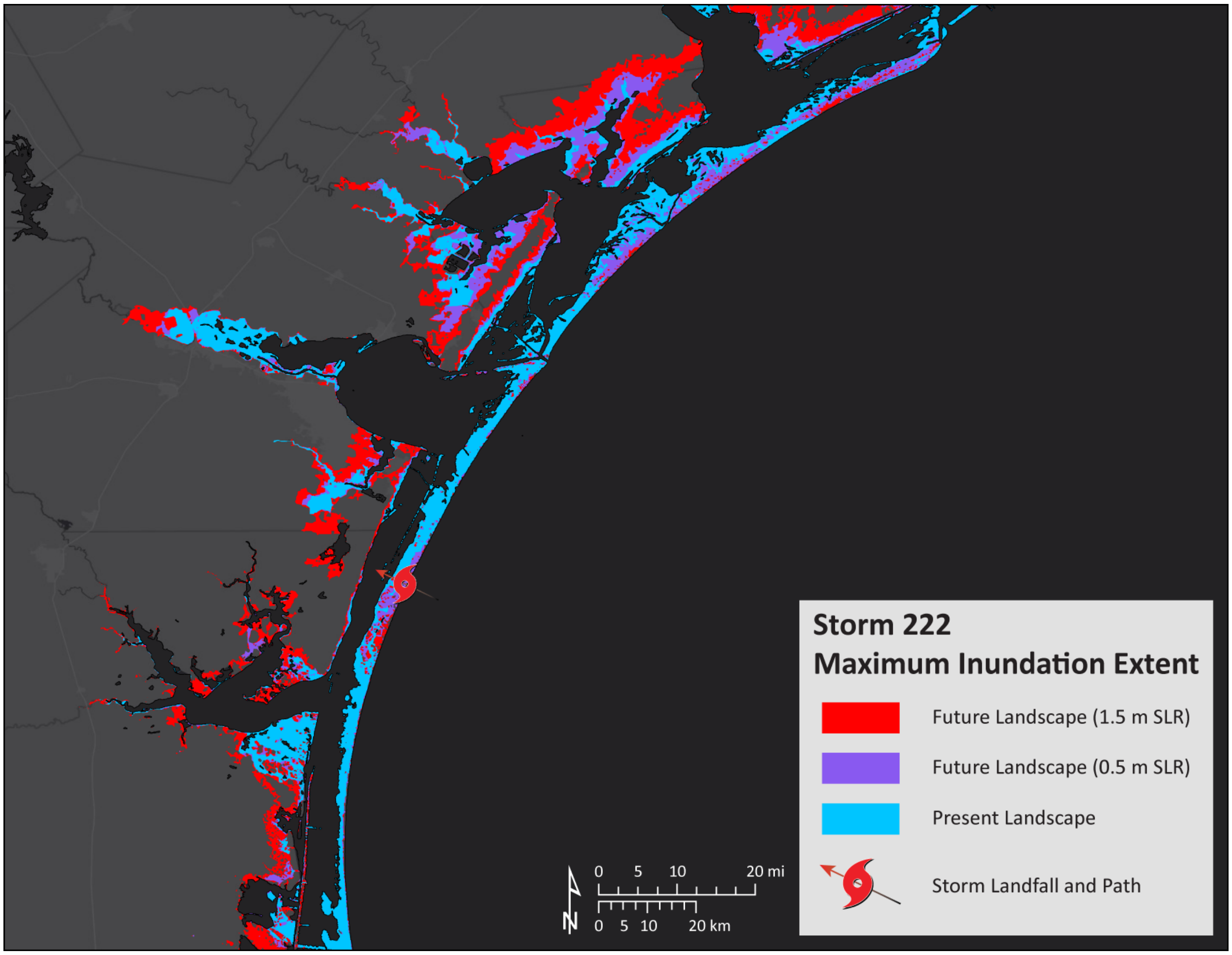


Figure 6-78. Maximum extent of inundation due to Storm 222.

Storm 416

Figure 6-79 shows the maximum water surface elevation resulting from Storm 416 in four distinct landscape and sea-level scenarios, including the MAXELE from the intermediate SLR scenario modeled for the 2019 Plan as a reference. This Category 2 storm made landfall near Malaquite Beach at North Padre Island, between the landfall of Storm 322 and Storm 222. Despite its strong wind speed similar to Storm 322, the storm surge impact due to Storm 416 was the least among these three storms. Under the present landscape, no widespread storm surge flooding was observed in the barrier islands, unlike the other two storms. However, a similar trend of storm surge inundation was observed in the Nueces River Delta area and around Aransas Bay and Baffin Bay. In all three future landscape scenarios, the storm surge inundation extended considerably farther inland in the east of Corpus Christi Bay along the Aransas Bay and San Antonio Bay areas.

In the Region 3 area, Storm 416 caused a total land inundation area of 177 square miles under the present landscape, which is less than that caused by Storm 322 and Storm 222. However, in the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 416 in Region 3 was 288 and 498 square miles, representing a 63% and 181% increase from the present landscape, respectively. **Figure 6-80** shows the extent of the inundation due to Storm 416 in the present landscape compared to two future landscapes.

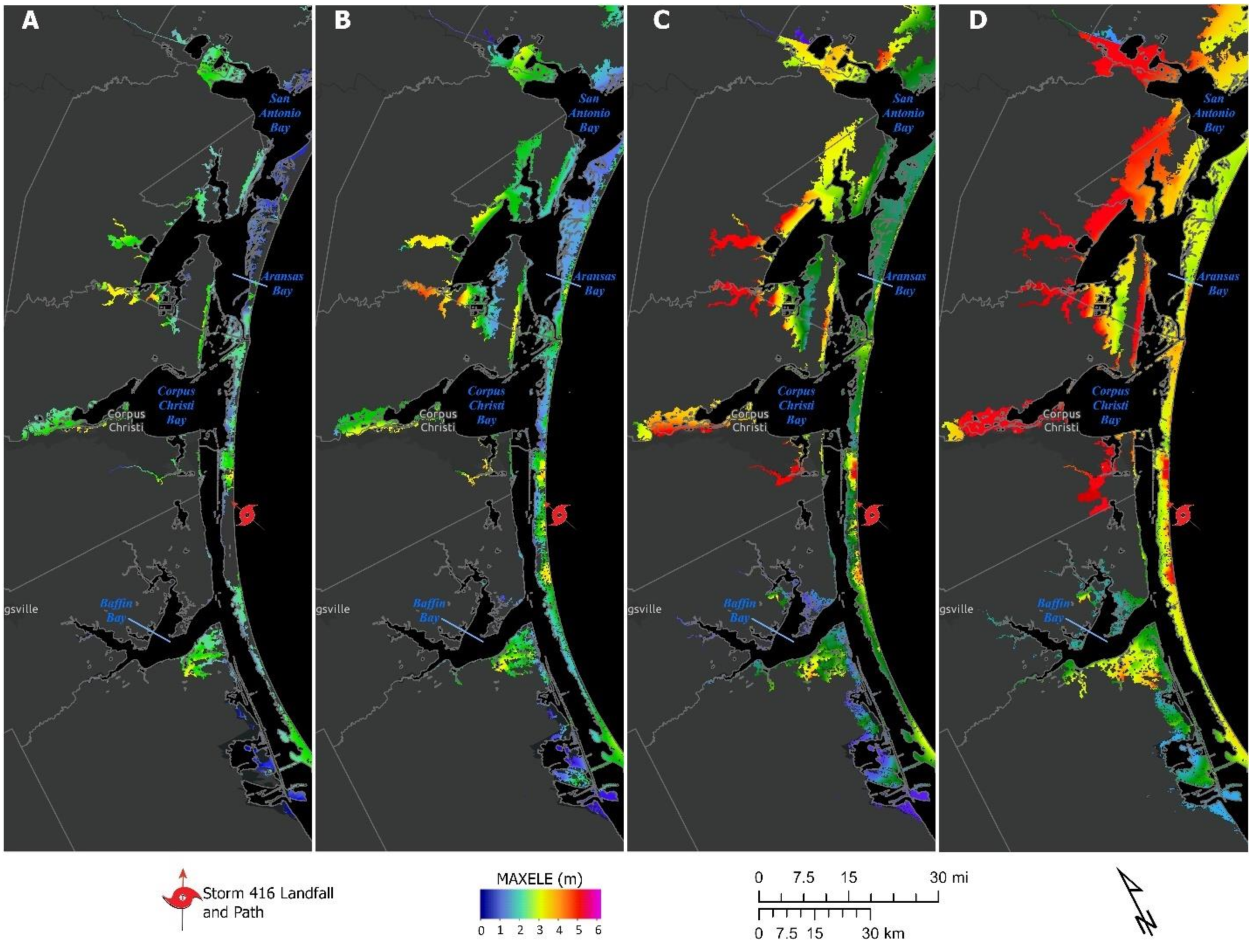


Figure 6-79. Maximum water surface elevation (MAXELE) due to Storm 416 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, (C) Future landscape - Intermediate SLR scenario (from 2019 Plan), and (D) Future landscape - Intermediate-high SLR scenario.

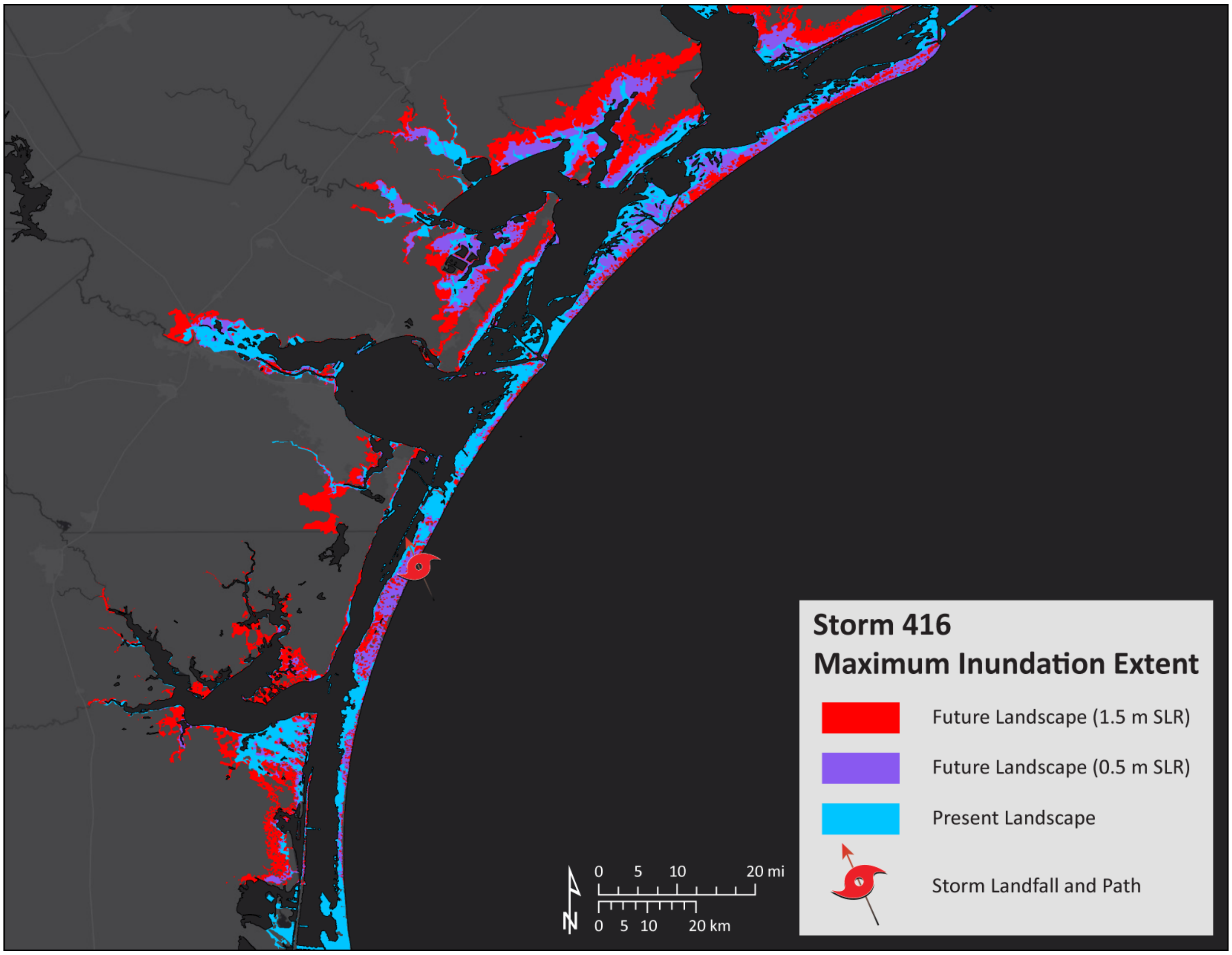


Figure 6-80. Maximum extent of inundation due to Storm 416.

Region 4

This study analyzed four storms that made landfall in Region 4 under the present condition and two future conditions – Storm 214, Storm 206, Storm 305, and Storm 400. Of these storms, two were Category 1, one was Category 2 and the remaining Storm 222 was a Category 3 storm. Storm 400 was also modeled for the 2019 Plan. Each storm had unique characteristics, such as forward speed, a RMW, central pressure, orientation, and more (see **Table**), which resulted in different storm surge impacts as presented in the following subsections.

Table 6-18. Selected storms that made landfall in Region 4 and their characteristics.

Storm	Wind Speed (kt)	RMW (Nmi)	Forward Speed (kt)	Central Pressure (mb)	Heading (deg)	Landfall Location
Storm 214	76.44	35.06	4.6	921.3	-60	Northern Laguna Madre
Storm 206	83.4	31.19	13.4	921.3	-60	South Padre Island
Storm 305	101.3	9.89	6.8	905.2	-40	6 miles south of US-Mexico border
Storm 400	79.44	32.17	13.6	933.7	-20	65 miles south of US-Mexico border

To quantify the extent of flooding caused by a more intense storm surge in the future landscape, the total area of inundated land within Region 4 was calculated for both present and future landscapes in the intermediate-low and intermediate-high scenarios. Based on the landscape change modeling, it was found that in the intermediate-low scenario, approximately 302 square miles of land in Region 3 were lost and converted to open water due to RSLR. This area increased significantly to 351 square miles in the intermediate-high scenario.

Storm 214

Storm 214 was a slow-moving Category 1 storm with a large wind field that made landfall at the northern Laguna Madre. The strong currents generated by the large wind field drove storm surge not only in Region 4 but also inundated a significant area in Region 3. The Baffin Bay area experienced up to 5 m of storm surge where as the Nueces River Delta area experienced more than 5 m of surge in the present landscape. Region 4 is the most vulnerable region to land loss among the four regions and is predicted to lose significant land and convert to open water in the future landscape. As a result, storm surge was able to penetrate much farther inland in the future landscape compared to the present landscape. A significant increase in storm surge inundation was observed throughout the region in the future landscapes, resulting in a considerable increase in the inundation area. **Figure 6-81** displays the maximum water surface elevation resulting from Storm 214 in the present landscape and two future landscapes with SLR.

Within the Region 4 area, Storm 214 caused a total land inundated area of 431 square miles in the present landscape. In the future landscape, the total area of inundation resulting from Storm 214 in Region 4 was 580 square miles in the intermediate-low scenario, which is a 35% increase. In the intermediate-high scenario, the total area of inundation resulting from Storm 214 in Region 4 was 914 square miles, representing a 112% increase. However, the storm surge impact within Region 3 was also similar to that of Region 4 as higher inundation was observed on the right side of the landfall. For example, the total area of inundation within Region 3 in the present landscape due to Storm 214 was 371 square miles and it increased by 130% to 855 square miles in the intermediate-high scenario. **Figure 6-82** shows the extent of the inundation due to Storm 214 in the present landscape compared to two future landscapes.

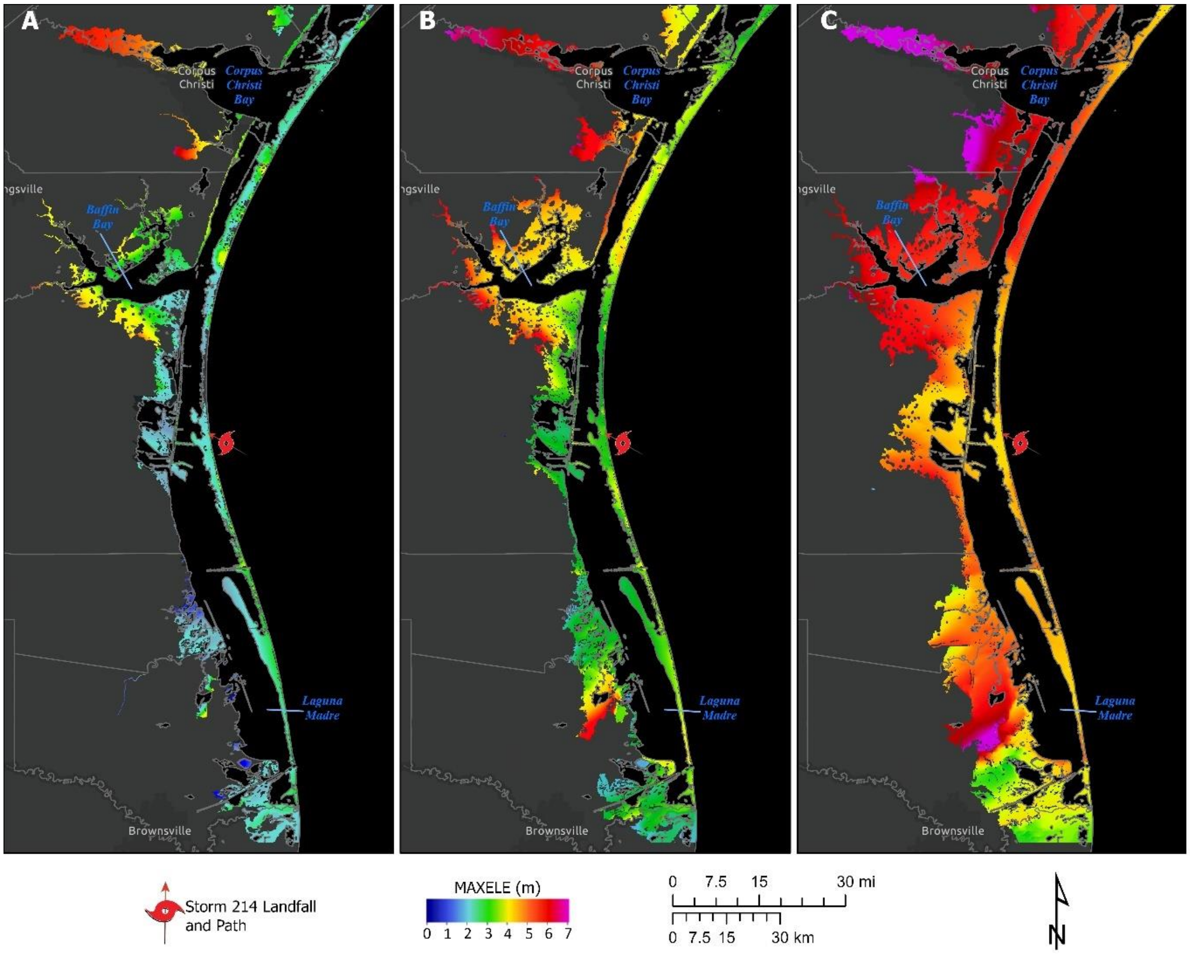


Figure 6-81. Maximum water surface elevation (MAXELE) due to Storm 214 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

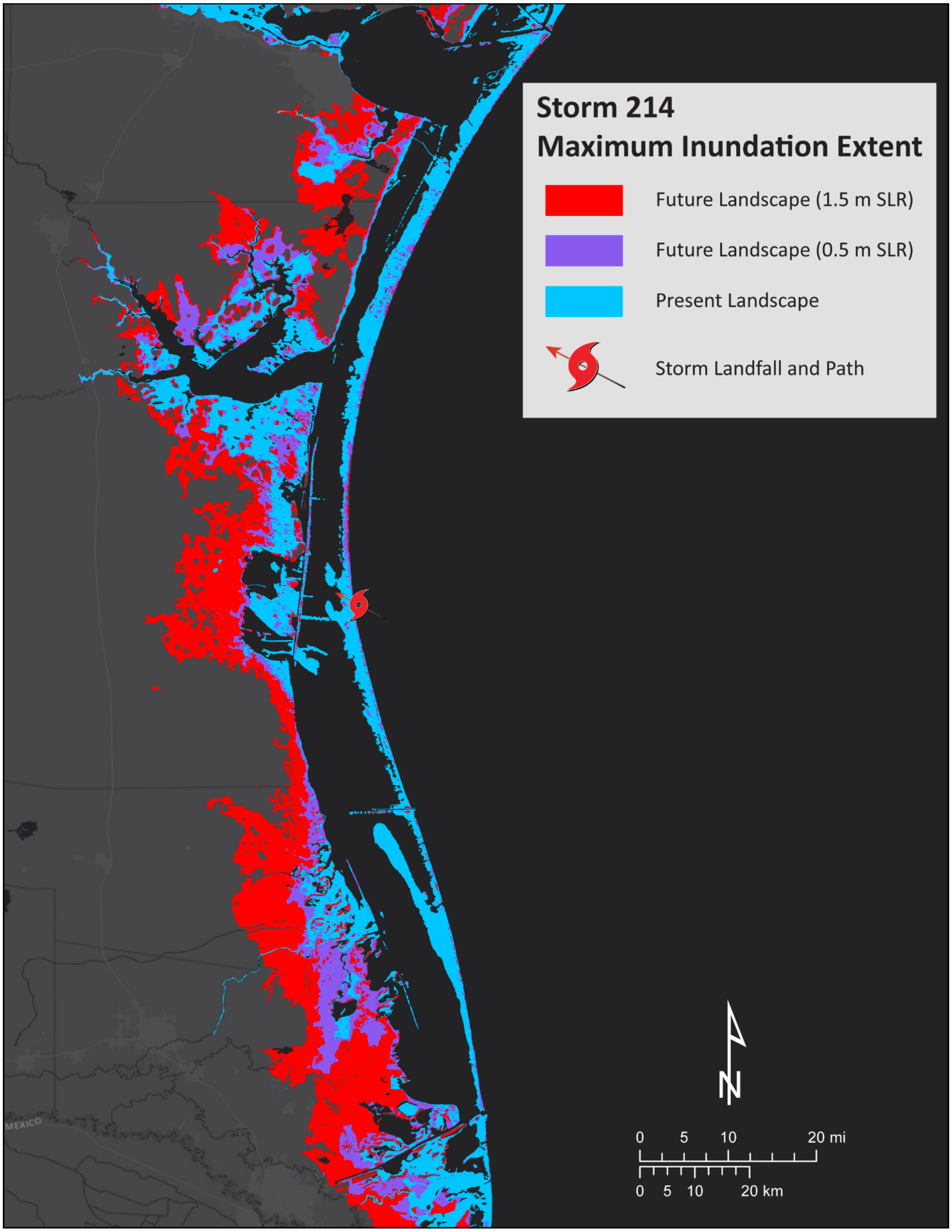


Figure 6-82. Maximum extent of inundation due to storm 214.

Storm 206

Figure 6-83 shows the maximum water surface elevation resulting from Storm 206 in the present landscape and two future landscapes with SLR. This strong Category 2 hurricane with a large wind field made landfall in South Padre Island, causing a storm surge of 2 – 3.5 m in the island in the present landscape. In the intermediate-low scenario, the surge height increased to 3 – 5 m in the island that increased to more than 6 m in the intermediate-high scenario. The storm surge penetrated much farther inland in the future landscapes around Laguna Madre, Baffin Bay and Corpus Christi Bay systems, causing a widespread inundation throughout the region.

In the Region 4 area, Storm 206 caused a total land inundation of 489 square miles in the present landscape. In the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 206 was 621 and 951 square miles, representing a 27% and 94% increase from the present landscape, respectively. Figure 6-84 shows the extent of the inundation due to storm 206 in the present landscape compared to two future landscapes.

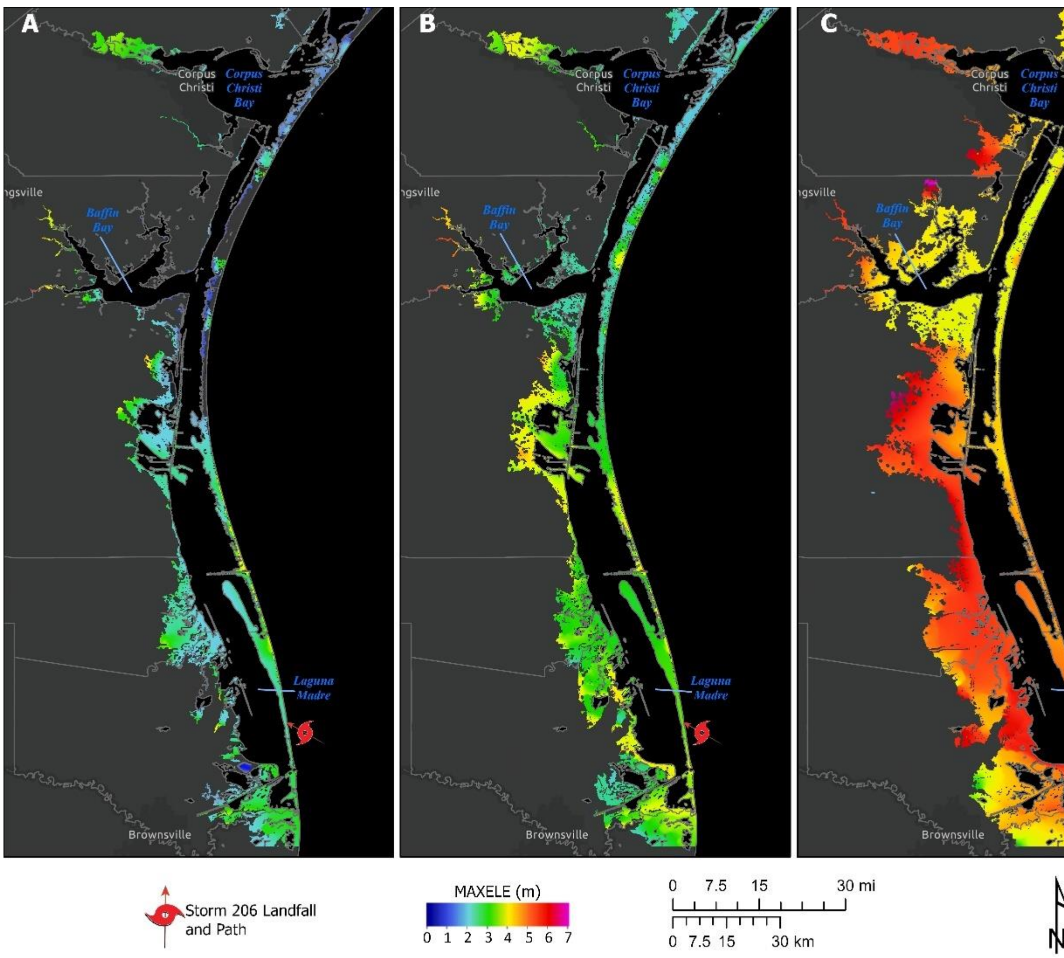


Figure 6-83. Maximum water surface elevation (MAXELE) due to Storm 206 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

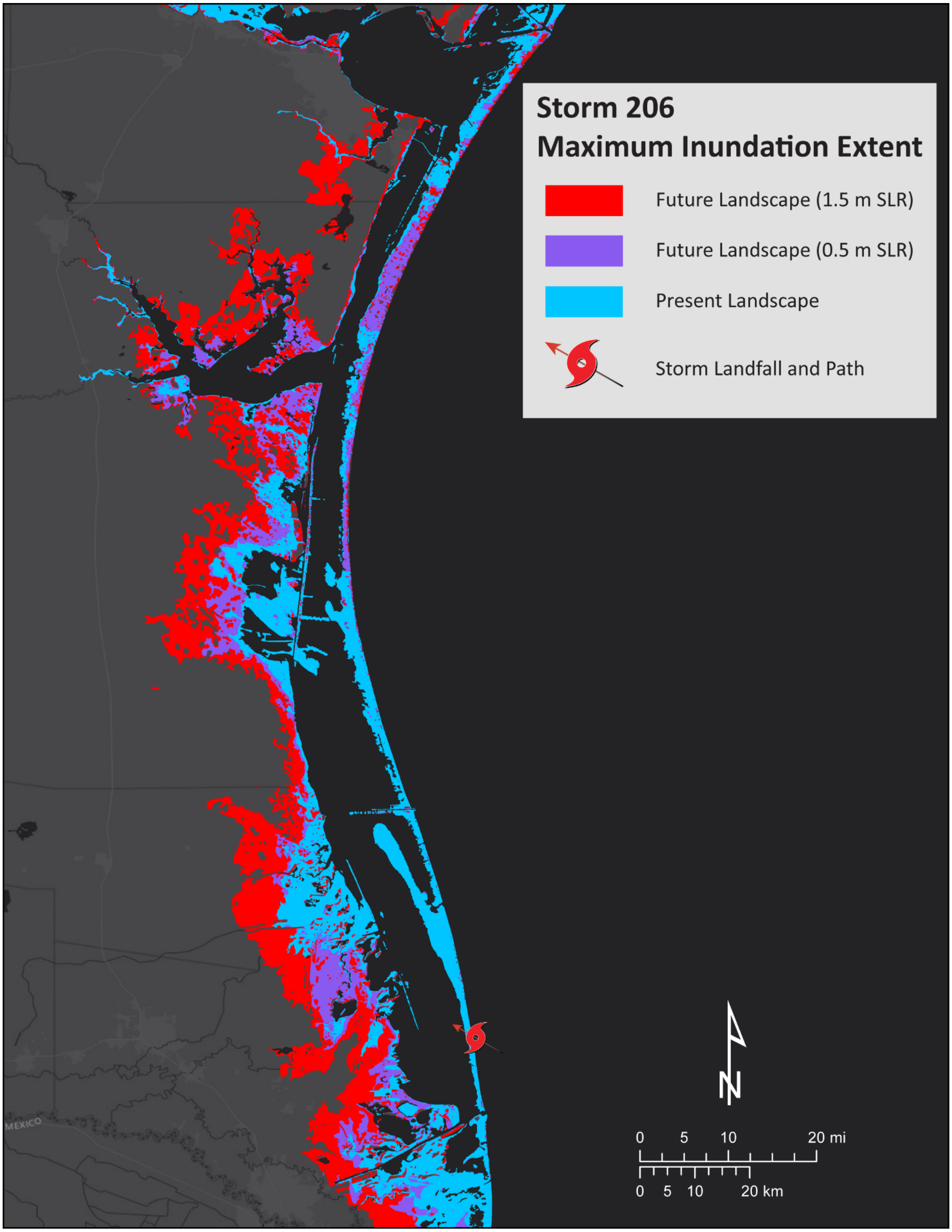


Figure 6-84. Maximum extent of inundation due to storm 206.

Storm 305

Storm 305 was a powerful Category 3 hurricane with a relatively small wind field that made landfall 6 miles south of the US-Mexico border. **Figure 6-85** shows the maximum water surface elevation resulting from Storm 305 in the present landscape and two future landscapes with SLR. Despite its strength, Storm 305 did not cause widespread storm surge inundation as seen in other storms in Region 4, due to its small size. However, a surge height of 2 – 4 m was observed in the US-Mexico border area under the present landscape. It increased to 3 – 5 m in the intermediate-low scenario and to more than 5 m in the intermediate-high scenario. The storm surge penetrated much farther inland in the future landscapes around Laguna Madre, Baffin Bay, and the Nueces River Delta area, causing a widespread inundation throughout the region.

Storm 305 caused a total land inundation area of 399 square miles in the present landscape in the Region 4 area, which is 18% less than that caused by Storm 206. In the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 305 in Region 4 was 507 and 745 square miles, representing a 27% and 87% increase from the present landscape, respectively. Figure 6-86 shows the extent of the inundation due to Storm 305 in the present landscape compared to two future landscapes.

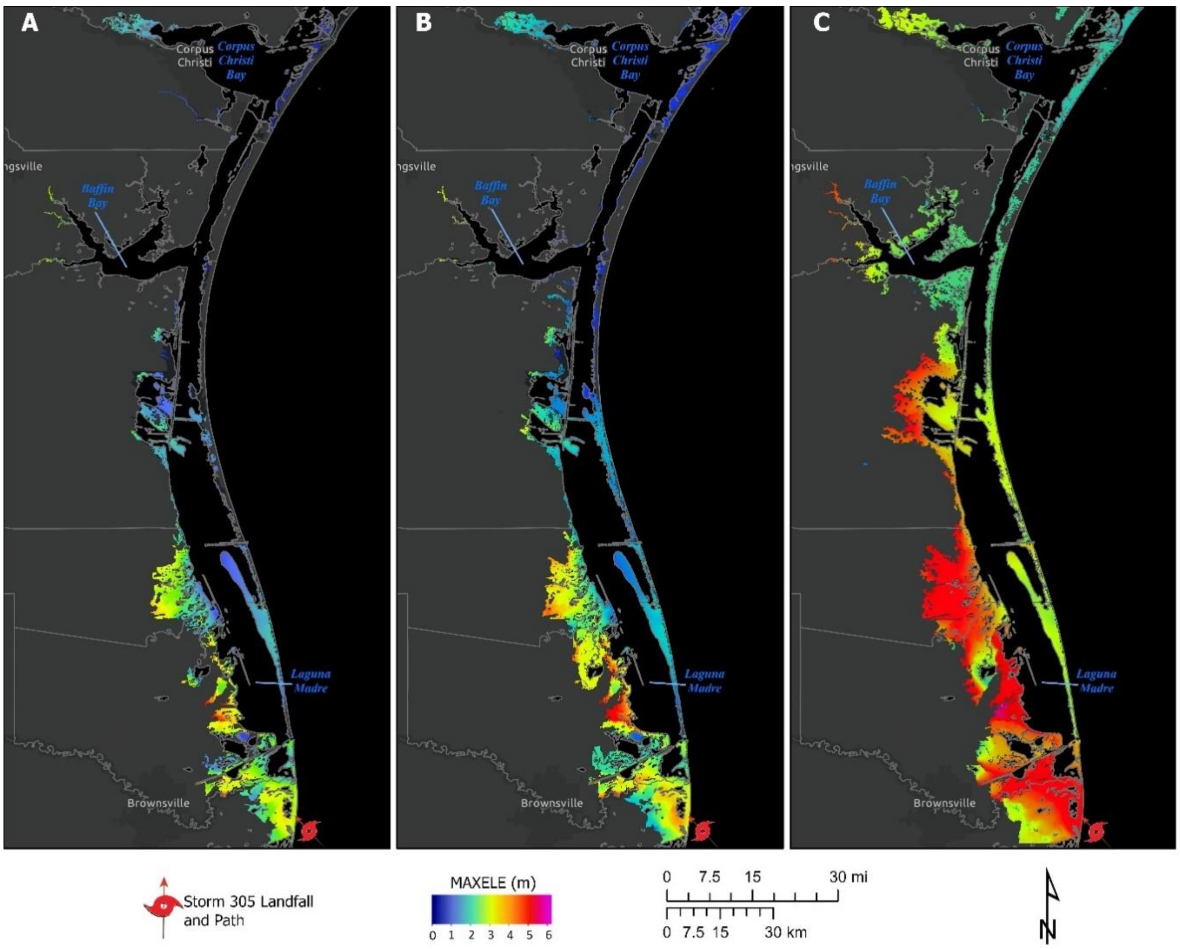


Figure 6-85. Maximum water surface elevation (MAXELE) due to Storm 305 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, and (C) Future landscape – Intermediate-High SLR scenario.

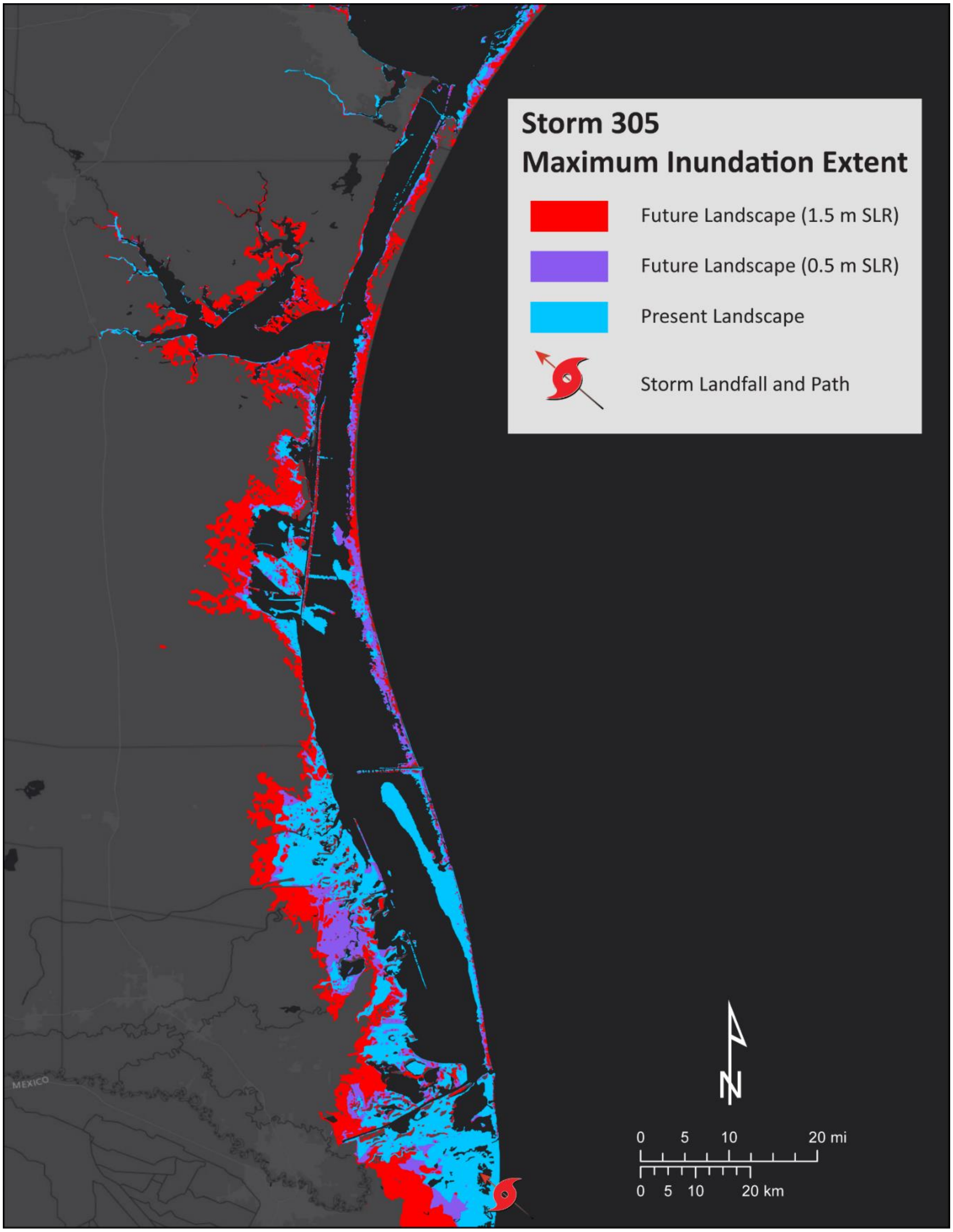


Figure 6-86. Maximum extent of inundation due to storm 305.

Storm 400

Figure 6-87 shows the maximum water surface elevation resulting from Storm 400 in four distinct landscape and sea-level scenarios, including the MAXELE resulting from the intermediate SLR scenario modeled for the 2019 Plan for a reference. Storm 400 was a Category 1 hurricane with large wind field that made landfall 65 miles south of the US-

Mexico border. Despite its wind speed, the strong currents generated by the large wind field drove storm surge into the Region 4, inundating barrier islands as well as inland area around Laguna Madre under the present landscape. The northern section of Region 4 in Kenedy County, which did not experience inundation in the present landscape, was inundated with a surge height of up to 6 m in the future landscapes.

In the Region 4 area, Storm 400 caused a total land inundation area of 412 square miles in the present landscape, which is 3% more than that caused by Storm 305. In the intermediate-low and intermediate-high scenarios of the future landscape, the total area of inundation resulting from Storm 400 in Region 4 is 535 and 855 square miles, respectively. This represents a 30% and 108% increase from the present landscape, respectively. While the percentage increase from the present to future landscapes is more than that of Storm 305, the total inundation area within Region 4 in the future landscapes is also 6% and 15% more than that due to Storm 305 in the intermediate-low and intermediate-high scenarios. **Figure 6-88** shows the extent of the inundation due to Storm 400 in the present landscape compared to two future landscapes.

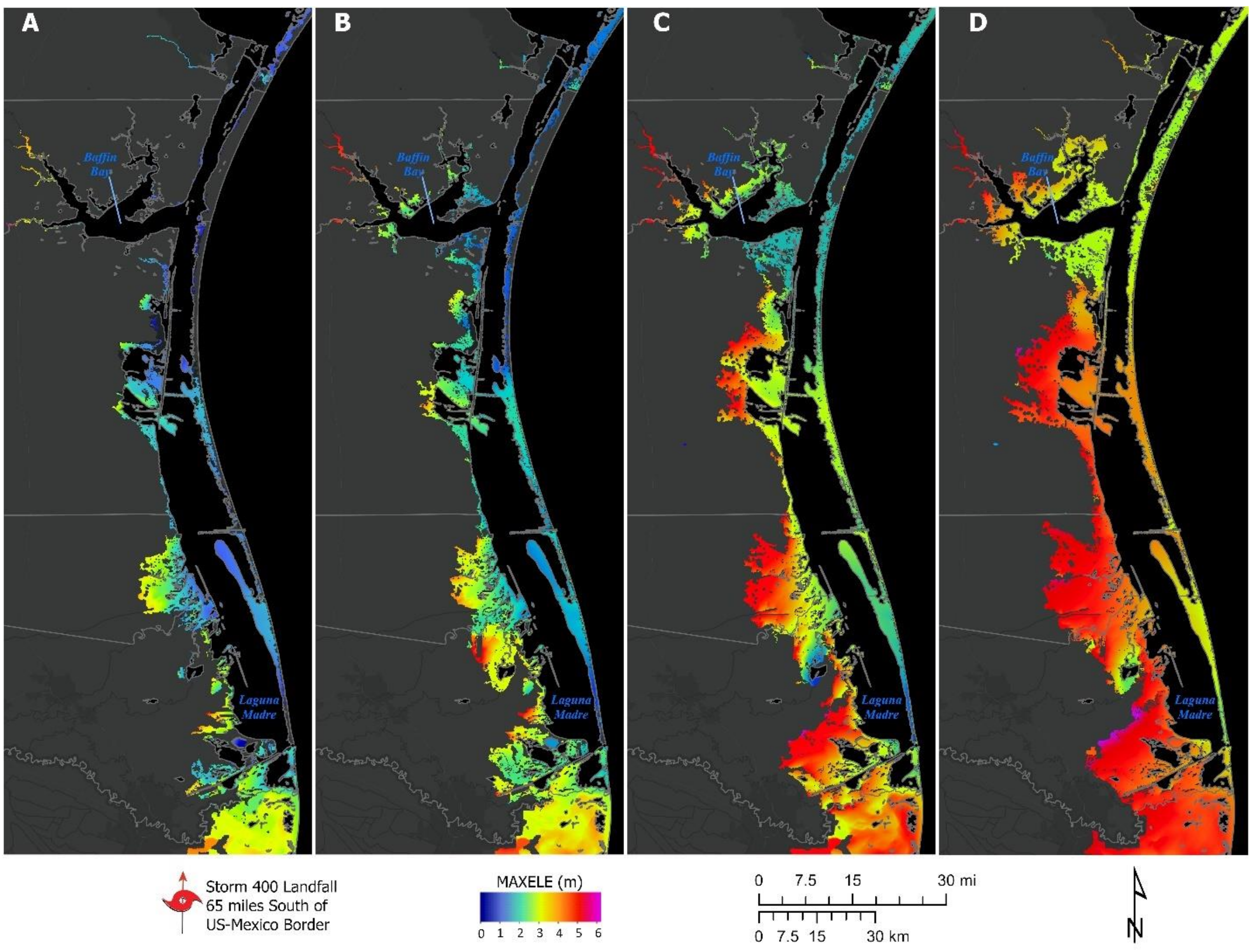


Figure 6-87. Maximum water surface elevation (MAXELE) due to Storm 400 on (A) Present landscape, (B) Future landscape - Intermediate-Low SLR scenario, (C) Future landscape - Intermediate SLR scenario (from 2019 Plan), and (D) Future landscape - Intermediate-high SLR scenario.

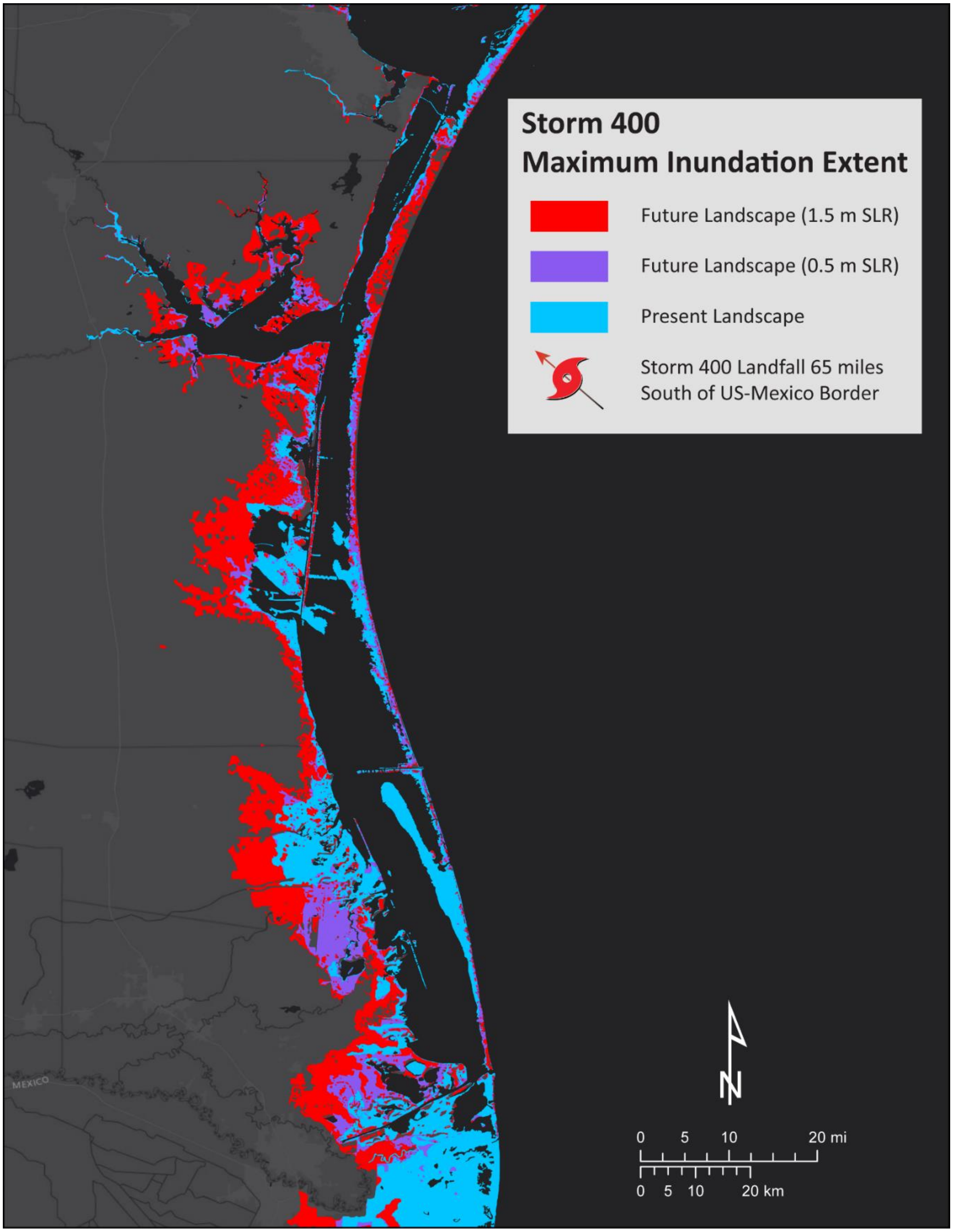


Figure 6-88. Maximum extent of inundation due to storm 400.

Storm Surge Vulnerability Mapping

A storm surge vulnerability map was developed by considering simulated storm surge inundation due to the modeled nineteen storms. These selected storms of varied characteristics pass throughout the Texas coast and provide thorough coverage along the coast. The same storms are simulated on the present landscape, and again on the two future 2100 landscapes with higher sea levels, thus a total of 57 storm surge model simulations are performed. The model simulations compute the maximum storm surge elevation at each node in the computational mesh which provides information about the maximum inundation pattern during a storm event.

The storm surge vulnerability index of the range 0 to 1 is calculated using the maximum storm surge elevation of all these 57 storm scenarios. Finally, a storm surge vulnerability index map is generated that has a value from 0 to 1 for each region. The value of 1 on the maps means an area is inundated in all 57 scenarios, and 0 means it is not inundated in any scenarios. The vulnerability index map shows spatial coverage of potential storm surge flooding vulnerability of the coast and provides baseline information to improve the resilient capacity of the community now and in the future. It is found that 72% of land along the coast has the vulnerability less than 0.5 and 28% of the land along the coast has the highest vulnerability. However, Region 1 has almost 50% of the land with the highest vulnerability to storm surge flooding. The following subsections present the results of storm surge vulnerability mapping effort of each regions.

Region 1

Figure 6-89 shows spatial coverage of potential storm surge flooding vulnerability in Region 1 by considering all modeled storms in the present and future landscape scenarios. The highest vulnerability (value 1) in this map shows an area inundated in all storm scenarios, and the lowest vulnerability (value 0) shows an area not being inundated due to the storm surge in any scenario. The map shows that 49% of the land in Region 1 has a high vulnerability (value greater than 0.5) and Jefferson county is the most vulnerable county in the region. Region 1 is the most vulnerable region to storm surge flooding among the four regions.

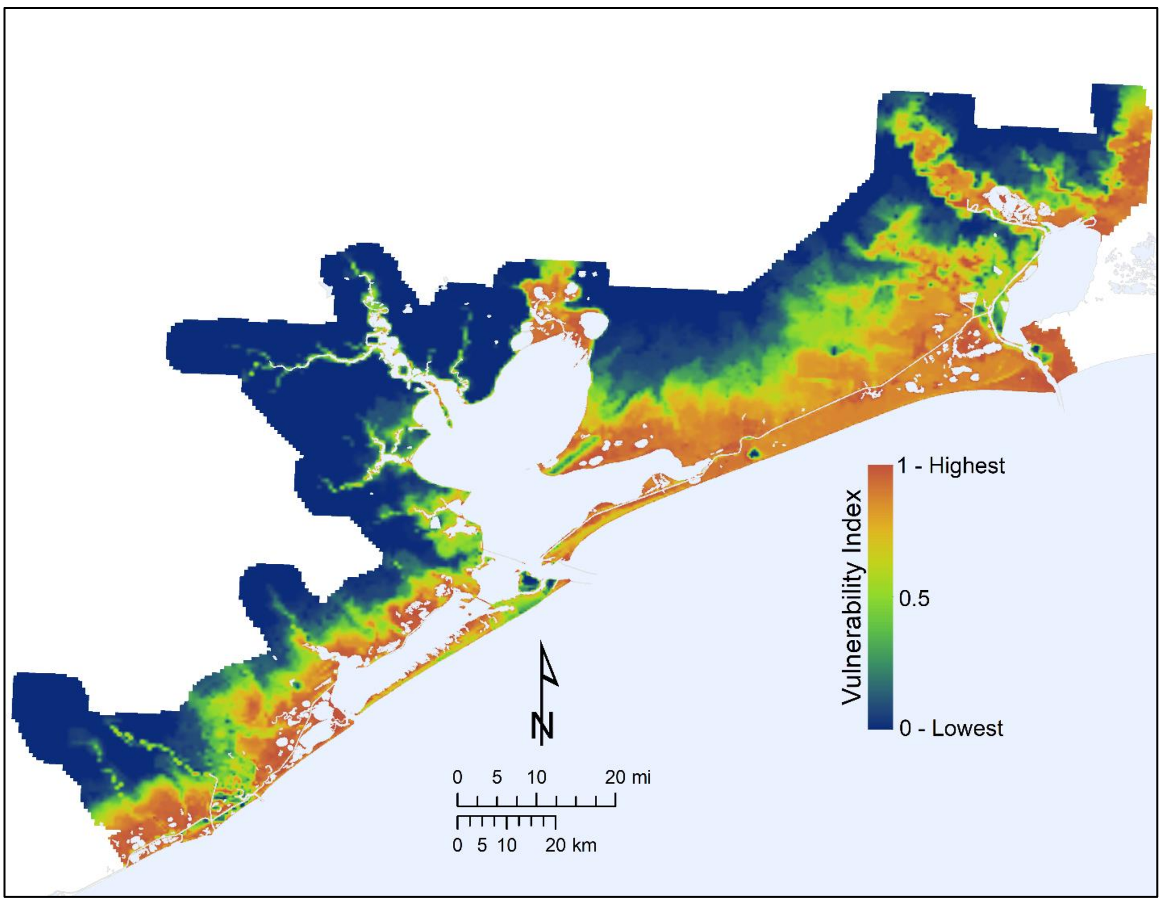


Figure 6-89. Map showing the vulnerability to storm surge in Region 1

Region 2

Figure 6-90 shows spatial coverage of potential storm surge flooding vulnerability in Region 2 by considering all modeled storms in the present and future landscape scenarios. The highest vulnerability in this map shows an area inundated in all storm scenarios and the lowest vulnerability shows an area not being inundated due to the storm surge in any scenario. The map shows that 30% of the land in Region 2 has a high vulnerability to storm surge (value greater than 0.5). Matagorda county is the most vulnerable county in Region 2.

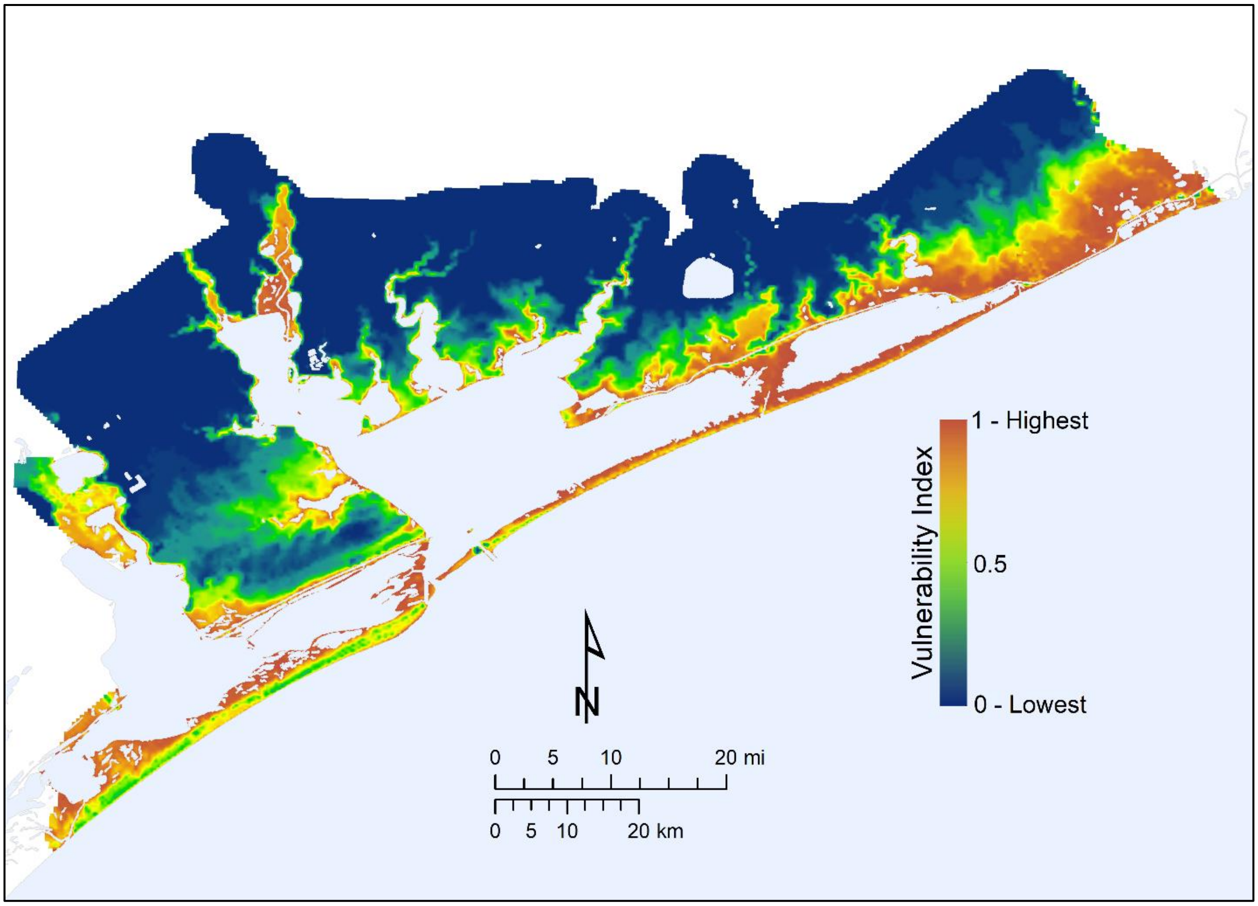


Figure 6-90. Map showing the vulnerability to storm surge in Region 2

Region 3

Figure 6-91 shows spatial coverage of potential storm surge flooding vulnerability in Region 3 by considering all modeled storms in the present and future landscape scenarios. The highest vulnerability (value 1) in this map shows an area inundated in all storm scenarios and the lowest vulnerability (value 0) shows an area not being inundated due to the storm surge in any scenario. The map shows that 13% of the land in Region 3 has a high vulnerability to storm surge. Aransas county is the most vulnerable county in the region with 40% of its land having the highest storm surge vulnerability.

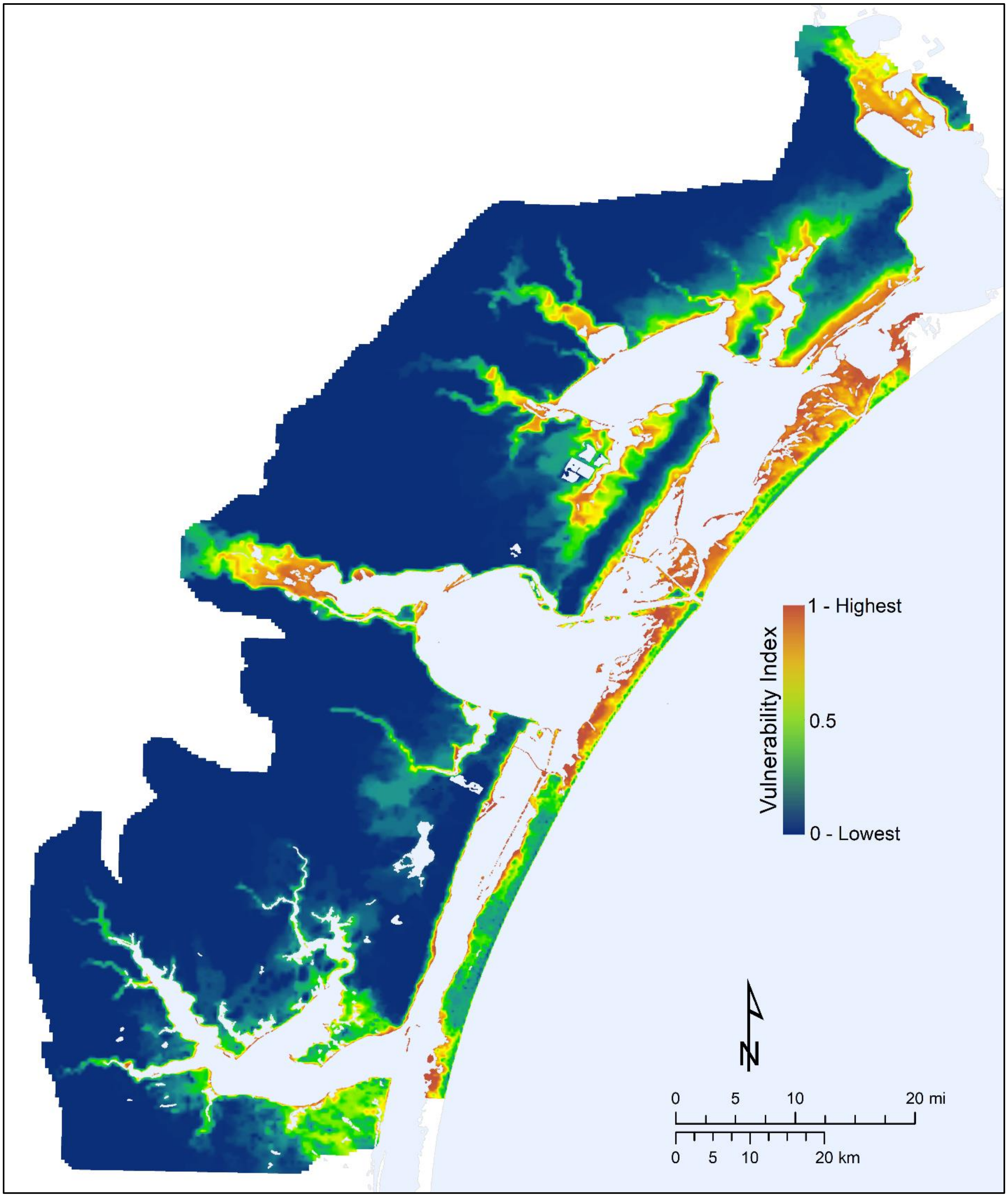


Figure 6-91. Map showing the vulnerability to storm surge in Region 3

Region 4

Figure 6-92 shows spatial coverage of potential storm surge flooding vulnerability in Region 4 by considering all modeled storms in the present and future landscape scenarios. The highest vulnerability in this map shows an area inundated in all storm scenarios and the lowest vulnerability shows an area not being inundated due to the storm surge in any scenario. The map shows that 14% of the land in Region 4 has a high vulnerability to storm surge, especially along the backside of South Padre Island's shoreline and along the Lower Laguna Madre.

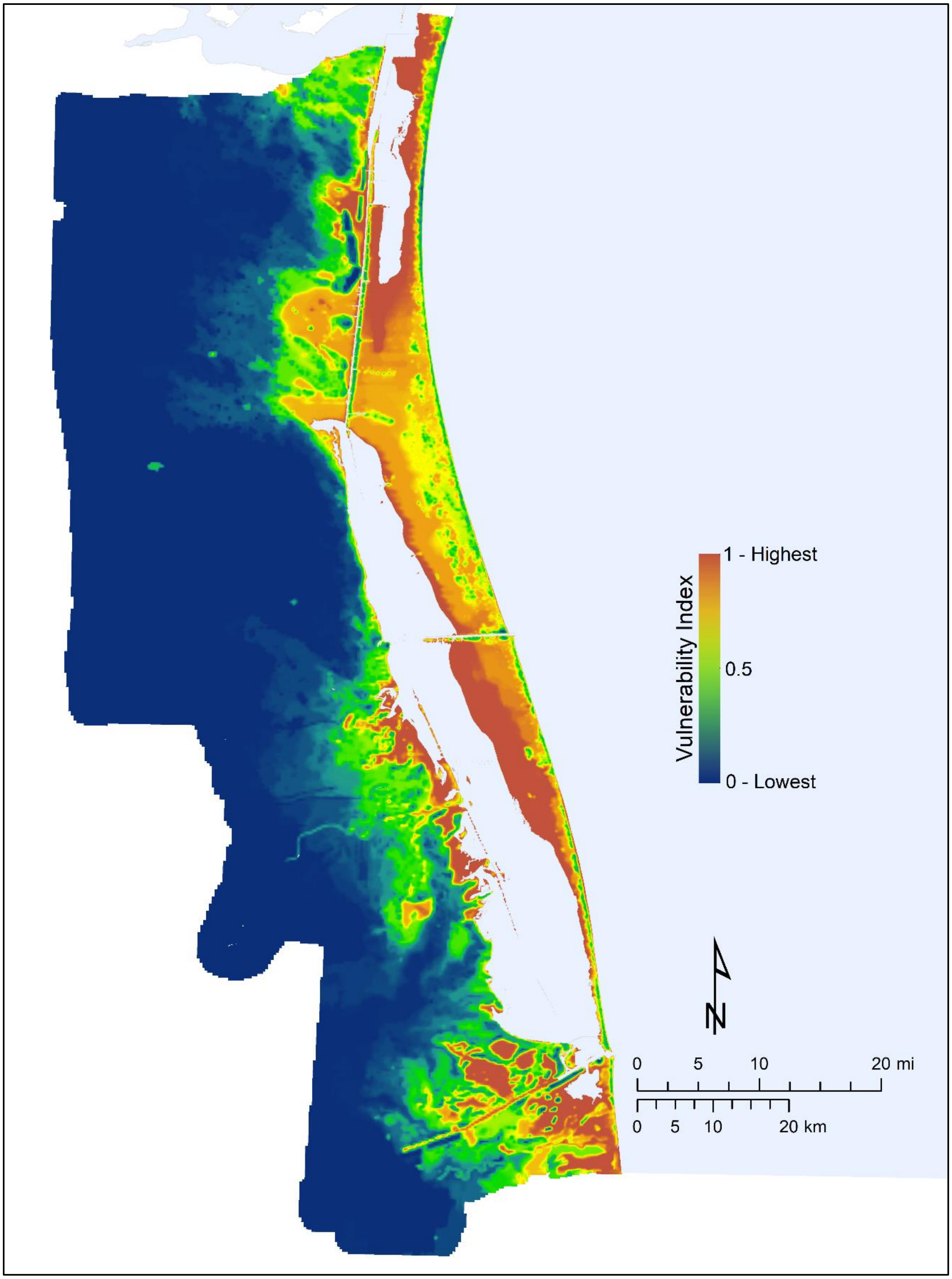


Figure 6-92. Map showing the vulnerability to storm surge in Region 4

6.3.3 Hazus Analyses

Model Inputs

Nineteen total synthetic storms selected for the 2023 TCRMP were run in SWAN+ADCIRC; of these storms, 5 Category 2 storms were selected to be run in Hazus for individual metro areas (**Figure 6-93**). The results of the SWAN+ADCIRC model runs were converted into inundation depth grids that were directly imported into Hazus version 5.1 (released 2021). The inputs were used to produce comparable storm damage values for three scenarios: current conditions and 2100 no-action conditions, for both the intermediate-low (0.5m or 1.6 ft of SLR) and intermediate-high (1.5m or 4.9 ft) SLR scenarios. A fourth scenario, "with-project", was also run for Regions 1a and 3—for present day sea level and 2100 intermediate-low—which provided quantified damage values and damage reduction values for correlation with the future project build-out that can be applied categorically to the 2023 Tier 1 projects. Additionally, in order to have comparable coastwide results, the FEMA 1% flood depth grid was also input into Hazus. All storms and scenarios run through Hazus can be referenced in **Table 6-19**.

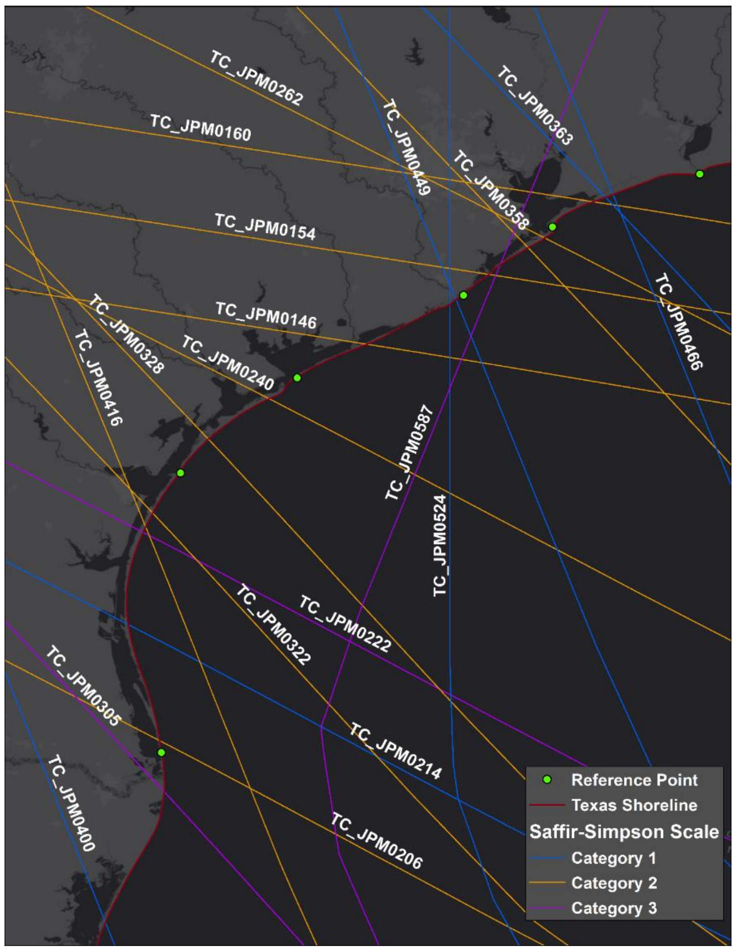


Figure 6-93. Synthetic Storms Modeled for the 2023 Plan in ADCIRC+SWAN (Storms 466, 154, 328, 416, and 206 used in this analysis)

Table 6-19. Storms, Counties, and Scenarios Run in Hazus for Each Metro Region

Region	Storm	Counties	Scenarios: Present-Day	Scenarios: Int-Low SLR	Scenarios: Int-High SLR	Scenarios: With-Project: Present-Day	Scenarios: With-Project: Int-Low SLR
Coastwide	1% FEMA	All	X	X	X		
Sabine	466	Orange, Jefferson	X	X	X	X	X
Houston-Galveston	154	Chambers, Galveston, Harris, Brazoria	X	X	X		
Matagorda	328	Matagorda, Jackson, Victoria, Calhoun	X	X	X		
Corpus Christi	416	Aransas, Refugio, San Patricio, Nueces Kleberg, Kenedy	X	X	X	X	X
South Padre Island	206	Willacy, Cameron	X	X	X		
		Total	**8**	**8**	**8**	**2**	**2**
						Total:	**28**

The FEMA 1% flood depth, no-action and with-project scenarios of SWAN+ADCIRC data were used to run a Level 2 Hazus flood analysis. A Level 2 Hazus flood analysis is defined as an analysis that includes user-provided data for either hazard or structure information. For this study, the flood hazard data was user-provided in the form of flood depth grids from SWAN+ADCIRC outputs. The structure information utilized the default Hazus General Building Stock (GBS) for Texas in Hazus v4.2 SP01, which consisted of census block data based on the 2010 census with 2018 replacement values based on RS Means. Hazus GBS data since 2015 has been dasymetrically-clipped, where the census block geometry is modified to only include land covers associated with development.

Model Results

Hazus version 5.1 was used for all loss analyses, utilizing cloud-based virtual machines (VMs). Traditionally, Hazus is hosted and run on individual computers, with each individual study area (which may cover all or a portion of a scenario) taking up to several days to complete all run-time calculations. On a project like this with a large study area and detailed flood depth grids, this traditional approach would have taken several months. The use of VMs allowed for the development of a large number of Hazus instances to run multiple study areas at the same time. Also, the VMs have the flexibility to be configured to run faster than traditional computers by using faster processors and expanded run-time available working memory.

Loss estimates were modeled in Hazus for physical damage resulting from storm surge and SLR on residential and non-residential structures such as commercial buildings, schools, and critical facilities, along with business interruptions. The models targeted the impacts on the counties containing and surrounding 5 metro areas on the Texas coast: Beaumont/Port Arthur/Orange, Houston/Galveston, Calhoun/Matagorda, Corpus Christi/Coastal Bend, and South Padre Island. The models were run for current conditions and future conditions (2100 intermediate-low and intermediate-high SLR scenarios) with no action. The resulting Hazus data provided information for each metro area regarding estimated physical damage and approximate economic loss estimates. Four tables were generated for each metro area to summarize their physical and economic loss.

Hazus model results for physical damage data included statistics regarding building use per metro area, and physical damage occurring to those buildings as a result of storm surge and SLR. Hazus categorized buildings as either residential or non-residential (primarily commercial). Residential buildings were further classified into: 1 story, 2 story, 3 story, or split level. Commercial buildings were classified as low rise, midrise, or high rise. These classifications were summarized into tables for each metro area, which can be found in the **"Building Statistics"** table under each metro area's results below.

The **"Physical Damage Results"** table under each metro area summarizes the physical damages that are predicted to occur to the buildings due to storm surge and SLR. Water levels output from the SWAN+ADCIRC results were analyzed to determine the percentage of physical damage that would occur in each building. The total number of buildings with damages was determined by summing the number of buildings with any percentage of damage, ranging from 1 percent to 100 percent. Buildings damaged by 50 percent or greater are defined by FEMA as having substantial damage and are a subset of the total number of buildings with damages.

In addition to the physical damages, Hazus models also included economic loss estimates for each metro area. Losses were modeled by Hazus for seven different economic categories. According to the Hazus User Manual, the seven economic loss categories are defined as:

1. **Building Loss** – building repair or replacement costs for damaged or destroyed buildings
2. **Content Loss** – damaged furniture or equipment that is not an essential part of the building or business
3. **Inventory Loss** – damage to property within the building that is part of the occupant's business activities
4. **Relocation Cost** – disruption costs of relocation when buildings or portions of buildings are unusable while being repaired, and rental costs of temporary space
5. **Income Loss** – losses in productivity, services, or sales that occur when building damage disrupts commercial activity
6. **Rental Income Loss** – loss of rental income to building owners when the building or portions of the building are unusable while being repaired
7. **Wage Loss** – loss of income of employees when building damage disrupts business activities

These seven categories add up to the total loss in economic damages resulting from storm surge and SLR. Economic loss values generated in Hazus are approximate (particularly considering that 2018 development conditions are used to determine both the current condition and 2100 scenario results), are given in 2018 U.S. dollars (USD), and are summarized in the **"Economic Damage Results"** table under each metro area's results.

In addition to the economic loss categories, Hazus also tabulated ranges of total estimated building losses and tabulated the number of census blocks falling within that range in each metro area. A summary of these results may be found in the **"Total Building Loss per Census Block"** table under each metro area's results.

Sabine

About 66% of residential buildings in Orange and Jefferson counties are classified as one story, and 98% of non-residential buildings are considered low-rise (**Table 6-20**). The total number of buildings in this area with damages due to storm surge or SLR is project to increase by 818% by 2100 (low scenario) and 2,007% by 2100 (high scenario) if no action were to occur (**Table 6-21**). Due to the increase of building damages, the cost of building losses would increase by 524% (low)/1,857% (high) and the total economic loss would increase by 532% (low)/1,629% (high) for the counties (**Table 6-22**). In 2100, results show that an additional 2,627 (low) and 3,648 (high) census blocks would be impacted by the hurricane modeled (**Table 6-23**).

The results from **Table 6-22** are shown spatially in **Figure 6-94** for current conditions and **Figure 6-95** and **Figure 6-96** for future conditions.

Table 6-20 Beaumont/Port Arthur/Orange Building Statistics

Residential Building Statistics		Non-Residential Building Statistics	
Residential 1 Story	66%	Percent Low Rise	98%
Residential 2 Story	32%	Percent Mid Rise	1%
Residential 3 Story	1%	Percent High Rise	1%
Residential Split Level	1%		

Table 6-21 Beaumont/Port Arthur/Orange Storm Landfall - Physical Damage Results

	Current Conditions	2100 - Low	2100 - High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
Buildings Damaged 1 to 10%	255	1,200	904	371%	255%	-25%
Buildings Damaged 11 to 20%	477	4,863	4,137	919%	767%	-15%
Buildings Damaged 21 to 30%	209	1,828	4,710	775%	2154%	158%
Buildings Damaged 31 to 40%	124	1,676	2,267	1252%	1728%	35%
Buildings Damaged 41 to 50%	67	1,426	1,943	2028%	2800%	36%
Substantial Loss	516	4,128	20,766	700%	3924%	403%
Number of Buildings with Damages 1-50%	1,132	10,993	13,961	871%	1133%	27%
Number of Buildings with Substantial Damages	516	4,128	20,766	700%	3924%	403%
Total Number of Damaged Buildings	**1,648**	**15,121**	**34,727**	**818%**	**2007%**	**130%**

Table 6-22 Beaumont/Port Arthur/Orange Storm Landfall - Economic Damage Results

Damages in $1000s USD						
Category	**Current Conditions**	**2100-Low**	**2100-High**	**Percent Change in Damages - Present to Low**	**Percent Change in Damages - Present to High**	**Percent Change in Damages - Low to High**
Building Loss	303,452	1,894,363	5,938,565	524%	1857%	213%
Content Loss	256,720	1,671,534	4,956,937	551%	1831%	197%
Inventory Loss	5,482	26,684	68,839	387%	1156%	158%
Relocation Cost	94,967	628,200	1,395,143	561%	1369%	122%
Income Loss	62,913	373,938	812,150	494%	1191%	117%
Rental Income Loss	33,046	253,896	574,735	668%	1639%	126%
Wage Loss	142,026	832,944	1,791,186	486%	1161%	115%
Total Loss	**898,606**	**5,681,559**	**15,537,555**	**532%**	**1629%**	**173%**

Table 6-23 Beaumont/Port Arthur/Orange Storm Landfall - Total Building Loss per Census Block

	Number of Census Blocks					
Total Loss Range per Census Block	**Current Conditions**	**2100-Low**	**2100-High**	**Percent Change in Damages Present to Low**	**Percent Change in Damages - Present to High**	**Percent Change in Damages - Low to High**
$1-$100,000	441	471	343	7%	-22%	-27%
$100,001-$500,000	325	815	728	151%	124%	-11%
$500,001-$1M	333	810	1,056	143%	217%	30%
$1M-$5M	162	1,154	1,900	612%	1073%	65%
$5M-$10M+3	20	583	590	2815%	2850%	1%
$10M-$20M	10	61	213	510%	2030%	249%
$20M-$30M	2	21	57	950%	2750%	171%
$30M-$40M	1	4	28	300%	2700%	600%
$40M-$50M	0	1	15	-	-	1400%
$50M-$100M	0	1	10	-	-	900%
$100M+	0	0	2	-	-	-
Total Number of Census Blocks	**1,294**	**3,921**	**4,942**	**203%**	**282%**	**26%**

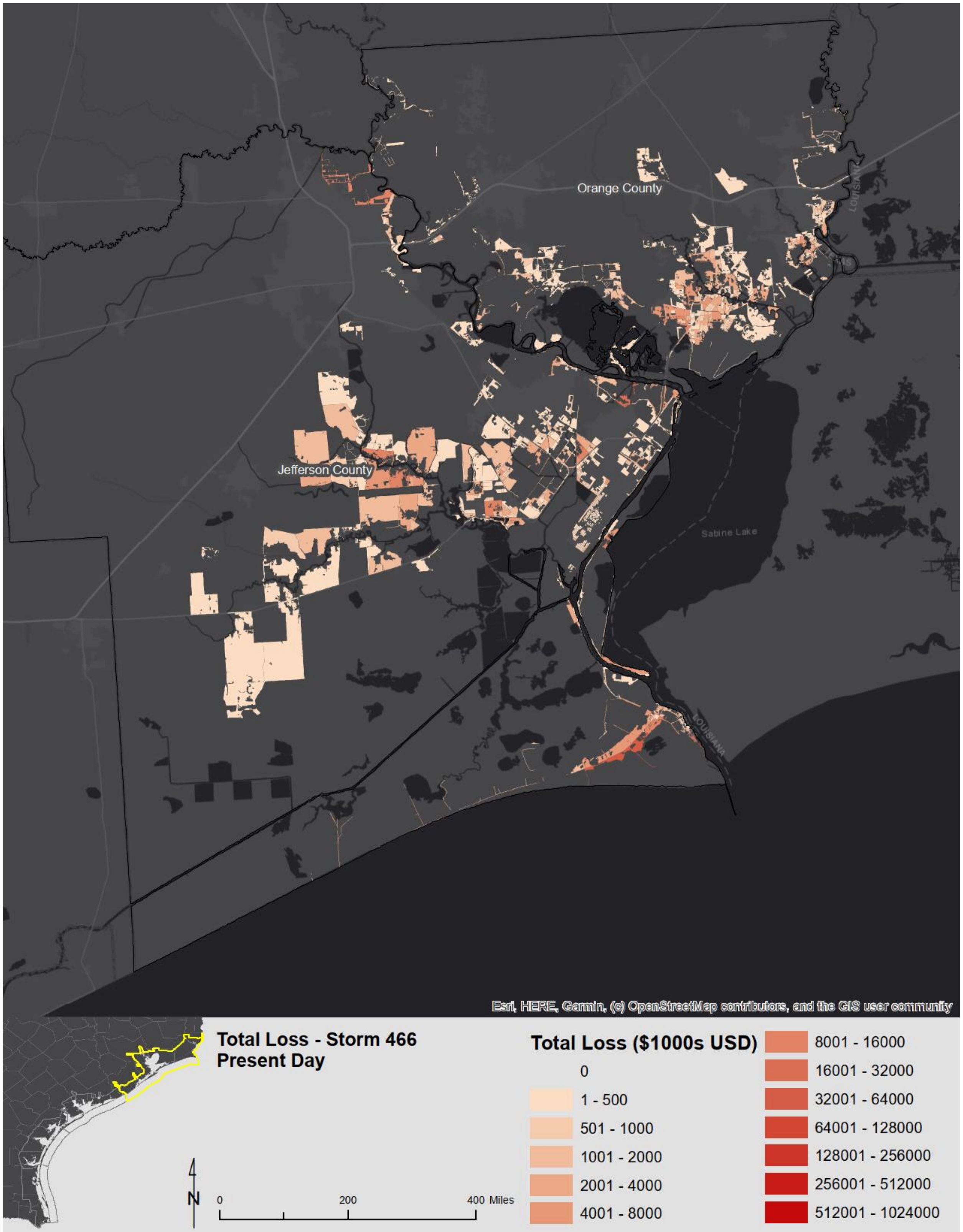


Figure 6-94 Beaumont/Port Arthur/Orange Storm Landfall – Current Condition Economic Loss

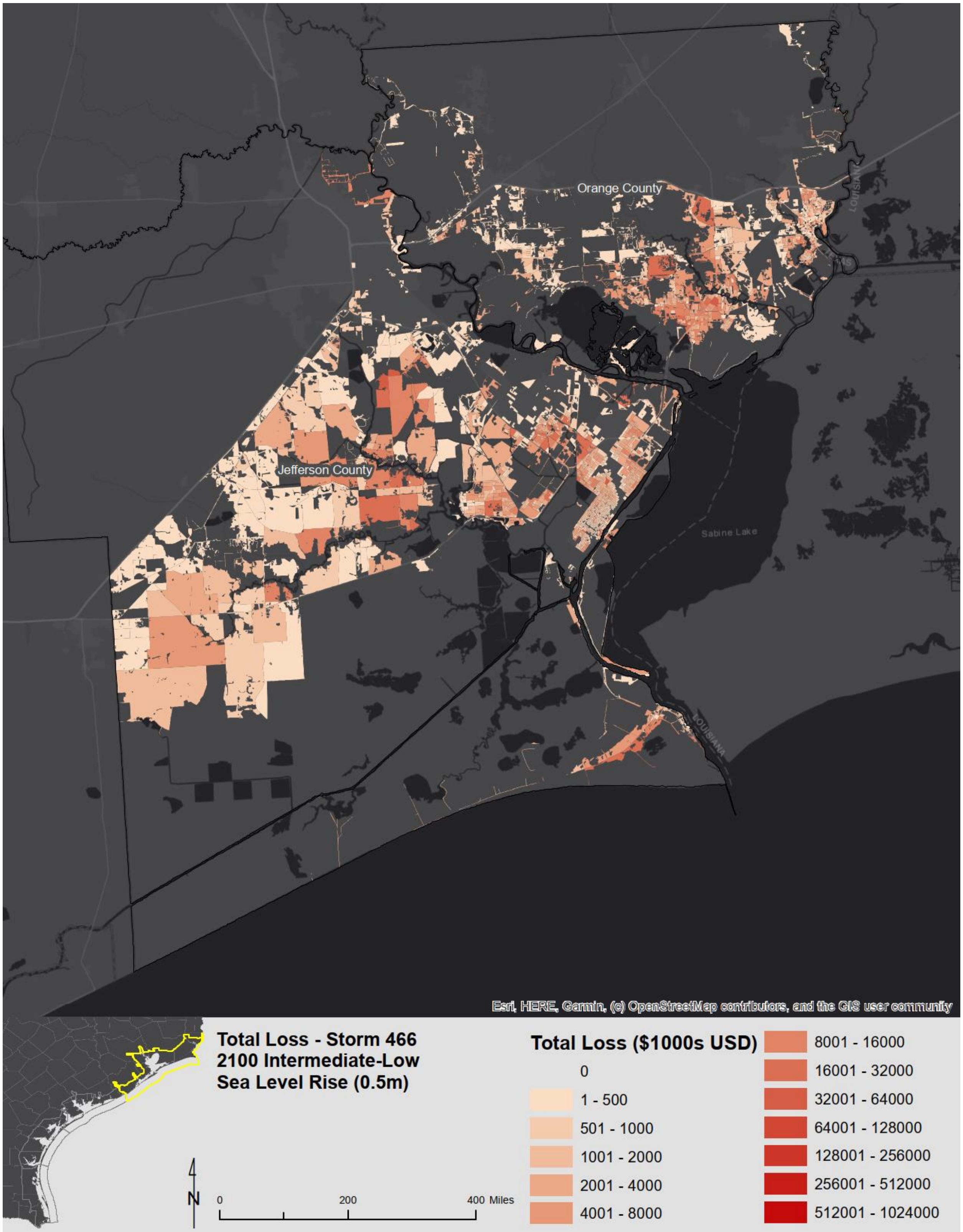


Figure 6-95 Beaumont/Port Arthur/Orange Storm Landfall – Intermediate-Low Future Condition Economic Loss

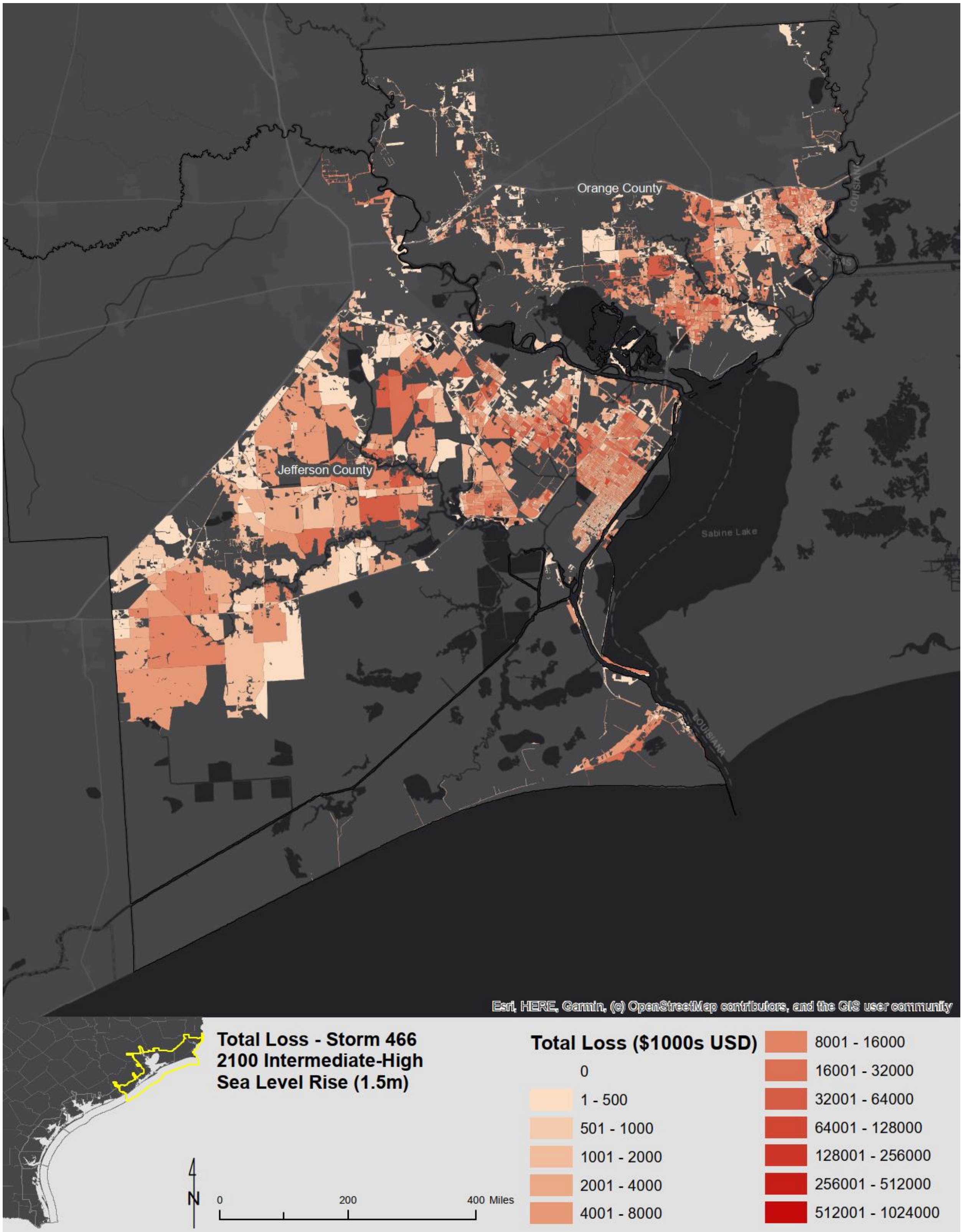


Figure 6-96 Beaumont/Port Arthur/Orange Storm Landfall – Intermediate-High Future Condition Economic

Houston – Galveston

About 66% of residential buildings in Houston/Galveston are classified as one story, and 98% of non-residential buildings are considered low rise (**Table 6-24**). The total number of buildings in this area with damages due to storm surge or SLR is project to increase by 242% (low) and 525% (high) by 2100 if no action were to occur (**Table 6-25**). Due to the increase of building damages, the cost of building losses would increase by 345% (low)/741% (high) and the total economic loss would increase by 243% (low)/492% (high) for the counties surrounding the metro area (**Table 6-26**). In 2100, results show that an additional 2,995 (low)/4,720 (high) census blocks would be impacted by the hurricane modeled (**Table 6-27**).

The results from **Table 6-26** are shown spatially in **Figure 6-97** for current conditions and Figure 6-98 and Figure 6-99 for future conditions.

Table 6-24 Houston/Galveston Building Statistics

Residential Building Statistics		Non-Residential Building Statistics	
Residential 1 Story	66%	Percent Low Rise	98%
Residential 2 Story	32%	Percent Mid Rise	1%
Residential 3 Story	1%	Percent High Rise	1%
Residential Split Level	1%		

Table 6-25 Houston/Galveston Storm Landfall - Physical Damage Results

	Number of Buildings					
	Current Conditions	2100 - Low	2100 - High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
Buildings Damaged 1 to 10%	494	774	1,384	57%	180%	79%
Buildings Damaged 11 to 20%	2,066	5,437	8,530	163%	313%	57%
Buildings Damaged 21 to 30%	718	2,102	4,056	193%	465%	93%
Buildings Damaged 31 to 40%	474	1,056	2,154	123%	354%	104%
Buildings Damaged 41 to 50%	395	1,045	1,760	165%	346%	68%
Substantial Loss	1,772	9,857	19,102	456%	978%	94%
Number of Buildings with Damages 1-50%	4,147	10,414	17,884	151%	331%	72%
Number of Buildings with Substantial Damages	1,772	9,857	19,102	456%	978%	94%
Total Number of Damaged Buildings	**5,919**	**20,271**	**36,986**	**242%**	**525%**	**82%**

Table 6-26 Houston/Galveston Storm Landfall - Economic Damage Results

	Damages in $1000s USD					
Category	**Current Conditions**	**2100-Low**	**2100-High**	**Percent Change in Damages - Present to Low**	**Percent Change in Damages - Present to High**	**Percent Change in Damages - Low to High**
Building Loss	914,913	4,082,564	7,696,888	346%	741%	89%
Content Loss	806,025	3,372,719	6,325,216	318%	685%	88%
Inventory Loss	11,775	50,858	108,697	332%	823%	114%
Relocation Cost	414,780	1,086,722	1,809,904	162%	336%	67%
Income Loss	368,603	856,739	1,310,176	132%	255%	53%
Rental Income Loss	170,815	467,460	791,844	174%	364%	69%
Wage Loss	798,613	1,730,626	2,580,756	117%	223%	49%
Total Loss	**3,485,524**	**11,647,688**	**20,623,481**	**234%**	**492%**	**77%**

Table 6-27 Houston/Galveston Storm Landfall - Total Building Loss per Census Block

	Number of Census Blocks					
Total Loss Range per Census Block	**Current Conditions**	**2100-Low**	**2100-High**	**Percent Change in Damages - Present to Low**	**Percent Change in Damages - Present to High**	**Percent Change in Damages - Low to High**
$1-$100,000	537	873	839	63%	56%	-4%
$100,001-$500,000	628	1,313	1,555	109%	148%	18%
$500,001-$1M	333	810	1,056	143%	217%	30%
$1M-$5M	505	1,671	2,531	231%	401%	51%
$5M-$10M	68	249	483	266%	610%	94%
$10M-$20M	34	126	229	271%	574%	82%
$20M-$30M	9	39	85	333%	844%	118%
$30M-$40M	3	21	29	600%	867%	38%
$40M-$50M	3	6	14	100%	367%	133%
$50M-$100M	0	4	13	-	-	225%
$100M+	1	4	7	300%	600%	75%
Total Number of Census Blocks	**2,121**	**5,116**	**6,841**	**141%**	**223%**	**34%**

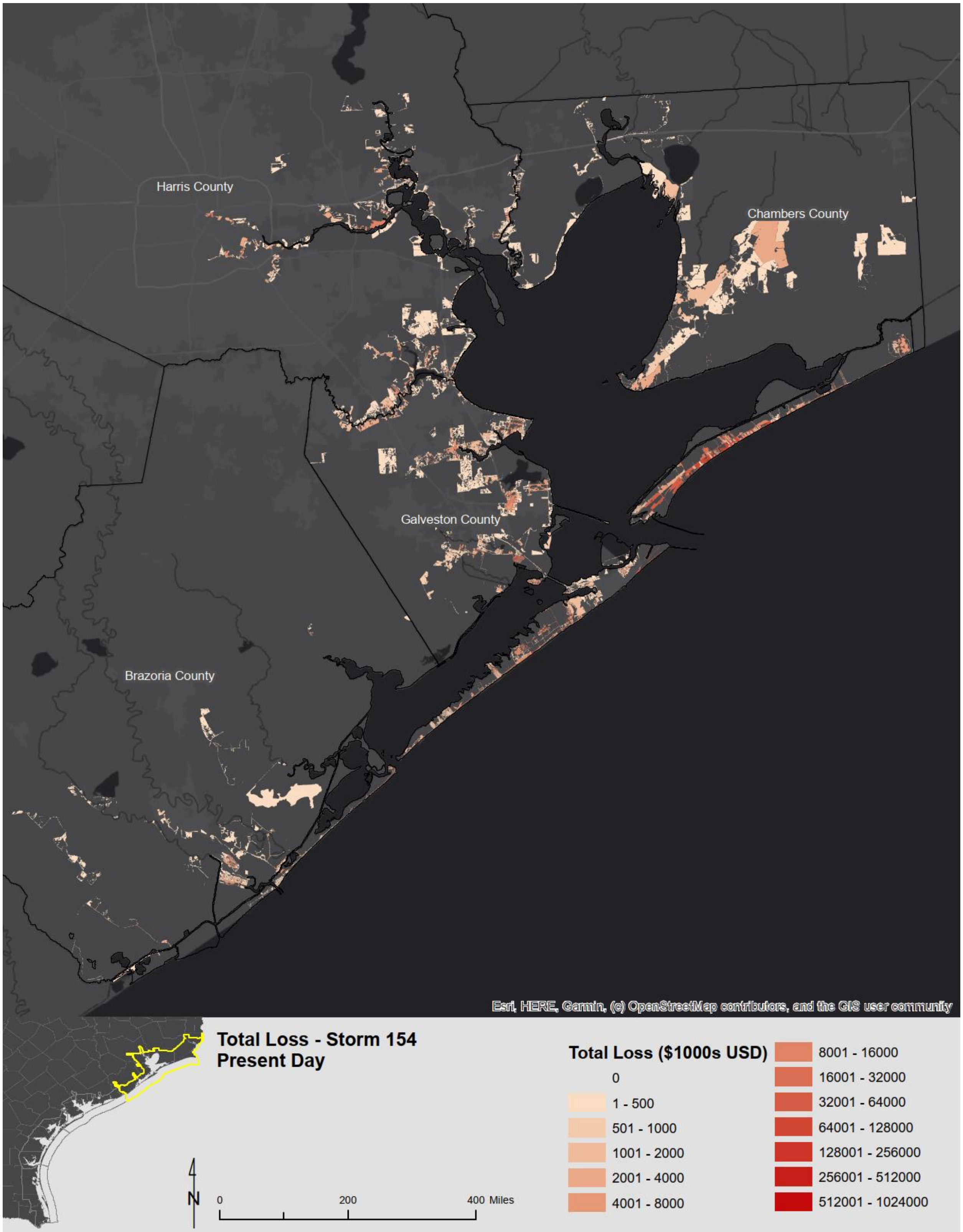


Figure 6-97 Houston/Galveston Storm Landfall – Current Condition Economic Loss

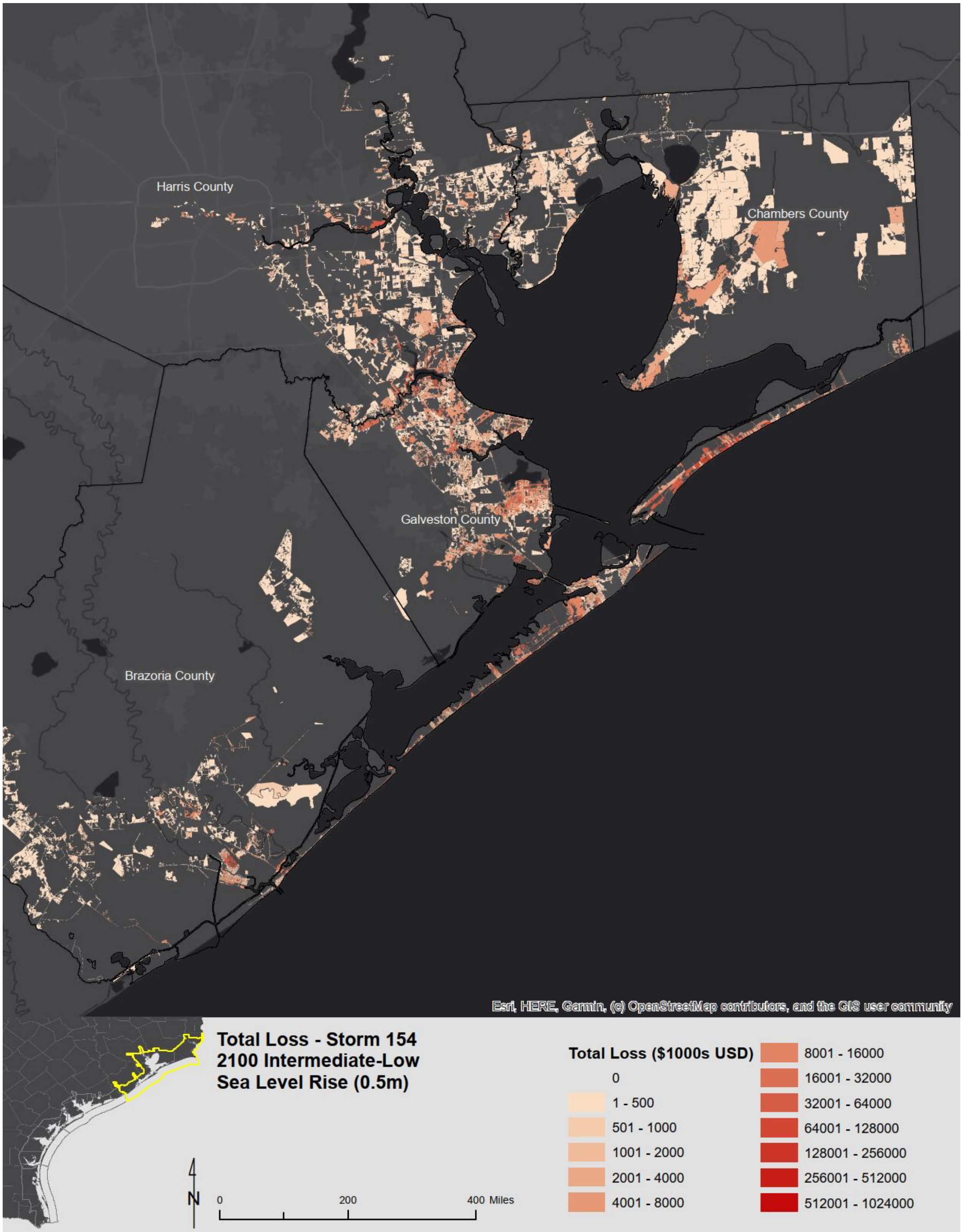


Figure 6-98 Houston/Galveston Storm Landfall – Intermediate-Low Future Condition Economic Loss

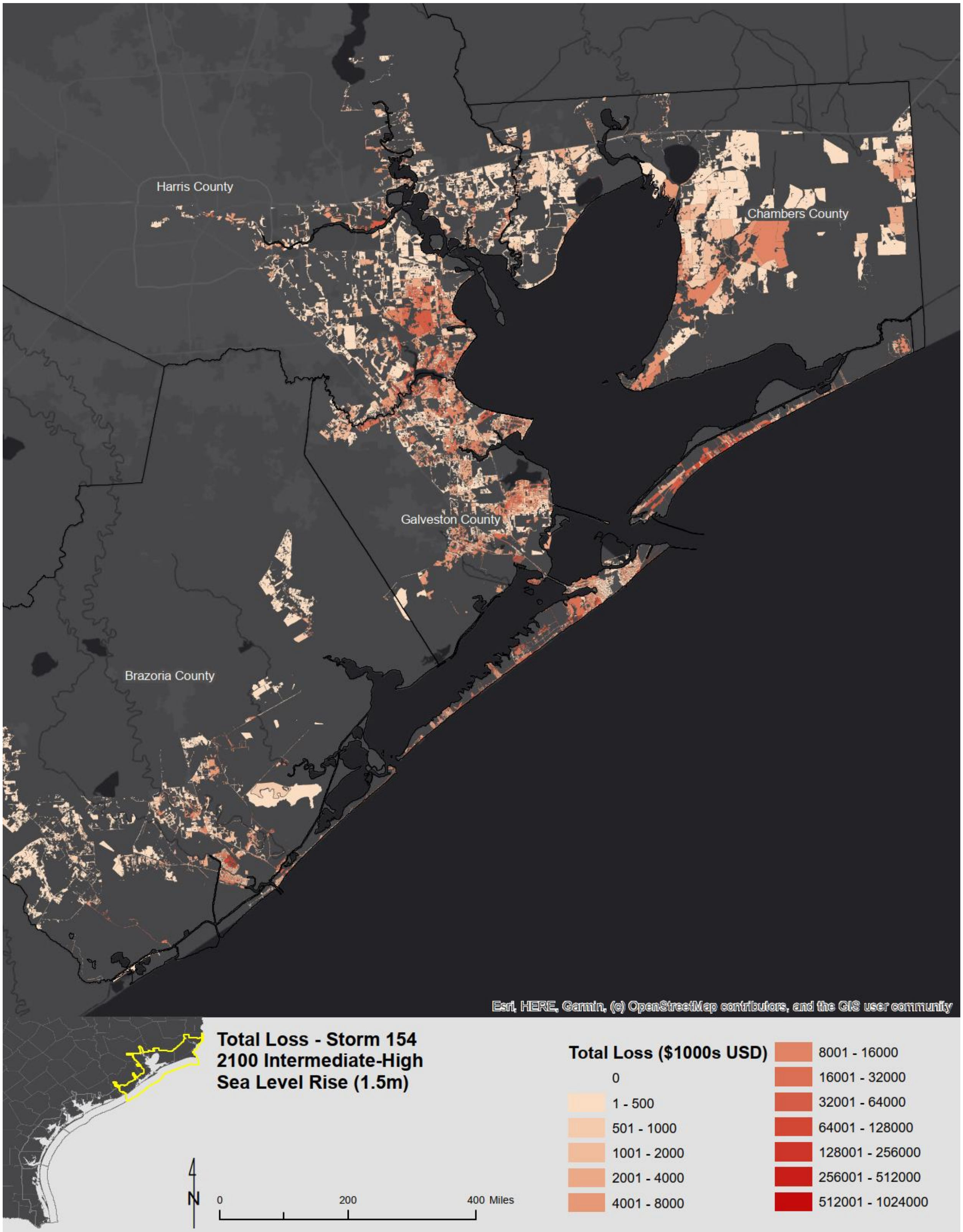


Figure 6-99 Houston/Galveston Storm Landfall – Intermediate-High Future Condition Economic Loss

Matagorda

About 66% of residential buildings in the Matagorda area are classified as one story, and 98% of non-residential buildings are considered low rise (**Table 6-28**). The total number of buildings in this area with damages due to storm surge or SLR is project to increase by 1,000% (low) and 2,634% (high) by 2100 if no action were to occur (**Table 6-29**). Due to the increase of building damages, the cost of building losses would increase by 918% (low)/2,8171% (high) and the total economic loss would increase by 554% (low)/1,685% (high) for the counties surrounding the metro area (**Table 6-30**). In 2100, results show that an additional 527 (low)/983 (high) census blocks would be impacted by the hurricane modeled (**Table 6-31**).

The results from **Table 6-30** are shown spatially in **Figure 6-100** for current conditions and **Figure 6-101** and **Figure 6-102** for future conditions.

Table 6-28 Matagorda Area Building Statistics

Residential Building Statistics		Non-Residential Building Statistics	
Residential 1 Story	66%	Percent Low Rise	98%
Residential 2 Story	32%	Percent Mid Rise	1%
Residential 3 Story	1%	Percent High Rise	1%
Residential Split Level	1%		

Table 6-29 Matagorda Area Storm Landfall - Physical Damage Results

	Number of Buildings					
	Current Conditions	2100 - Low	2100 - High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
Buildings Damaged 1 to 10%	13	70	97	438%	646%	39%
Buildings Damaged 11 to 20%	59	383	649	549%	1000%	69%
Buildings Damaged 21 to 30%	10	122	327	1120%	3170%	168%
Buildings Damaged 31 to 40%	6	86	105	1333%	1650%	22%
Buildings Damaged 41 to 50%	9	67	82	644%	811%	22%
Substantial Loss	48	867	2704	1706%	5533%	212%
Number of Buildings with Damages 1-50%	97	728	1260	651%	1199%	73%
Number of Buildings with Substantial Damages	48	867	2704	1706%	5533%	212%
Total Number of Damaged Buildings	**145**	**1,595**	**3,964**	**1000%**	**2634%**	**149%**

Table 6-30 Matagorda Area Storm Landfall - Economic Damage Results

Category	Damages in $1000s USD Current Conditions	2100-Low	2100-High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
Building Loss	24,022	244,654	700,626	918%	2817%	186%
Content Loss	19,046	162,706	478,360	754%	2412%	194%
Inventory Loss	155	996	4,498	543%	2802%	352%
Relocation Cost	12,425	87,537	181,032	605%	1357%	107%
Income Loss	8,259	23,814	60,932	188%	638%	156%
Rental Income Loss	4,827	28,543	60,229	491%	1148%	111%
Wage Loss	23,733	56,277	165,299	137%	596%	194%
Total Loss	**92,467**	**604,527**	**1,650,976**	**554%**	**1685%**	**173%**

Table 6-31 Matagorda Area Storm Landfall - Total Building Loss per Census Block

Total Loss Range per Census Block	Number of Census Blocks Current Conditions	2100-Low	2100-High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
$1-$100,000	116	301	327	159%	182%	9%
$100,001-$500,000	50	244	294	388%	488%	20%
$500,001-$1M	14	71	242	407%	1629%	241%
$1M-$5M	16	88	253	450%	1481%	188%
$5M-$10M	1	11	37	1000%	3600%	236%
$10M-$20M	2	9	17	350%	750%	89%
$20M-$30M	0	0	7	-	-	-
$30M-$40M	0	1	2	-	-	100%
$40M-$50M	0	1	1	-	-	0%
$50M-$100M	0	0	2	-	-	-
$100M+	0	0	0	-	-	-
Total Number of Census Blocks	**199**	**726**	**1,182**	**265%**	**494%**	**63%**

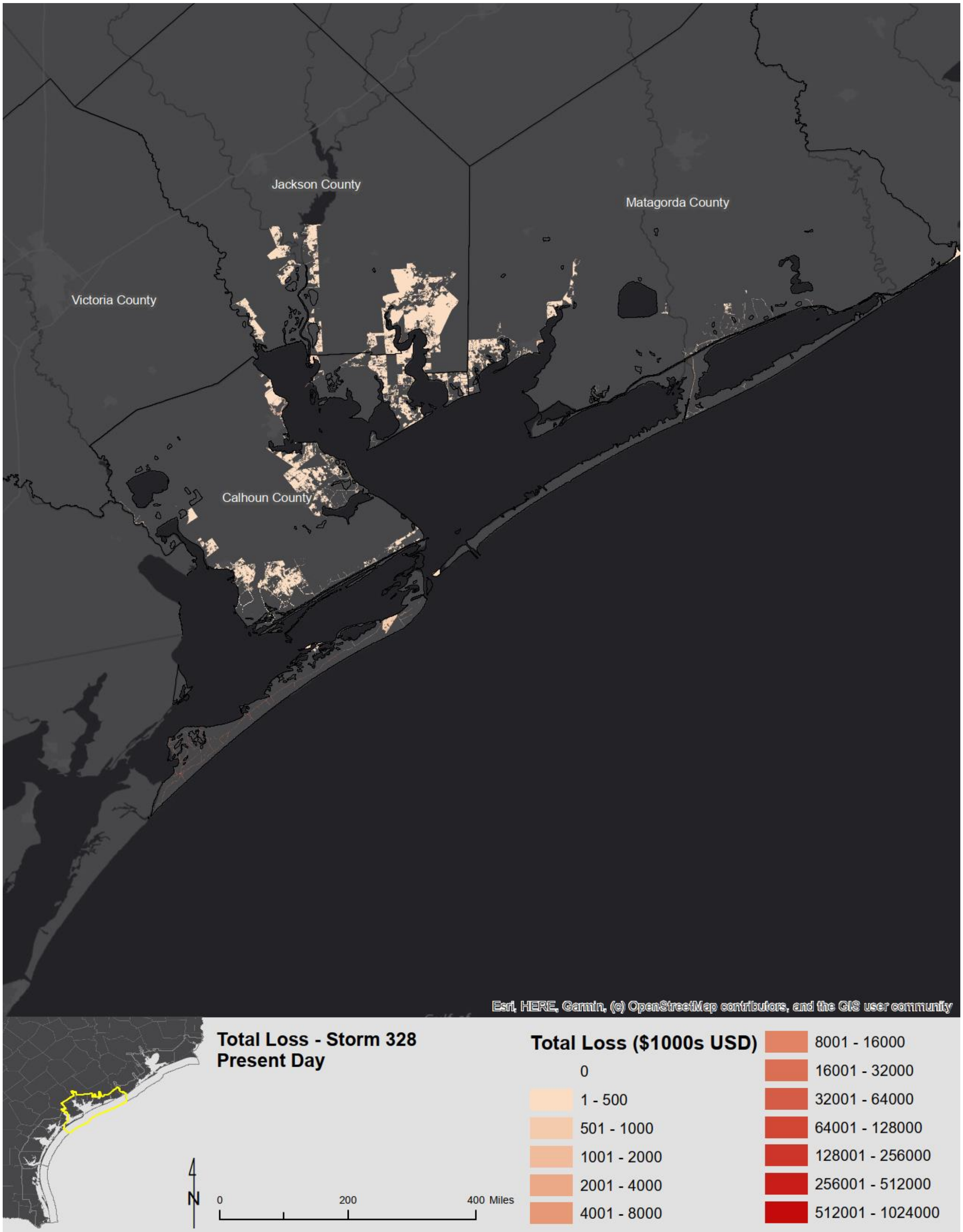


Figure 6-100 Matagorda Area Storm Landfall – Current Condition Economic Loss

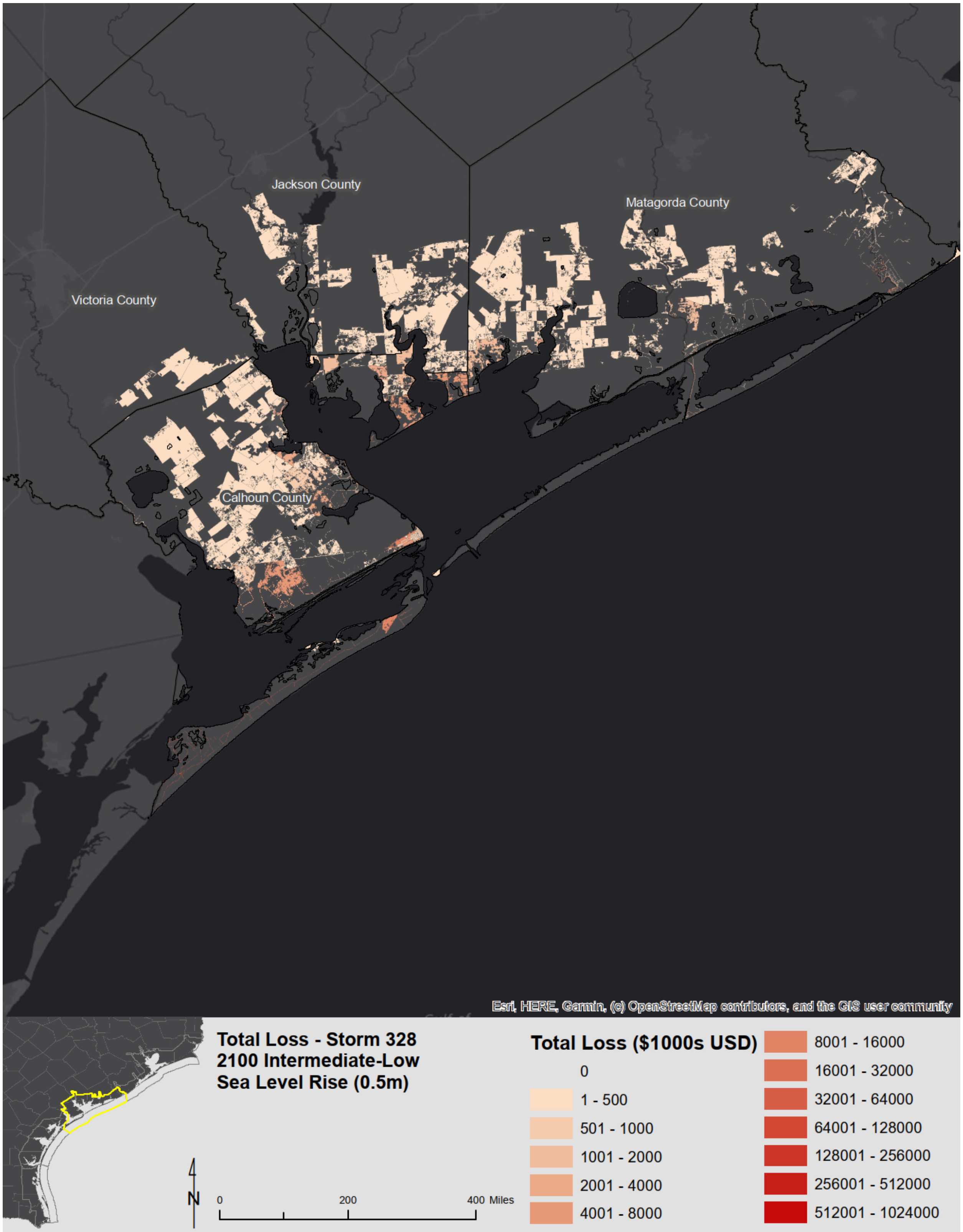


Figure 6-101 Matagorda Area Storm Landfall – Intermediate-Low Future Condition Economic Loss

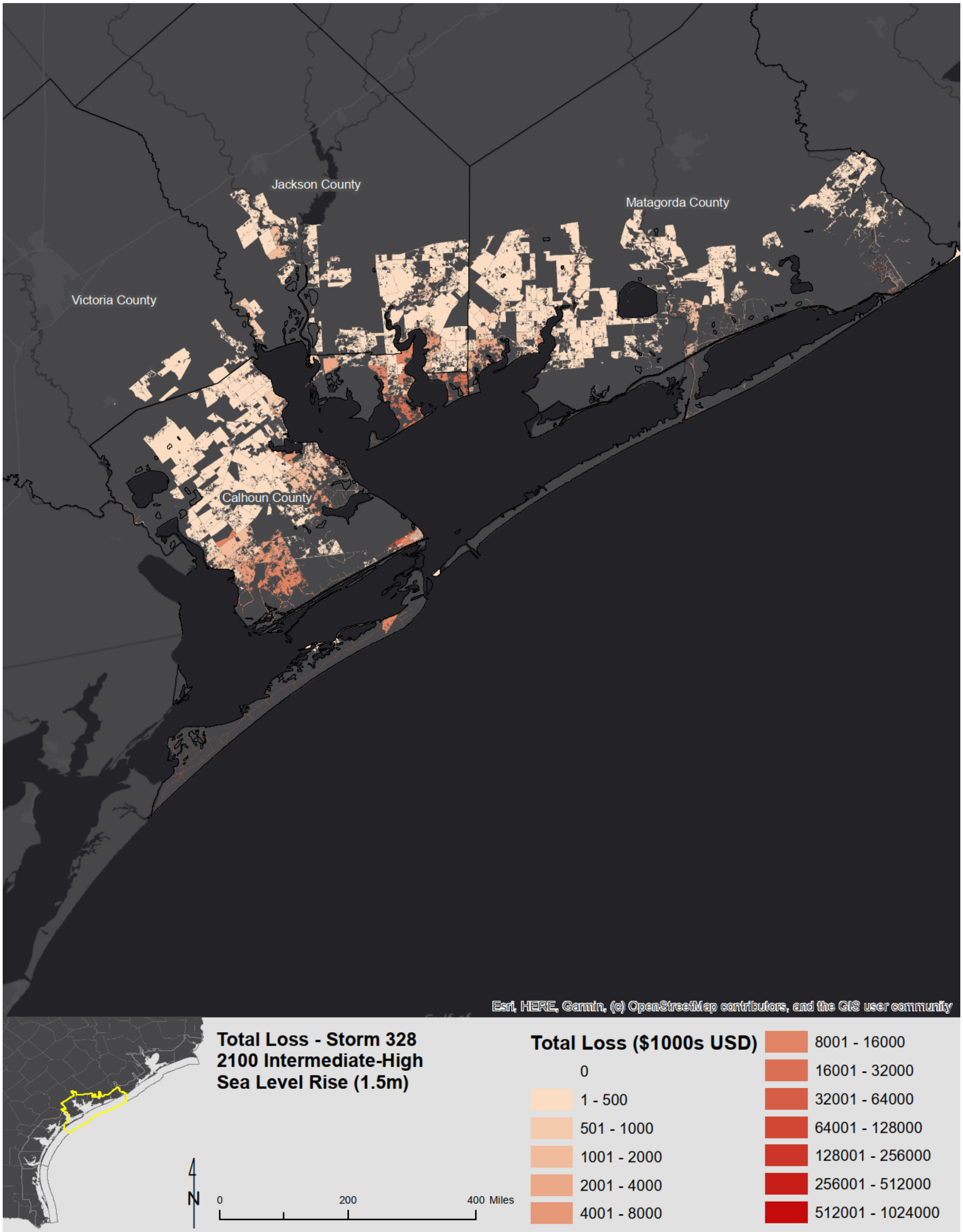


Figure 6-102 Matagorda Area Storm Landfall – Intermediate-High Future Condition Economic Loss

Corpus Christi

About 66% of residential buildings in the Corpus Christi area are classified as one story, and 97% of non-residential buildings are considered low rise (**Table 6-32**). The total number of buildings in this area with damages due to storm surge or SLR is project to increase by 232% (low) and 537% (high) by 2100 if no action were to occur (**Table 6-33**). Due to the increase of building damages, the cost of building losses would increase by 338% (low)/810% (high) and the total economic loss would increase by 237% (low)/537% (high) for the counties surrounding the metro area (**Table 6-34**). In 2100, results show that an additional 767 (low)/1451 (high) census blocks would be impacted by the hurricane modeled (**Table 6-35**).

The results from **Table 6-34** are shown spatially in **Figure 6-103** for current conditions and **Figure 6-104** and **Figure 6-105** for future conditions.

Table 6-32 Corpus Christi Area Building Statistics

Residential Building Statistics		Non-Residential Building Statistics	
Residential 1 Story	66%	Percent Low Rise	97%
Residential 2 Story	32%	Percent Mid Rise	2%
Residential 3 Story	1%	Percent High Rise	1%
Residential Split Level	1%		

Table 6-33 Corpus Christi Area Storm Landfall - Physical Damage Results

	Number of Buildings					
	Current Conditions	2100 - Low	2100 - High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
Buildings Damaged 1 to 10%	197	362	457	84%	132%	26%
Buildings Damaged 11 to 20%	581	1,345	1,945	131%	235%	45%
Buildings Damaged 21 to 30%	175	489	1,104	179%	531%	126%
Buildings Damaged 31 to 40%	119	347	482	192%	305%	39%
Buildings Damaged 41 to 50%	89	295	406	231%	356%	38%
Substantial Loss	417	2394	5,650	474%	1255%	136%
Number of Buildings with Damages 1-50%	1161	2,838	4,394	144%	278%	55%
Number of Buildings with Substantial Damages	417	2,394	5,650	474%	1255%	136%
Total Number of Damaged Buildings	**1,578**	**5,232**	**10,044**	**232%**	**537%**	**92%**

Table 6-34 Corpus Christi Area Storm Landfall - Economic Damage Results

Category	Damages in $1000s USD					
	Current Conditions	2100-Low	2100-High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
Building Loss	234,541	1,027,189	2,134,125	338%	810%	108%
Content Loss	208,439	861,813	1,780,929	313%	754%	107%
Inventory Loss	2,562	10,564	21,060	312%	722%	99%
Relocation Cost	121,312	319,406	530,520	163%	337%	66%
Income Loss	160,301	360,738	592,632	125%	270%	64%
Rental Income Loss	73,783	178,634	297,041	142%	303%	66%
Wage Loss	186,959	571,150	936,661	205%	401%	64%
Total Loss	**987,897**	**3,329,494**	**6,292,968**	**237%**	**537%**	**89%**

Table 6-35 Corpus Christi Area Storm Landfall - Total Building Loss per Census Block

Total Loss Range per Census Block	Number of Census Blocks					
	Current Conditions	2100-Low	2100-High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
$1-$100,000	173	363	476	110%	175%	31%
$100,001-$500,000	232	375	509	62%	119%	36%
$500,001-$1M	96	201	273	109%	184%	36%
$1M-$5M	122	353	630	189%	416%	78%
$5M-$10M	23	67	98	191%	326%	46%
$10M-$20M	11	41	74	273%	573%	80%
$20M-$30M	2	14	24	600%	1100%	71%
$30M-$40M	1	2	9	100%	800%	350%
$40M-$50M	1	0	6	-100%	500%	-
$50M-$100M	2	7	7	250%	250%	0%
$100M+	0	7	8	-	-	14%
Total Number of Census Blocks	**663**	**1,430**	**2,114**	**116%**	**219%**	**48%**

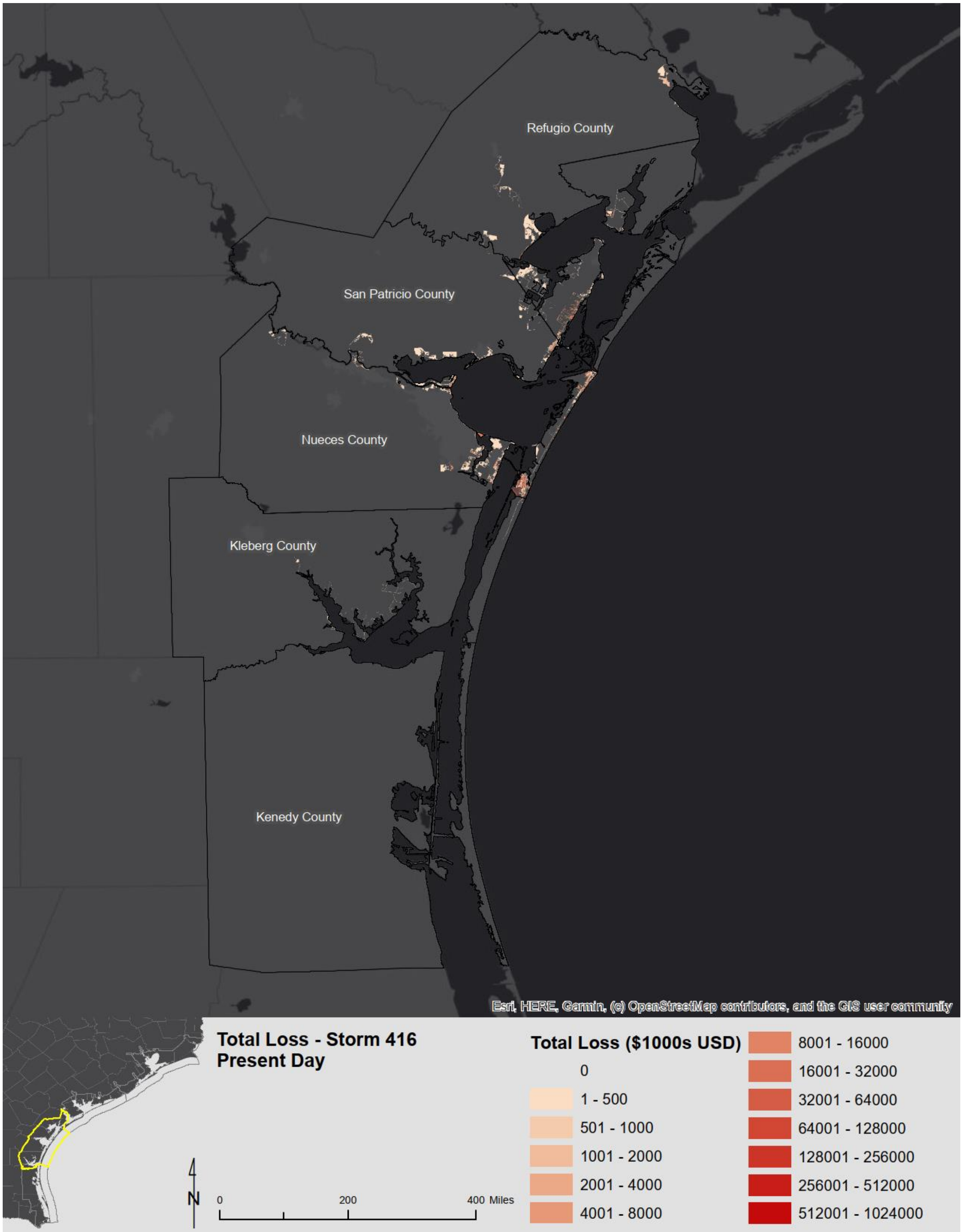


Figure 6-103 Corpus Christi Area Storm Landfall – Current Condition Economic Loss

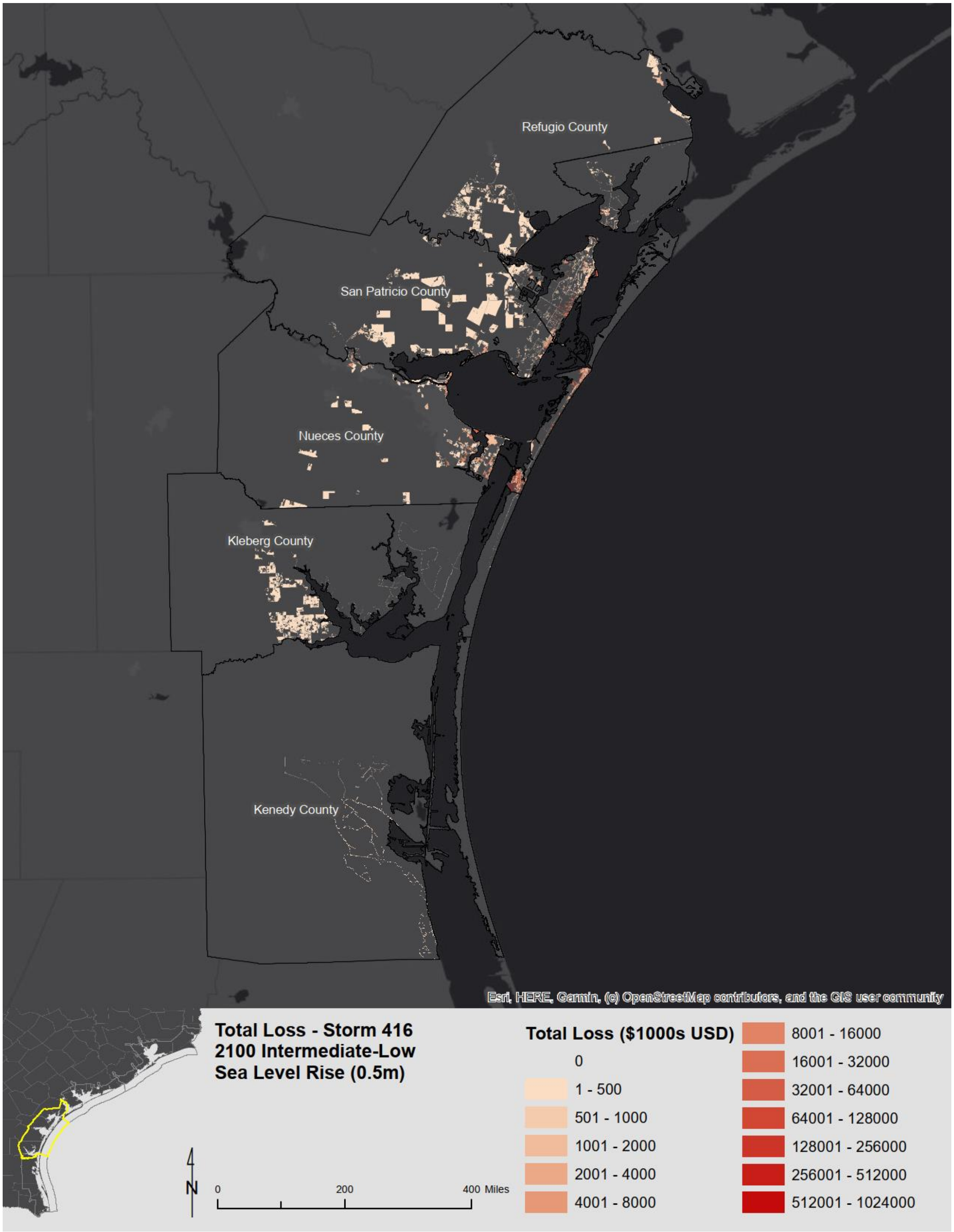


Figure 6-104 Corpus Christi Area Storm Landfall – Intermediate-Low Future Condition Economic Loss

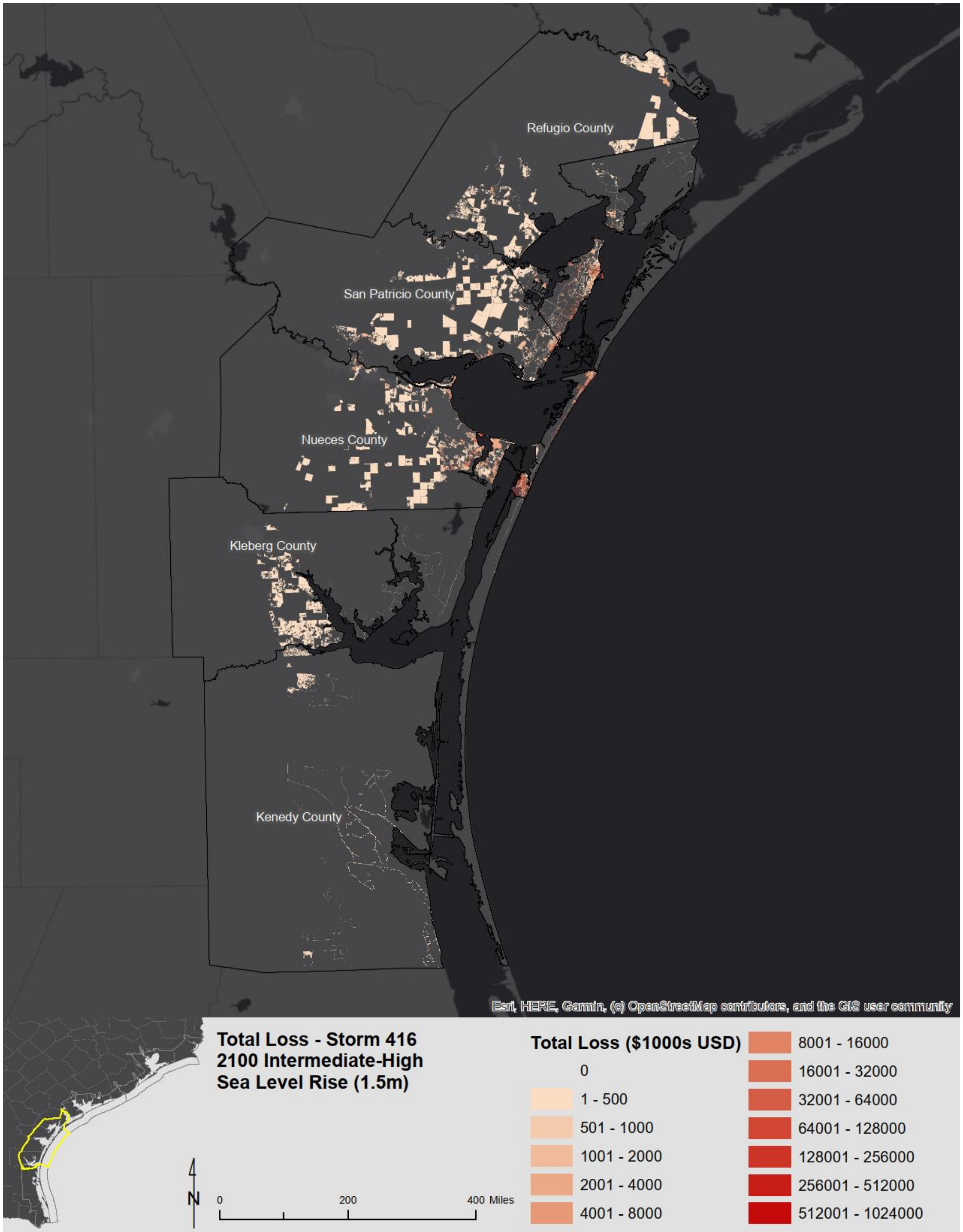


Figure 6-105 Corpus Christi Area Storm Landfall – Intermediate-High Future Condition Economic Loss

South Padre Island

About 66% of residential buildings in the South Padre Island area are classified as one story, and 97% of non-residential buildings are considered low rise (**Table 6-36**). The total number of buildings in this area with damages due to storm surge or SLR is project to increase by 193% (low) and 413% (high) by 2100 if no action were to occur (**Table 6-37**). Due to the increase of building damages, the cost of building losses would increase by 175% (low)/419% (high) and the total economic loss would increase by 132% (low)/312% (high) for the counties surrounding the metro area (**Table 6-38**). In 2100, results show that an additional 284 (low)/590 (high) census blocks would be impacted by the hurricane modeled (**Table 6-39**).

The results from **Table 6-38** are shown spatially in **Figure 6-106** for current conditions and **Figure 6-107** and **Figure 6-108** for future conditions.

Table 6-36 South Padre Island Area Building Statistics

Residential Building Statistics		Non-Residential Building Statistics	
Residential 1 Story	66%	Percent Low Rise	97%
Residential 2 Story	32%	Percent Mid Rise	2%
Residential 3 Story	1%	Percent High Rise	1%
Residential Split Level	1%		

Table 6-37 South Padre Island Area Storm Landfall - Physical Damage Results

Number of Buildings						
	Current Conditions	2100 - Low	2100 - High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
Buildings Damaged 1 to 10%	44	89	46	102%	5%	-48%
Buildings Damaged 11 to 20%	308	649	306	111%	-1%	-53%
Buildings Damaged 21 to 30%	108	320	553	196%	412%	73%
Buildings Damaged 31 to 40%	43	126	310	193%	621%	146%
Buildings Damaged 41 to 50%	41	126	199	207%	385%	58%
Substantial Loss	687	2,299	4,901	235%	613%	113%
Number of Buildings with Damages 1-50%	544	1,310	1,414	141%	160%	8%
Number of Buildings with Substantial Damages	687	2,299	4,901	235%	613%	113%
Total Number of Damaged Buildings	**1,231**	**3,609**	**6,315**	**193%**	**413%**	**75%**

Table 6-38 South Padre Island Area Storm Landfall - Economic Damage Results

Category	Damages in $1000s USD					
	Current Conditions	2100-Low	2100-High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
Building Loss	264,235	726,696	1,371,121	175%	419%	89%
Content Loss	208,064	582,449	1,083,423	180%	421%	86%
Inventory Loss	1,828	4,995	9,488	173%	419%	90%
Relocation Cost	93,604	174,282	278,894	86%	198%	60%
Income Loss	90,429	151,578	235,800	68%	161%	56%
Rental Income Loss	74,055	121,697	180,800	64%	144%	49%
Wage Loss	129,355	233,985	389,427	81%	201%	66%
Total Loss	**861,570**	**1,995,682**	**3,548,953**	**132%**	**312%**	**78%**

Table 6-39 South Padre Island Area Storm Landfall - Total Building Loss per Census Block

Total Loss Range per Census Block	Number of Census Blocks					
	Current Conditions	2100-Low	2100-High	Percent Change in Damages - Present to Low	Percent Change in Damages - Present to High	Percent Change in Damages - Low to High
$1-$100,000	69	140	258	103%	274%	84%
$100,001-$500,000	108	139	188	29%	74%	35%
$500,001-$1M	46	78	84	70%	83%	8%
$1M-$5M	93	196	263	111%	183%	34%
$5M-$10M	20	48	73	140%	265%	52%
$10M-$20M	10	20	46	100%	360%	130%
$20M-$30M	3	5	13	67%	333%	160%
$30M-$40M	2	4	5	100%	150%	25%
$40M-$50M	0	2	2	-	-	0%
$50M-$100M	0	3	7	-	-	133%
$100M+	1	1	3	0%	200%	200%
Total Number of Census Blocks	**352**	**636**	**942**	**81%**	**168%**	**48%**

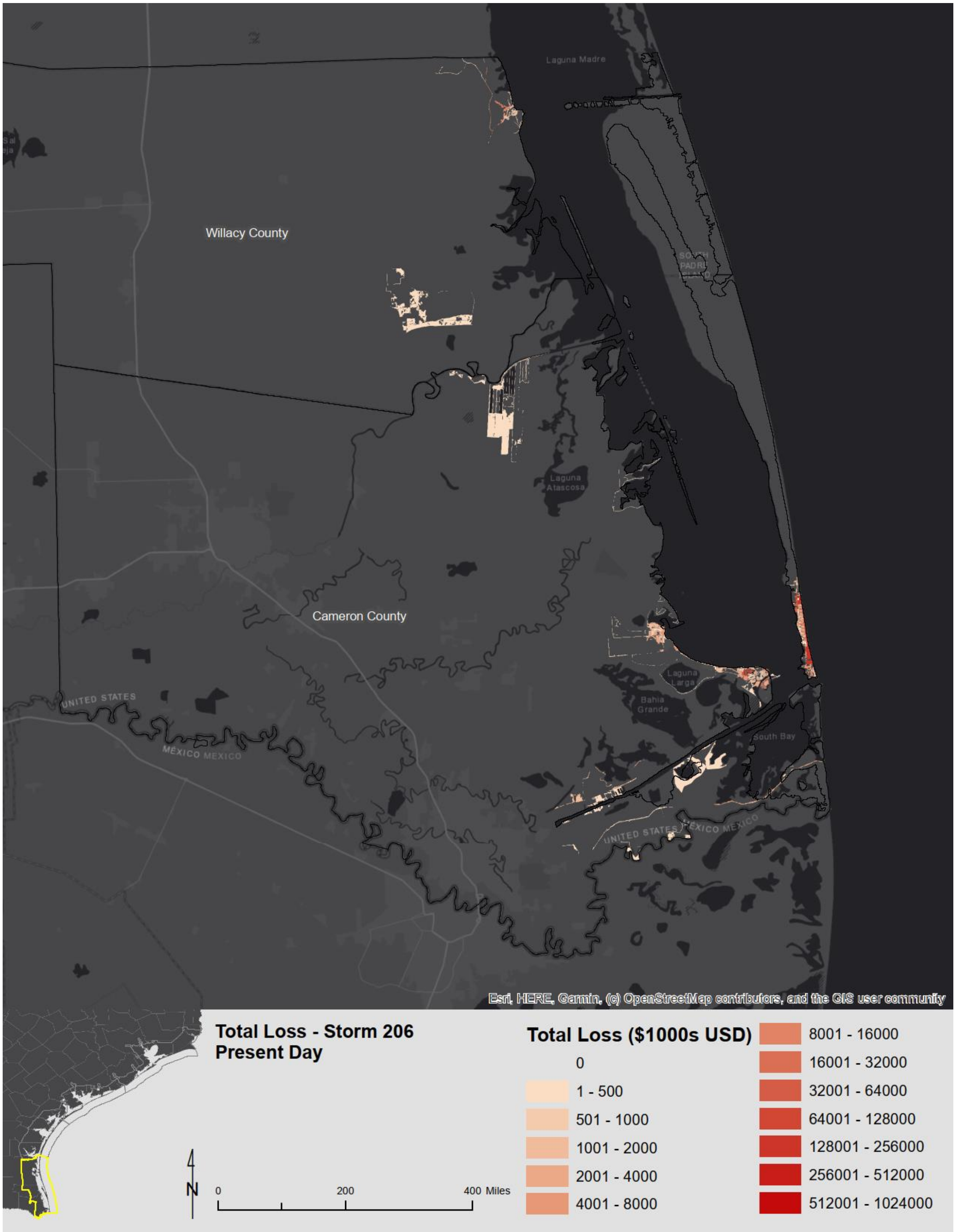


Figure 6-106 South Padre Island Area Storm Landfall – Current Condition Economic Loss

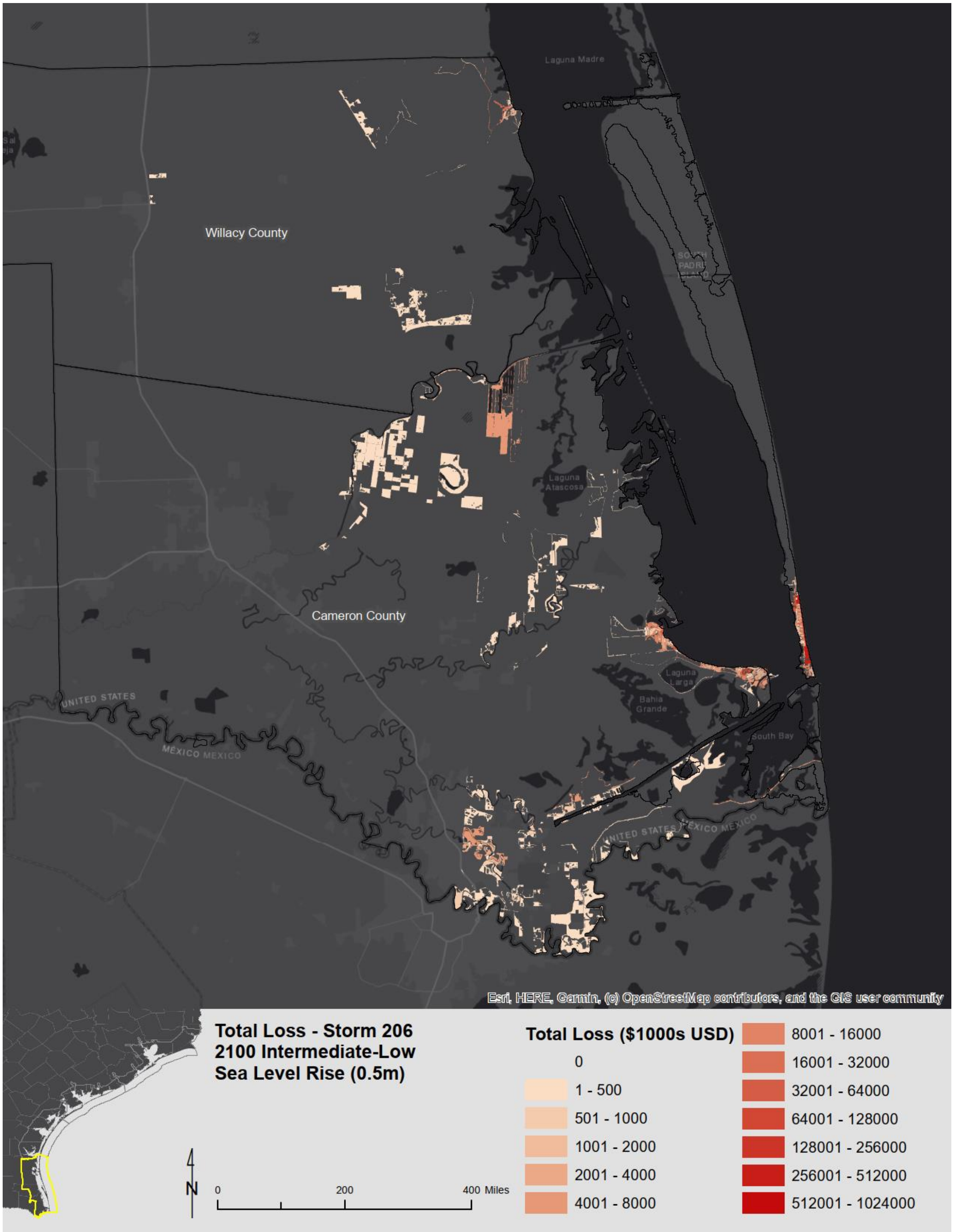


Figure 6-107 South Padre Island Area Storm Landfall – Intermediate-Low Future Condition Economic Loss

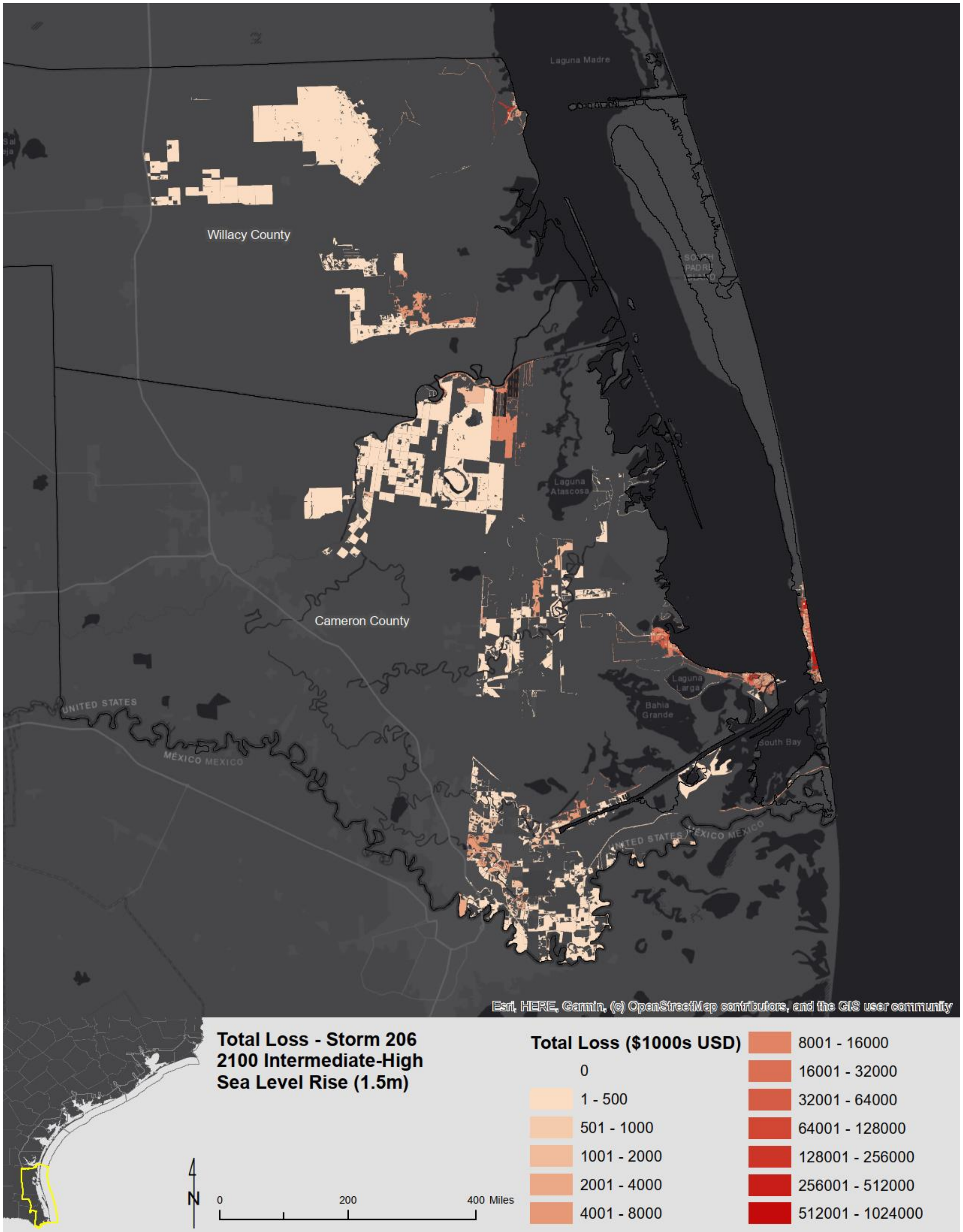


Figure 6-108 South Padre Island Area Storm Landfall – Intermediate-High Future Condition Economic Loss

Review and Conclusions

Some important considerations should be kept in mind when reviewing these findings. Damages (**Figure 6-109** through **Figure 6-111**) and associated losses (**Figure 6-112**) do not increase in a linear fashion as flood depths increase with SLR. When comparing scenarios in a particular county where flood depths increase, the losses will often increase drastically with a relatively small change in depth. This is evident in the comparison between the present-day sea level damages and losses and those of the intermediate-low scenario, where the rise is only 0.5m in 100 years. The average percent increase of total losses coastwide from present day to 2100-low is +931%, whereas the average increase between the two 2100 scenarios is +118%. There are several main reasons for this non-linear increase. First, increases in flood depth have both a vertical and horizontal dimension. A two-foot increase in depth will not only have low-lying, previously-flooded structures with even more flooding, but will expand horizontally to flood many more structures that may have not been flooded before. This is especially true in more built-up areas, where a slightly higher scenario may flood large neighborhoods that previously had been dry. This also happens when a scenario crosses the boundary associated the FEMA Special Flood Hazard Area (100-yr or 1%-annual-chance-event), where development tends to be much denser on the “other side of the line”.

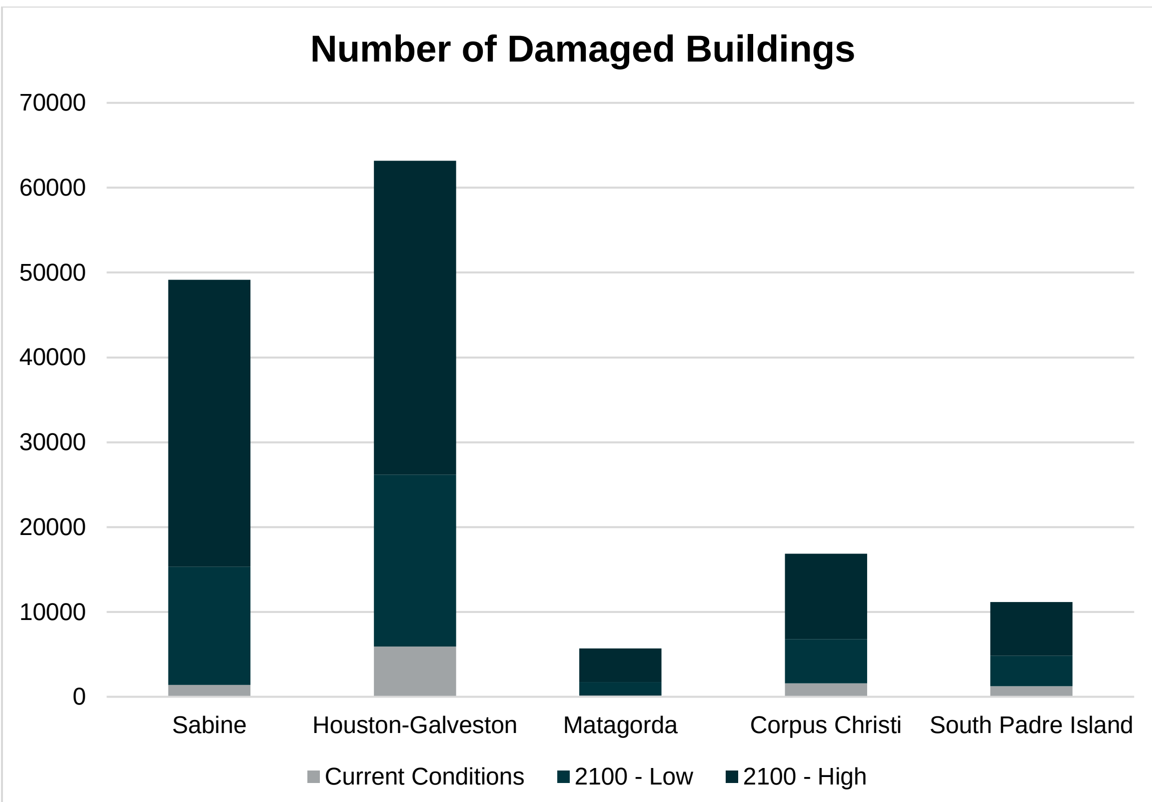


Figure 6-109 Changes in Number of Damaged Buildings

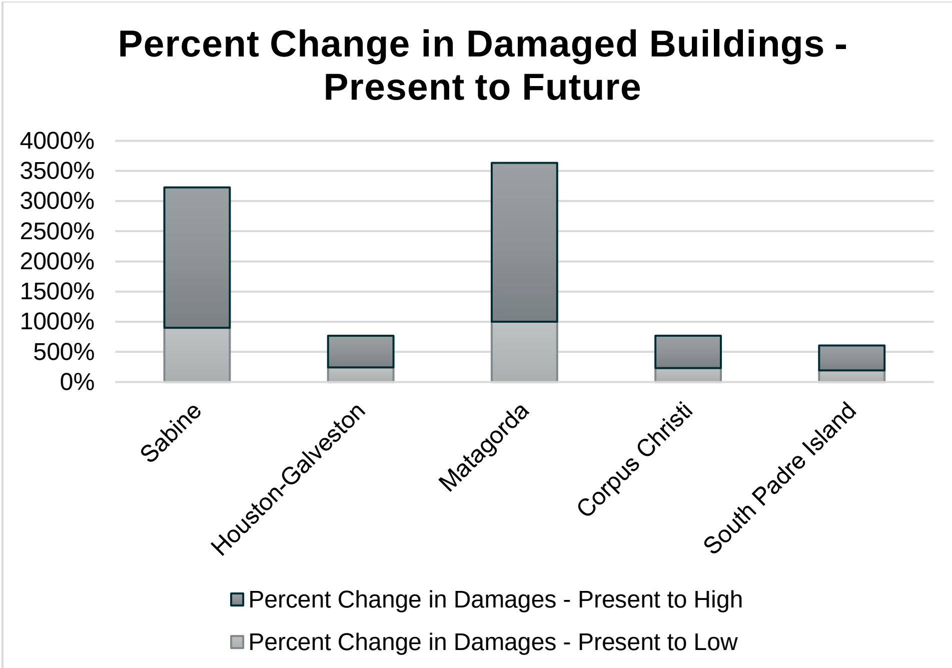


Figure 6-110 Percent Change in Damaged Buildings from Current Day to 2100

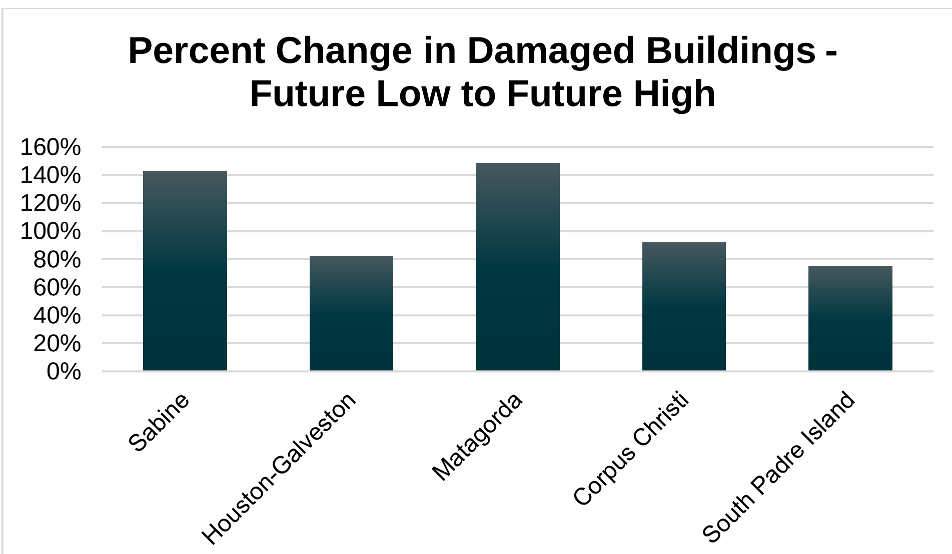


Figure 6-111 Percent Change in Damaged Buildings - 2100 Low and 2100 High

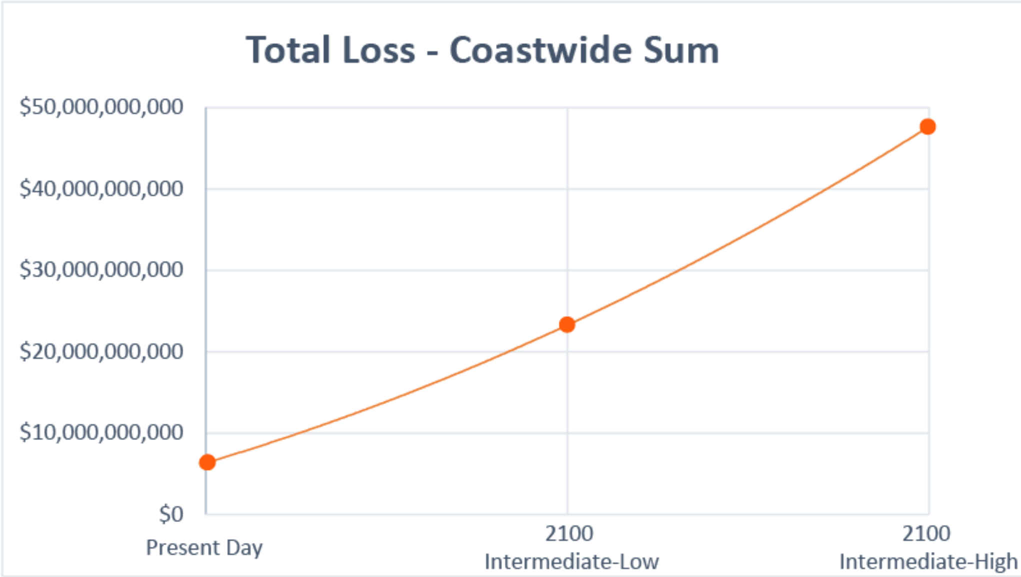


Figure 6-112 Coastwide Sums of Total Losses for Each Scenario

A second reason for non-linear loss increases is the nature of flood depth-damage relationships. An individual building will have different subassemblies (foundation, superstructure, roof, floors, electric and HVAC, etc.) that have different vulnerabilities to flooding. As relative flood depth increases in a structure, the damages to these subassemblies will increase at their own rates, and cumulatively may cause the overall damage to drastically increase over a relatively small flood depth increase. This is especially true in structures like mobile homes, where flood depths over 2 ft will often cause complete structure failure.

Also, this Hazus analysis made use of aggregated GBS census block data, rather than individual structure data. The GBS data uses averages building characteristics and depth-damage curves to calculate damages and associated losses. If an individual structure analysis had been performed in Hazus, loss values would be different, because of the better quality of the data. The expectation is that the trends between lower and higher flood depths would be similar for larger areas such as counties. However, for individual communities or neighborhoods, it is hard to know if damages would be less or more when comparing the aggregated approach with the individual building approach. In some communities, a large group of buildings may be located just outside of the flood boundary, so the aggregated approach may overestimate the loss. However, in other cases the aggregated approach may assume most structures are on crawlspaces and located several feet above the ground, but in reality, are slab-on-grade construction and the individual building approach would produce higher damages. Usually the individual structure approach makes sense when comparing specific mitigation options that may protect a relatively smaller area like a neighborhood or individual community.

The results of the Hazus models for each metro area of the storm analyses indicate a significant increase in physical damages and economic losses due to storm surge and SLR between current conditions and future conditions for both SLR scenarios if no preventative actions were to be taken.

On average, the total number of buildings that would be damaged or destroyed from storm events across the Texas coast is predicted to increase by approximately 513% by 2100 for the low scenario (an increase of approximately 35,000 residential or commercial structures) and by 1,287% for the high scenario (81,000 residential or commercial structures). Between the low and high scenarios, there is an average increase of 108% in damaged buildings between 0.5m and 1.5m of SLR, with an additional estimated 47,000 structures damaged.

Total economic loss across the Texas coast resulting from coastal storm events is also predicted to significantly increase in the future, increasing by an average of approximately 338% (low) and 931% (high) compared to current conditions (or, from approximately $6.3 billion to $23.3 billion [low] and $47.6 billion[high]). These statistics indicate the need for preventative action in order to lessen the economic blow to Texas as a result of storm surge and SLR, even for a lower SLR projection. Moreover, these values are estimates for Category 2 storms. Larger hurricanes would be expected to show significantly larger damages. Although it is not possible to predict the exact track, travel speed, wind speed or location of impact for a hurricane on the Texas coast, the Hazus results give a general picture of the economic and structural losses that could be incurred by the state as a consequence of such a storm.

6.4 Geohazards Mapping

The geohazards maps were developed using output from SLR and storm surge models. These maps are, therefore, a synthesis of all the modeling work done for the Plan as one product and provide detailed mapping of the present and future state of different geo-environments on the Texas coastal plain. Two sets of geohazards maps were developed for the two SLR scenarios. Each map is divided into six categories based on the level of hazard potential: Extreme, Imminent, Future Flooding, High, Moderate, and Low. These 6 hazard potentials are color-coded in the geohazards maps as following:

EXTREME
Historic storm washover channels and future open water

IMMINENT
Present day critical environments (wetlands, dunes, and beaches)

FUTURE FLOODING
Present day urban areas and roads expected to flood in 2100

HIGH
Area expected to become future critical environments in 2100

MODERATE
Upland areas not expected to become critical environments and storm surge vulnerability > 0.5

LOW
Upland areas not expected to become critical environments and storm surge vulnerability < 0.5

The following subsections describe the results of the geohazards mapping effort. First, the Texas coast as a whole is broadly examined, comparing each geohazard potential between two SLR scenarios modeled – intermediate-high and intermediate-low – in the form of maps and graphs. Subsequently, each of the four regions is discussed and analyzed in a more detailed approach.

6.4.1 Coastwide

Significant effects of SLR are predicted to impact the Texas coast which is vastly changing the landscape by 2100 in both SLR scenarios as shown in SLR modeling results (**Figure 6-17**). Similarly, more than a quarter of land along the coast has the highest storm surge vulnerability as shown in storm surge vulnerability mapping. Considering these results, an entire Texas coast was mapped based on the level of hazard potential as a geohazards map. **Figure 6-113** shows the geohazards maps of the Texas coast for both intermediate-high and intermediate-low SLR scenarios. The total mapped area covers more than 7,500 square miles of Texas coastal plain.

In the intermediate-low SLR scenario, nearly 8% of the mapped area falls under the Extreme geohazard potential category, which doubles in the intermediate-high scenario. The Imminent geohazard potential category, covering about 19% of the mapped area in the intermediate-low scenario, decreases to 11% in the intermediate-high scenario. This category includes presently critical environments, such as freshwater wetlands, transitional wetlands, regularly flooded estuarine wetlands, tidal flats, and beach/foredune systems. These environments are under higher pressure in higher SLR scenario and have greater potential to convert to open water thus there is less area under Imminent category in the intermediate-high scenario. The High geohazard potential category, projected to become Imminent geohazard areas in 2100, covers 5% of the mapped area in the intermediate-low SLR scenario, whereas the area doubles in the intermediate-high scenario.

The conversion of the current low marsh area to either tidal flat or open water by 2100 increases the area under Extreme and High geohazard potential categories. In addition to impacts on the natural environment, significant amounts of developed land and road networks are predicted to be inundated by 2100, which are mapped as Future Flooding geohazard potential category. In the intermediate-low scenario, about 1% of the mapped area is assigned the Future Flooding category, which doubles in the intermediate-high scenario.

The storm surge vulnerability index value help differentiate between the Moderate and Low geohazard potential areas. A cutoff value of 0.5 was used to distinguish between these two categories as both represent upland areas with higher elevation that are not expected to become critical environments in 2100. About 6% of the mapped area falls in the Moderate geohazard potential category in the intermediate-low scenario, which decreases to 2% of the mapped area in the intermediate-high scenario. The remaining 62% of the mapped area is categorized as having a Low geohazard potential in the intermediate-low SLR scenario, whereas 60% of the mapped area was categorized as Low geohazard potential in the intermediate-high scenario. However, in the higher SLR scenario, the Low and Moderate geohazard potential zones decrease as they transform to higher hazard potential categories, resulting in an increase in the area under the Extreme and High categories. **Figure 6-114** shows the areal changes of each 6 geohazard potential categories in the intermediate-low and intermediate-high SLR scenarios.

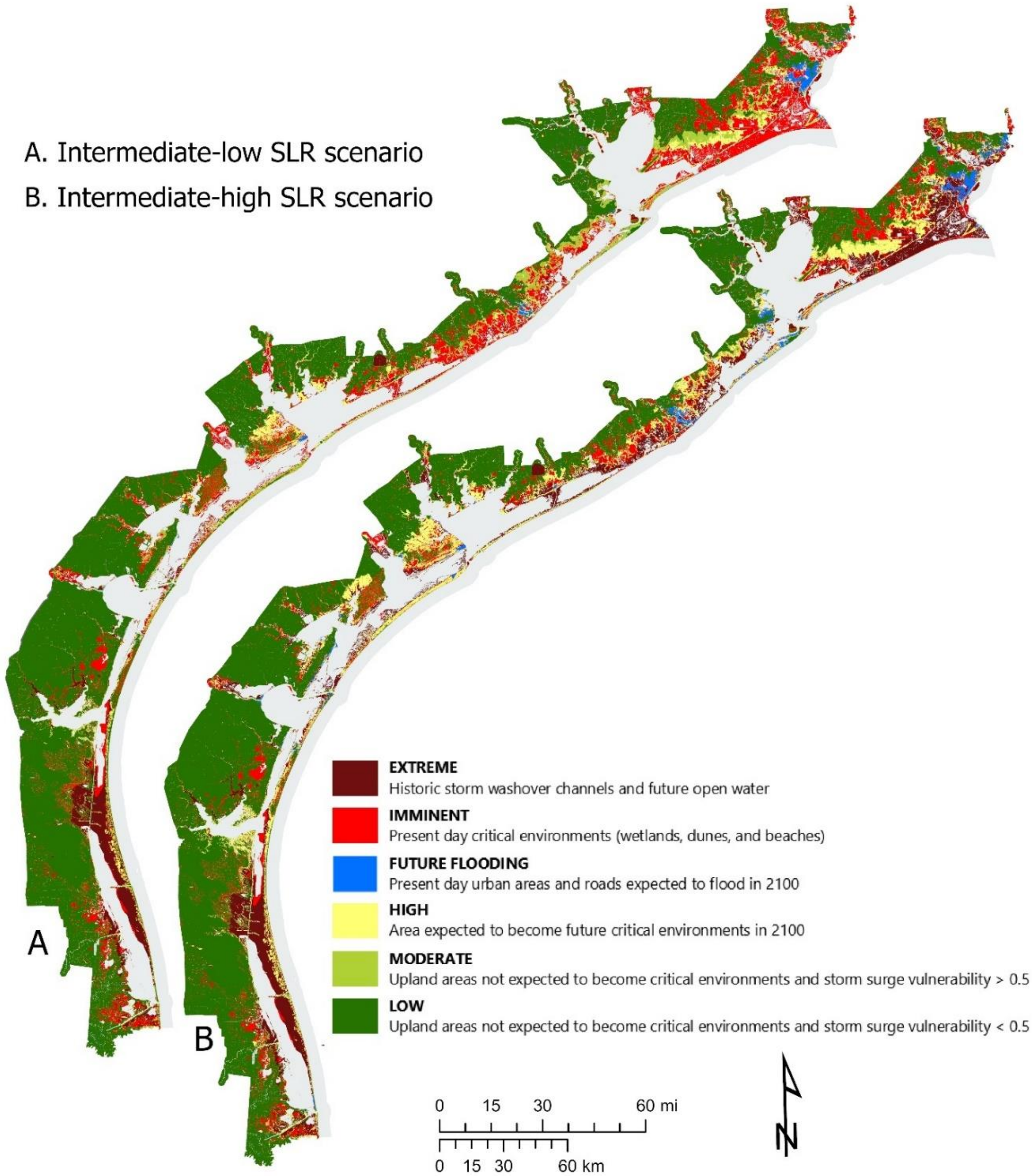


Figure 6-113. Geohazards map of the Texas coast. (A) Intermediate-high sea level rise scenario. (B) Intermediate-low sea level rise scenario

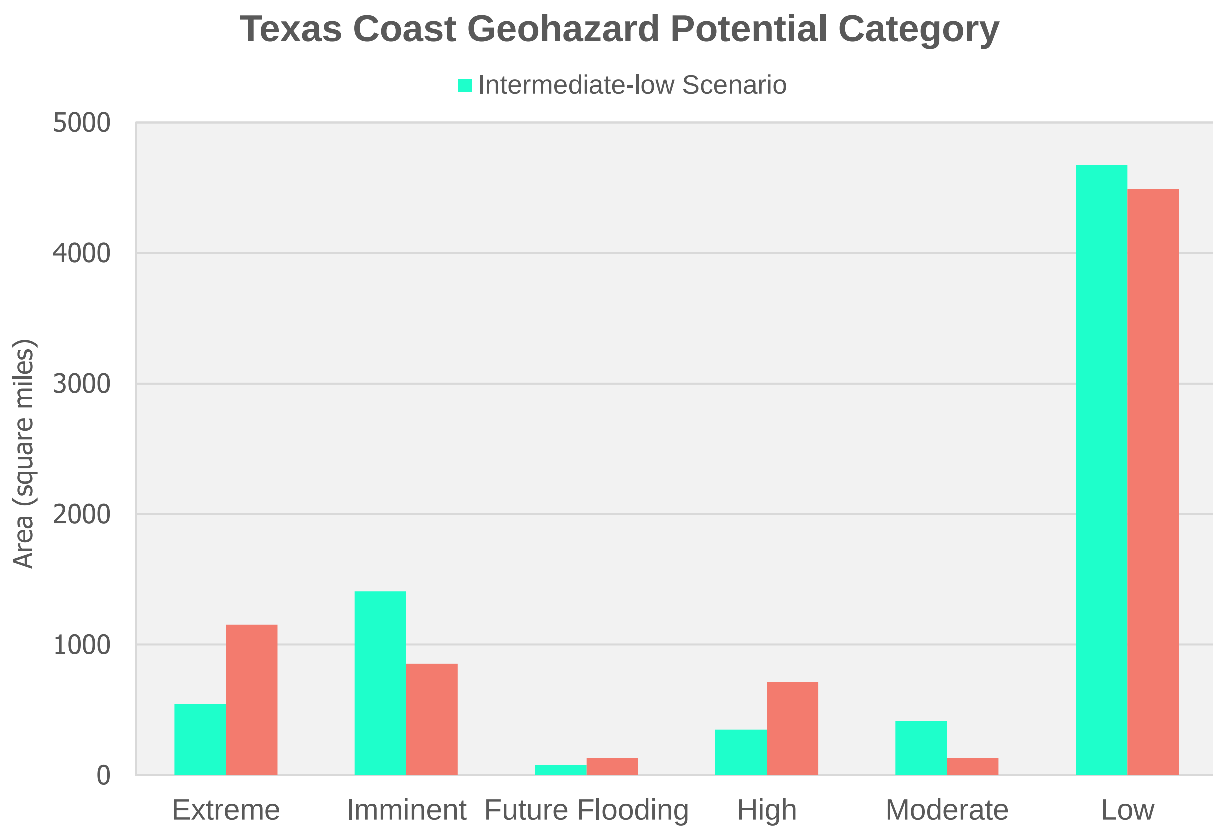


Figure 6-114. Areal difference (in square miles) of individual geohazard potential category between intermediate-low and intermediate-high sea level rise scenario along the Texas coast

6.4.2 Region 1

By 2100, Region 1 is expected to experience significant effects of SLR, leading to a drastic transformation of its landscape. In addition, this region is the most susceptible to storm surge flooding among the four regions, with nearly half of its land having the highest vulnerability. These findings have been confirmed by the geohazards map of Region 1, which was developed through landscape change and storm surge modeling. **Figure 6-115** shows the geohazards maps of Region 1 on the intermediate-low and intermediate-high SLR scenarios and **Figure 6-116** shows the geohazard potential category distribution under these two scenarios. These maps reveal a substantial increase in the Extreme geohazard category with the intermediate-high SLR scenario – it increases from 4% of the total mapped area within Region 1 in the intermediate-low scenario to 21% in the intermediate-high scenario.

There is a dramatic decrease in the amount of present-day critical environments between these two SLR scenarios which can be seen by the decrease in the Imminent category in Figure 6-116. This decrease in the Imminent zone in the intermediate-high scenario is due to the conversion of present-day environments to open water. **Figure 6-116** shows that there is less area in the Low and Moderate categories in the intermediate-high scenario as these categories are converting to a higher hazard potential, increasing the area of the Extreme and High categories. The intermediate-high SLR scenario shows that 50% of the total mapped area falls in the Extreme, Imminent, and High geohazard potential categories, up from 42% in the intermediate-low scenario. In addition to impacts on the natural environment, results show a significant amount of developed land in Region 1 is subject to inundation by 2100. A total of 63 square miles of an urban area and road in Region 1 is projected to be flooded in the intermediate-low SLR scenario which increases to 100 square miles in the intermediate-high scenario. Most of these inundated urban areas consist of low-lying coastal communities and critical infrastructure. Table shows the percentage coverage of different geohazard potential categories in Region 1 for both SLR scenarios.

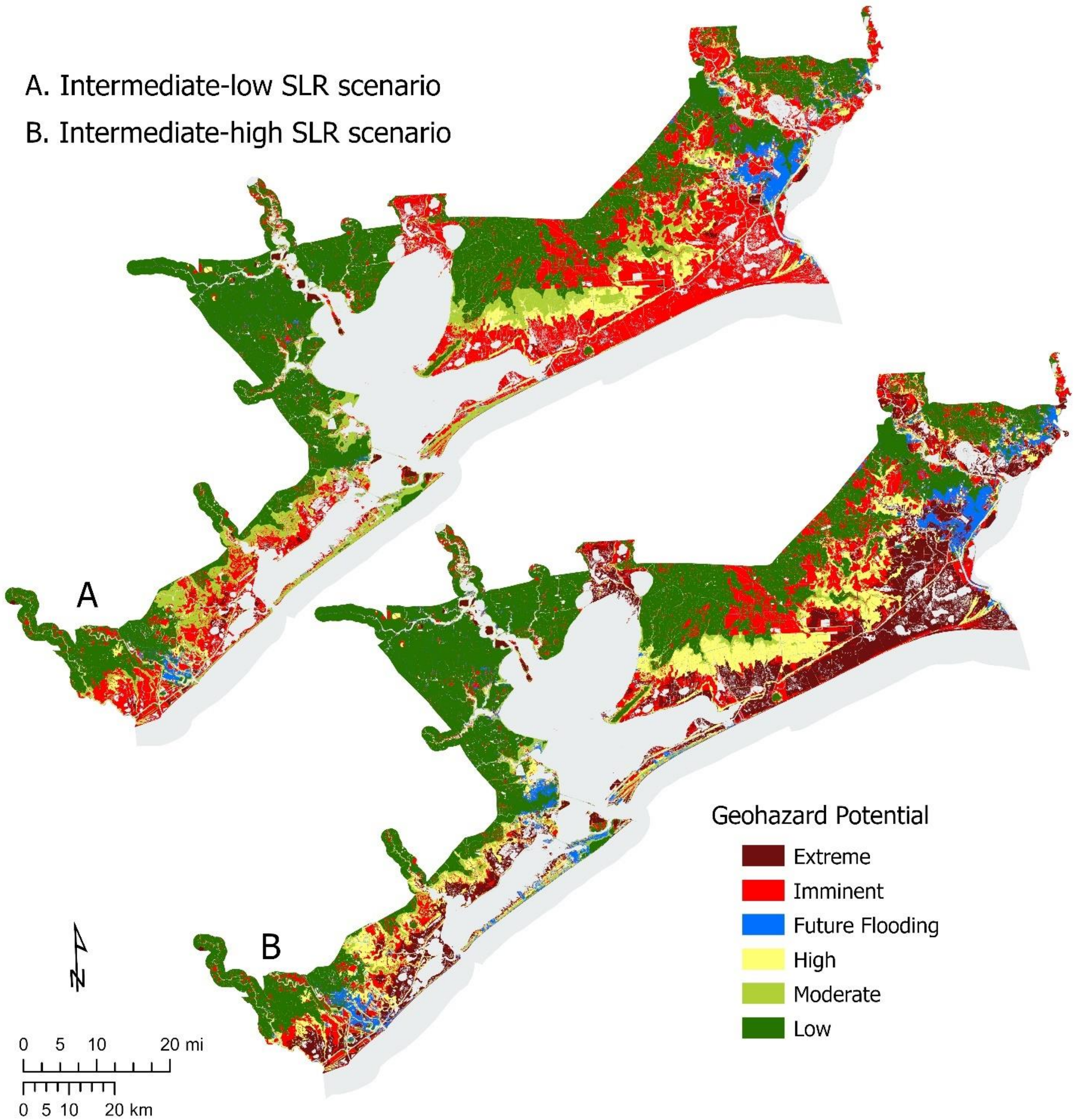


Figure 6-115. Map comparing geohazard potential category distribution in Regin 1 on (A) intermediate-low SLR scenario and (B) intermediate-high SLR scenario

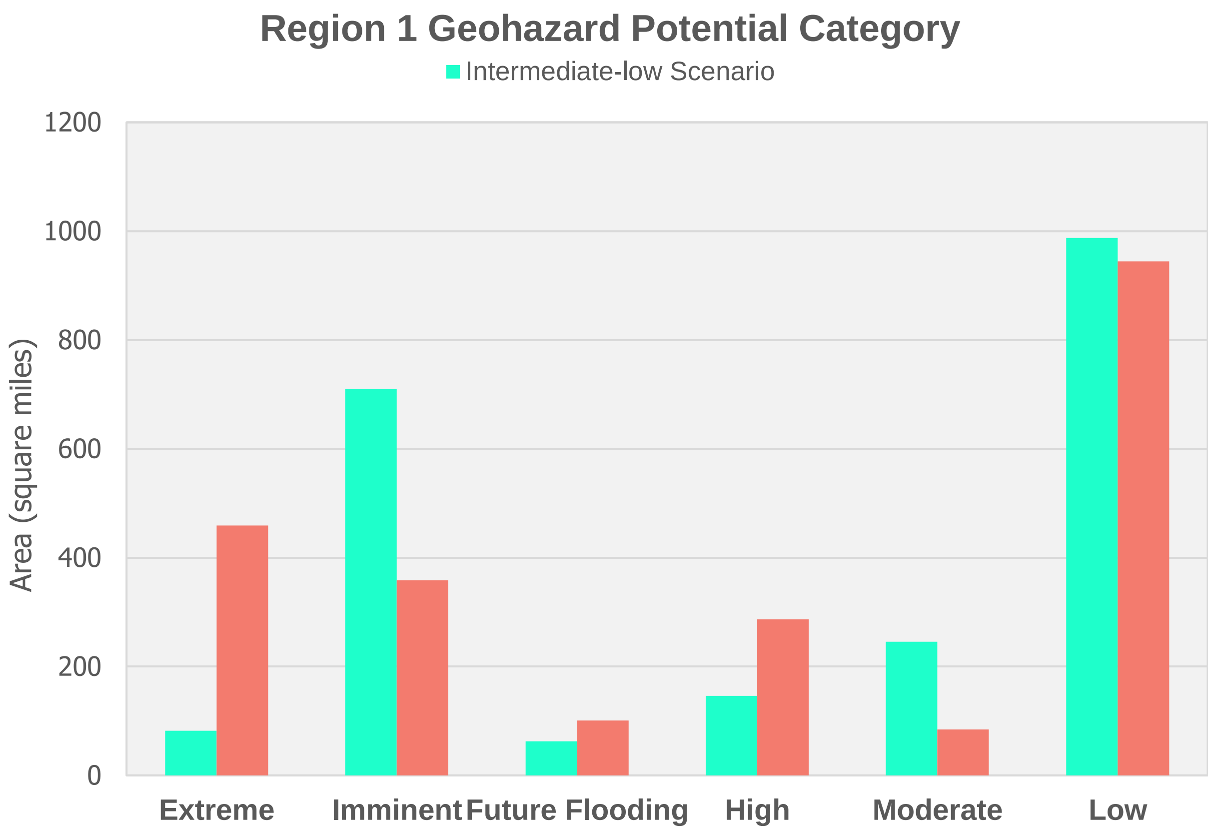


Figure 6-116. Graph comparing the geohazard potential category distribution in Region 1 on (A) the intermediate-low SLR scenario and (B) the intermediate-high SLR scenario

Table 6-40. Summary of geohazard potential category coverage in Region 1

	Intermediate-Low Scenario	Intermediate High Scenario
Extreme	4%	21%
Imminent	32%	16%
Future Flooding	3%	5%
High	7%	13%
Moderate	11%	4%
Low	44%	42%

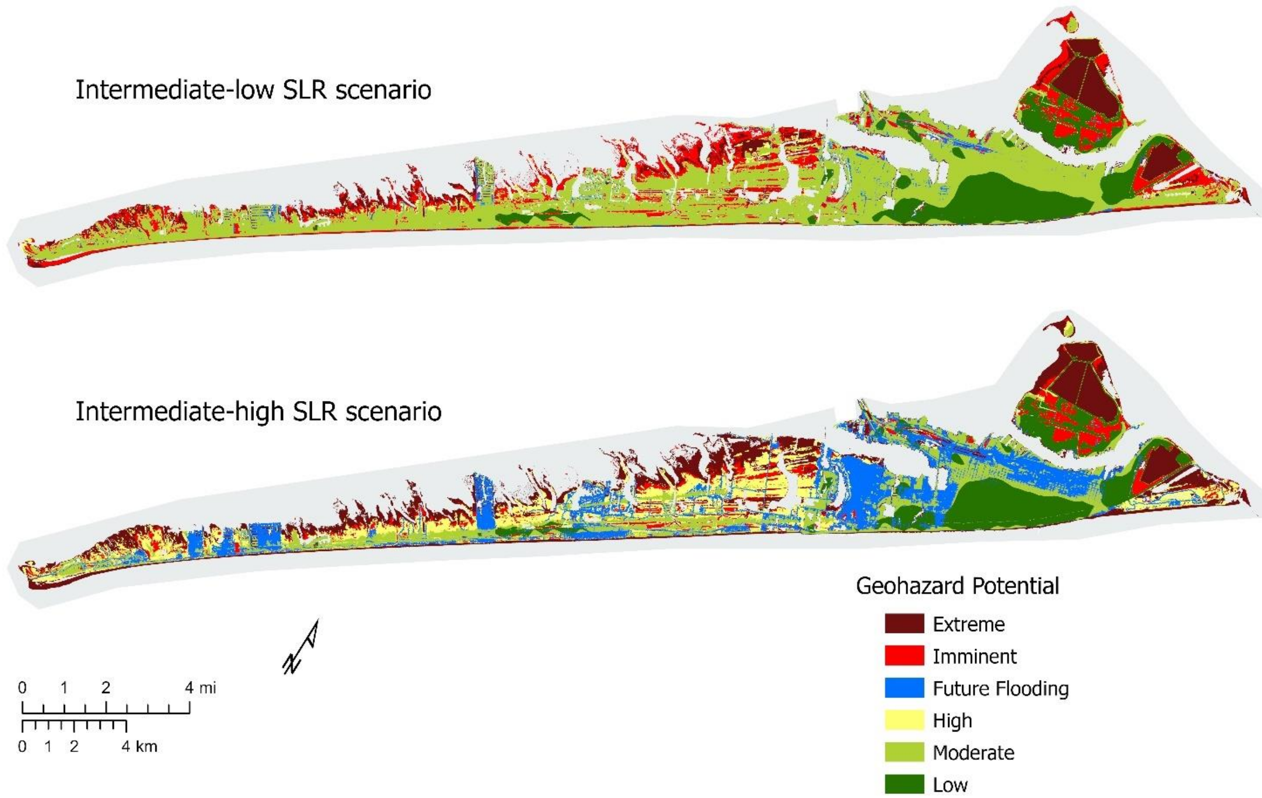


Figure 6-117. Map comparing geohazard potential category distribution in Galveston Island on intermediate-low SLR scenario and intermediate-high SLR scenario

Figure 6-117 provides a detailed view of Galveston Island showing the distribution of geohazard potential categories under intermediate-low and intermediate-high SLR scenarios. The maps reveal a substantial area of the island with a higher hazard potential in both SLR scenarios and cover a total of 42.8 square miles.

In the intermediate-low scenario, almost 13% of the mapped area falls under the Extreme geohazard potential category, which increases to nearly a quarter of the island in the intermediate-high scenario. The Imminent geohazard potential category covers about 17% of the mapped area in the intermediate-low scenario, mainly along the bay shoreline where the largest wetland extent is located, and the strip of beaches and foredunes on the Gulf side. However, this area decreases to 8% in the intermediate-high scenario.

The Future Flooding category, which represents areas at risk of flooding along the present-day urban areas and roads in the future, covers 2% of the mapped area in the intermediate-low scenario and increases to 21% in the intermediate-high scenario. The High geohazard potential category, which are areas projected to become imminent geohazard areas in 2100, covers 3% of the mapped area in the intermediate-low scenario and increases to 15% in the intermediate-high scenario.

Almost half of the mapped area falls under the Moderate geohazard potential category in the intermediate-low scenario, primarily located in the central area of Galveston Island. However, the Moderate category decreases significantly in the intermediate-high scenario, with a corresponding increase in the Extreme, Future Flooding, and High categories. The remaining 16% of the mapped area falls under the Low geohazard potential category in the intermediate-low scenario, covering developed areas on the northern end of Galveston Island and undeveloped areas with higher ground elevation. This area decreases slightly in the intermediate-high scenario but remains relatively stable. To summarize, **Figure 6-118** shows the distribution of geohazard potential categories in Galveston Island under both intermediate-low and intermediate-high SLR scenarios. The graph demonstrates that the island faces various types of geohazard potential, with some areas facing a significantly higher risk in the future.

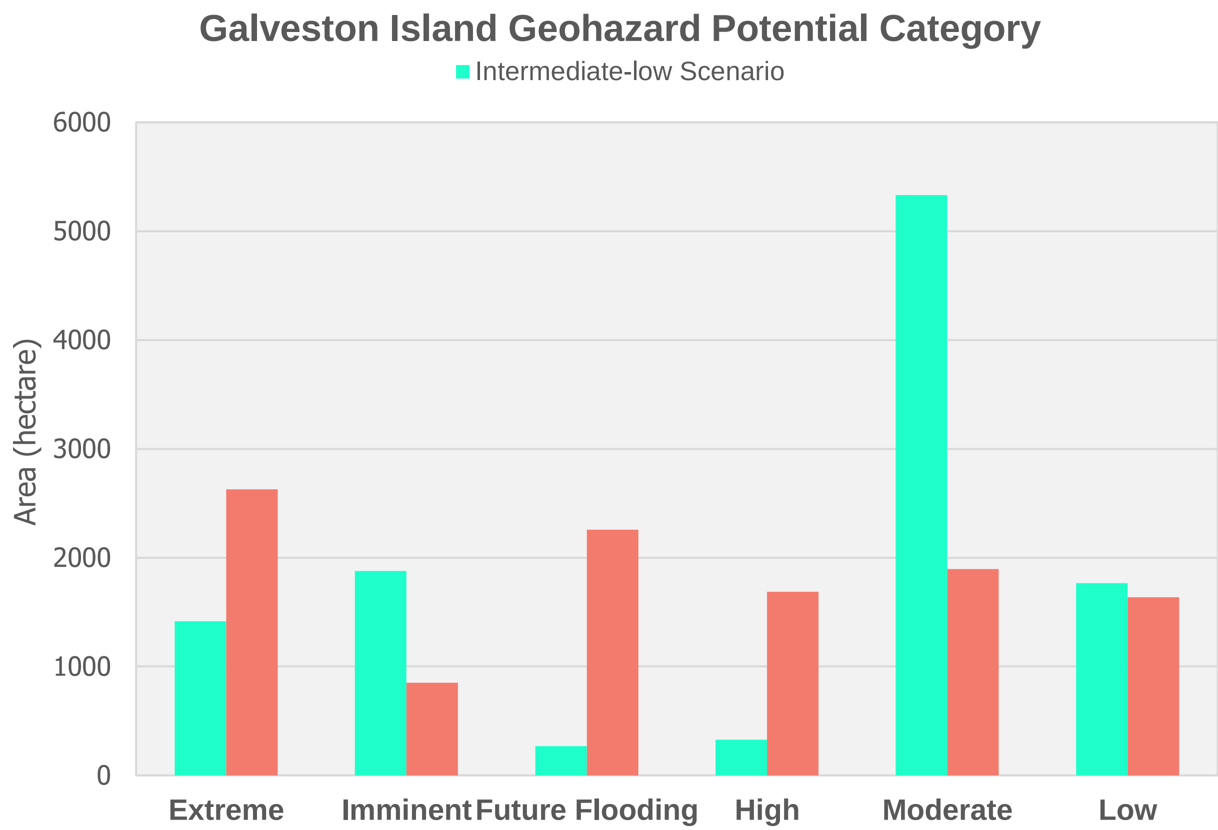


Figure 6-118. Graph comparing the geohazard potential category distribution in Galveston Island shown in the map above on (A) the intermediate-low SLR scenario and (B) the intermediate-high SLR scenario

6.4.3 Region 2

According to landscape change modeling, Region 2 is expected to experience significant effects from SLR, which will vastly alter the landscape by 2100. In addition, storm surge modeling reveals that 30% of the land in Region 2 is highly vulnerable to storm surge. These findings are depicted on the geohazards map of Region 2, as seen in **Figure 6-119** for intermediate-low and intermediate-high SLR scenarios, and **Figure 6-120** for geohazard potential category distribution under these scenarios.

Region 2's geohazard potential category distribution follows a similar trend as in Region 1, with the extreme geohazard category showing more than a two-fold increase from intermediate-low to intermediate-high scenario. Meanwhile, the imminent area decreases in the intermediate-high scenario compared to intermediate-low scenario, suggesting that critical environments today will convert to open water with higher SLR. The projected future flooding in Region 2 for the intermediate-low SLR scenario is 9.5 square miles, which increases to 14 square miles in the intermediate-high scenario, affecting an urban area and road.

In the intermediate-low scenario, about 8.5% of the mapped area in Region 2 falls in the High geohazard potential category, increasing to 15% in the intermediate-high scenario. These areas are expected to become imminent geohazard areas in 2100 and are concentrated along the west side of the Matagorda Bay and barrier islands. Meanwhile, the Moderate geohazard potential category decreases from 5% in the intermediate-low scenario to 1% in the intermediate-high scenario, as these areas are exposed as High geohazard potential with higher SLR. The remaining 59% of the mapped area in the intermediate-low scenario falls under the Low geohazard potential category, mostly in inland undeveloped areas and higher ground elevations along the barrier island. However, this percentage decreases to 55% in the intermediate-high scenario, and no Low zone is found along the barrier island under higher SLR scenarios.

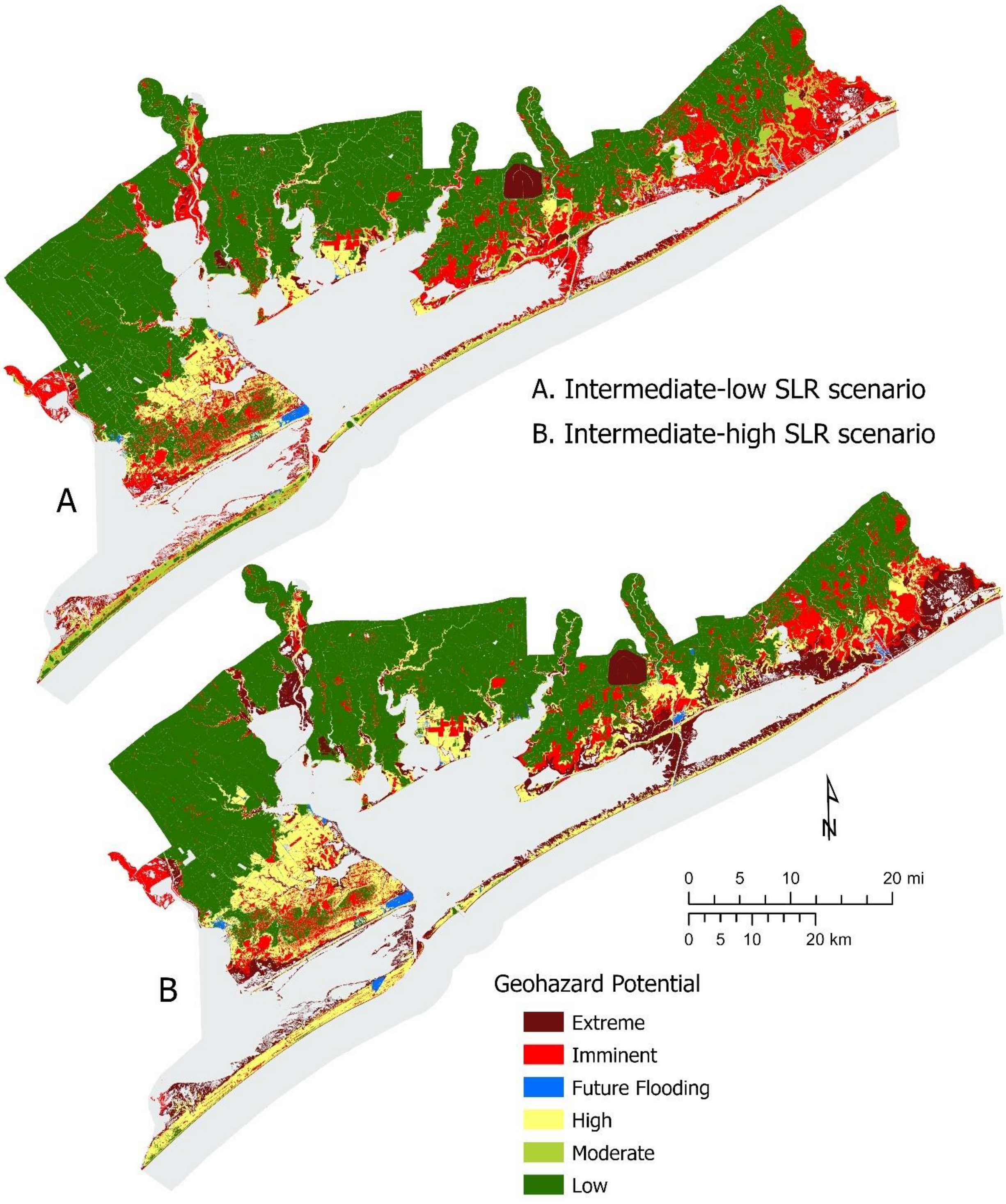


Figure 6-119. Map comparing geohazard potential category distribution in Regin 2 on (A) intermediate-low SLR scenario and (B) intermediate-high SLR scenario

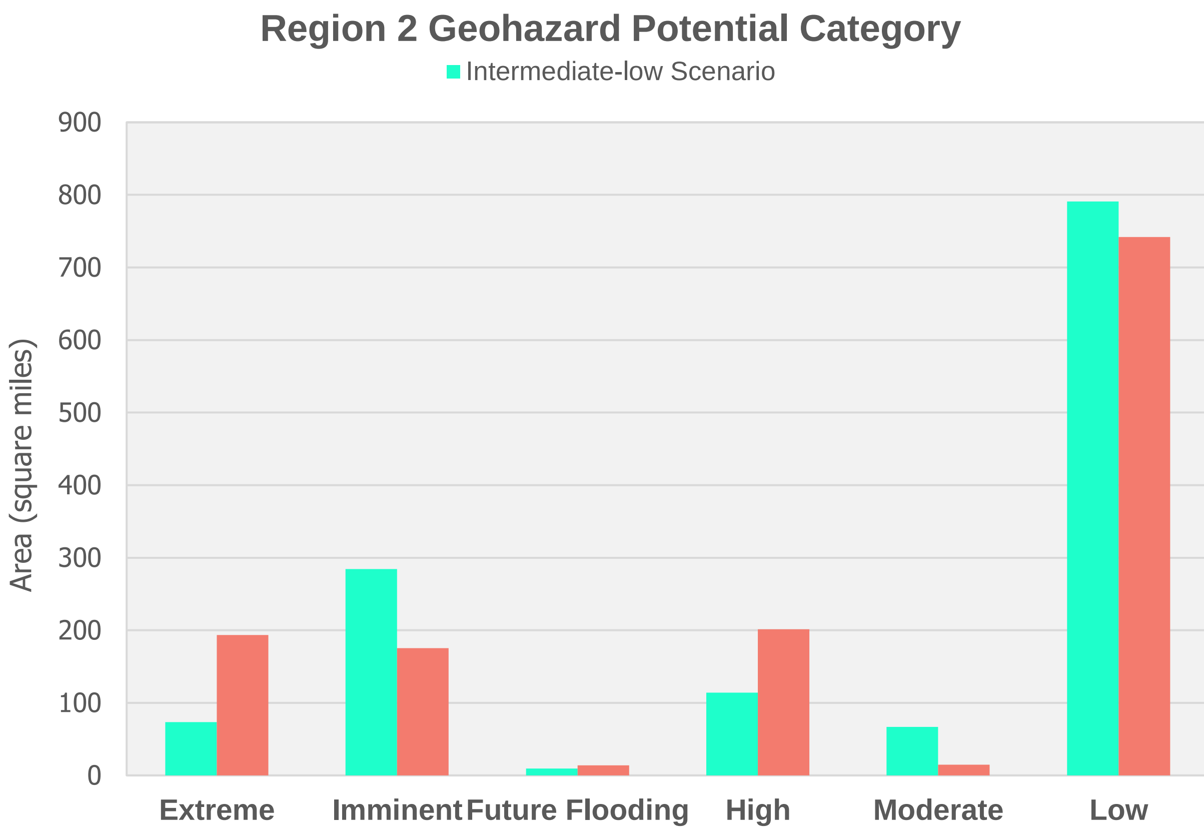


Figure 6-120. Graph comparing the geohazard potential category distribution in Region 2 on (A) the intermediate-low SLR scenario and (B) the intermediate-high SLR scenario

Table 6-41. Summary of geohazard potential category coverage in Region 2

	Intermediate-Low Scenario	Intermediate High Scenario
Extreme	5.5%	14.4%
Imminent	21.2%	13.1%
Future Flooding	0.7%	1%
High	8.5%	15%
Moderate	5%	1.1%
Low	59.1%	55.3%

Figure 6-121 shows a close-up of the Port O'Connor area, where significant landscape changes are expected to occur by 2100, based on landscape change modeling. The map shows a substantial area east of Matagorda Bay with a higher hazard potential in both SLR scenarios. The total mapped area in these maps covers 48.4 sq. mile.

In the intermediate-low scenario, almost 79% of the mapped area falls under the High to Extreme geohazard potential category. This area increases to 90% in the intermediate-high scenario. The transition trend between the two scenarios follows a similar pattern observed in Galveston Island. For instance, the Extreme and High categories increase from 8% and 30% of the mapped area in intermediate-low scenario to 17% and 39%, respectively, in the intermediate-high scenario. Conversely, the Imminent category decreases from 35% to 27% between these two scenarios. The Future Flooding category remains relatively stable between the two SLR scenarios, as the area is largely undeveloped.

The remaining 21% of the mapped area falls under the Low geohazard potential in the intermediate-low scenario and includes undeveloped areas where the ground elevation is generally higher. The area decreases to 10% in the intermediate-high scenario and changes to higher geohazard potential category. **Figure 6-122** displays the detail distribution of geohazard potential categories of the area under both intermediate-low and intermediate-high SLR scenarios. The maps highlight a significant area with a higher hazard potential in both scenarios, indicating the need for appropriate measures to mitigate the associated risks.

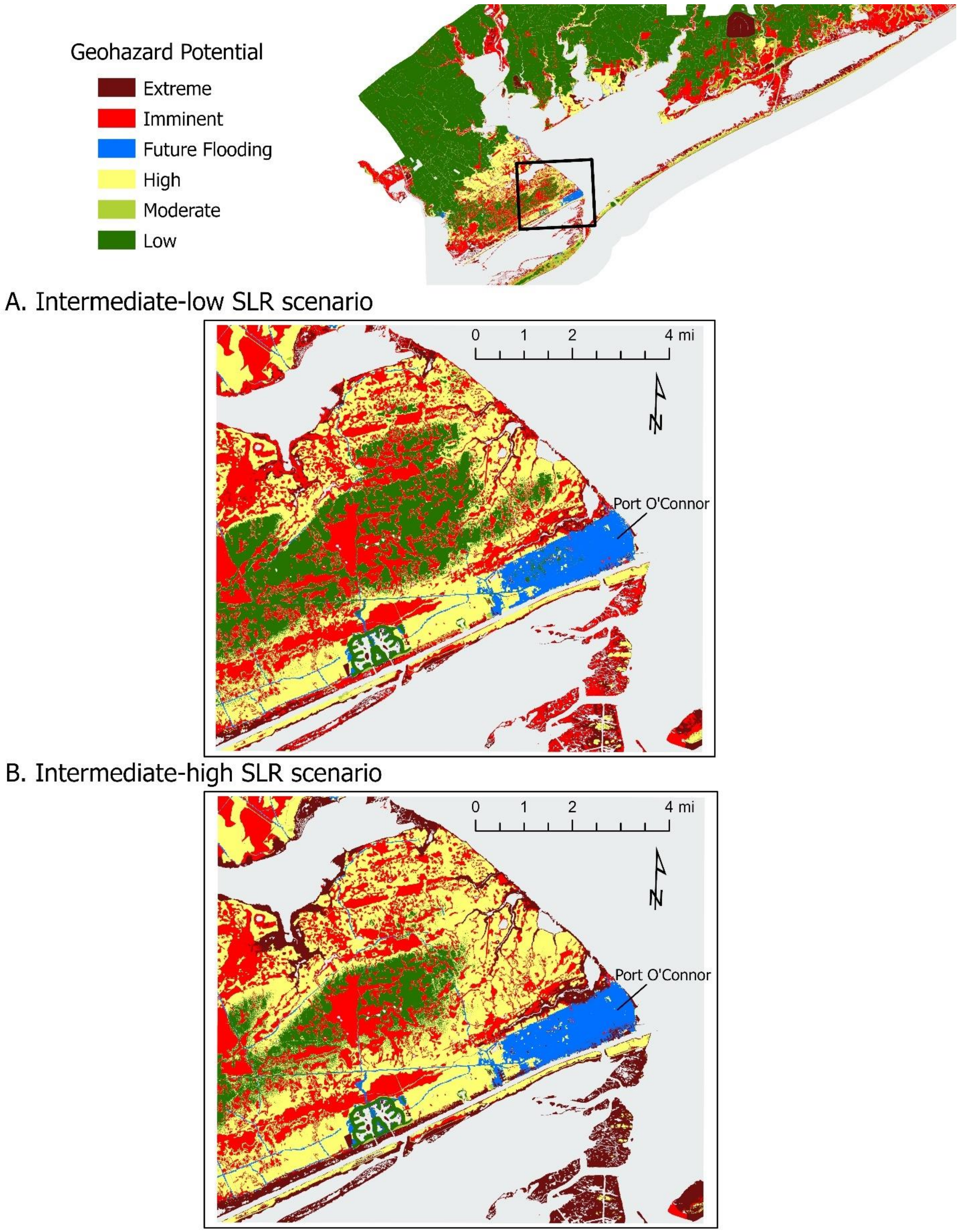


Figure 6-121. Map comparing geohazard potential category distribution around Port O'Connor area on intermediate-low SLR scenario and intermediate-high SLR scenario

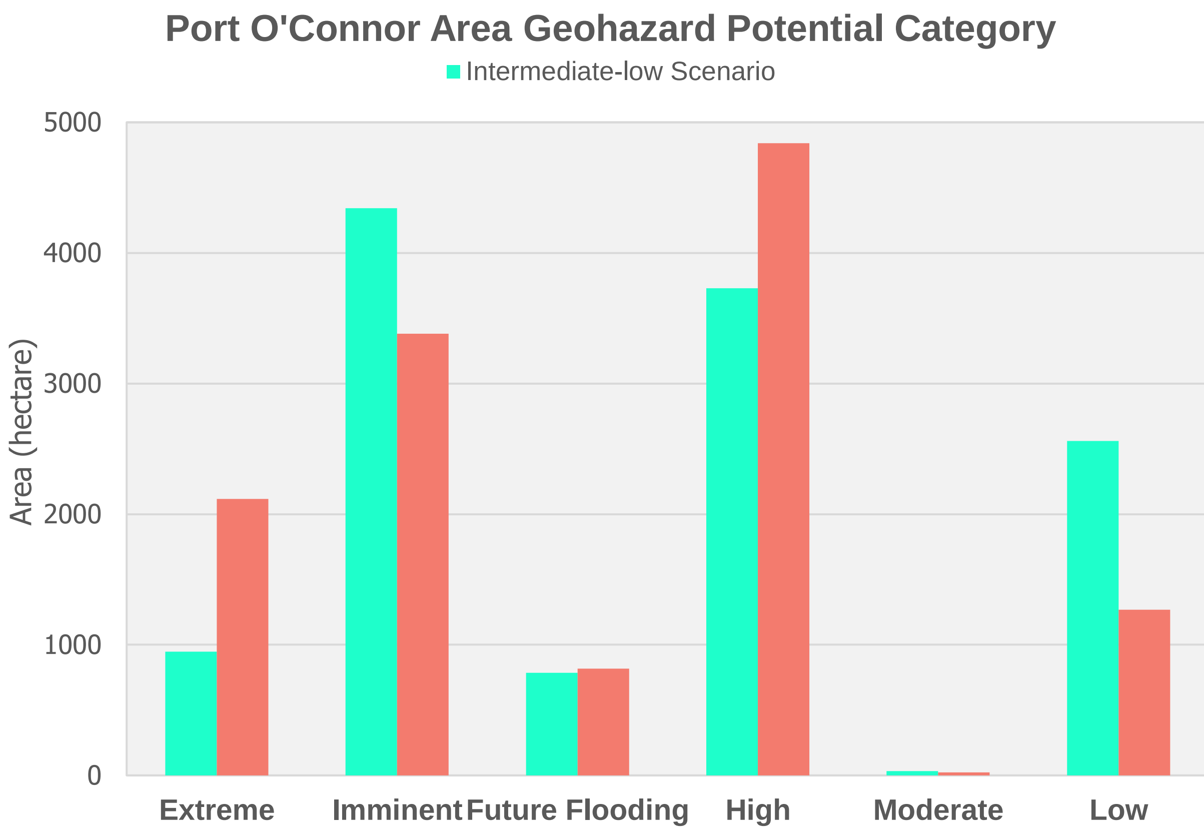


Figure 6-122. Graph comparing the geohazard potential category distribution in Port O'Connor area shown in the map above on (A) the intermediate-low SLR scenario and (B) the intermediate-high SLR scenario

6.4.4 Region 3

Region 3 is expected to undergo significant effects of SLR based on the landscape change modeling, resulting in a drastic transformation of its landscape by 2100. Although Region 3 is less vulnerable to storm surge compared to other regions, storm surge modeling shows that 13% of its land is highly vulnerable to this hazard. The geohazards map of Region 3, as seen in **Figure 6-123** for intermediate-low and intermediate-high SLR scenarios, displays these findings. Figure 6-124 shows the geohazard potential category distribution under these two scenarios, which shows similar trend in the changes in distribution as the previous two regions.

These maps show about 4.2% of the total 2,050 sq. miles mapped area was assigned to the Extreme geohazard potential category in the intermediate-low scenario. This figure increases to about 7.3% of the mapped area in the intermediate-high scenario, mainly along the backside of barrier islands, Nueces River Delta, Baffin Bay, and Aransas Bay area. About 10.1% of the mapped area falls in the Imminent geohazard potential category in the intermediate-low scenario, which decreases to 7.4% in the intermediate-high scenario. The transition to the Extreme category due to the conversion to open water causes this decrease in the Imminent zone in the intermediate-high scenario. In the intermediate-low scenario, a total of 6.4 square miles of an urban area and road in Region 3 are projected to be flooded, which doubles in the intermediate-high scenario.

The high geohazard potential category, which includes areas projected to become imminent geohazard areas in 2100, covers 2.3% of the mapped area in the intermediate-low scenario. It is highly concentrated on the low-lying areas along the east side of Copano Bay and around Baffin Bay, as well as along the back side of barrier islands. In the intermediate-high scenario, it increases to 6.1% of the mapped area with a significant increase in the east side of Copano Bay. Meanwhile, the Moderate geohazard potential category decreases from 2.7% in the intermediate-low scenario to 1% in the intermediate-high scenario, as these areas are exposed to a higher geohazard potential with higher SLR. The remaining 80.4% of the mapped area is categorized as having a Low geohazard potential in the intermediate-low SLR scenario and mainly includes undeveloped areas where the ground elevation is generally higher. It decreases slightly to 77.6% in the intermediate-high scenario. In the intermediate-high scenario, there is a less area in the Low and Moderate geohazard potential zones as they are converting to a higher hazard potential, increasing the area of the Extreme and High classification.

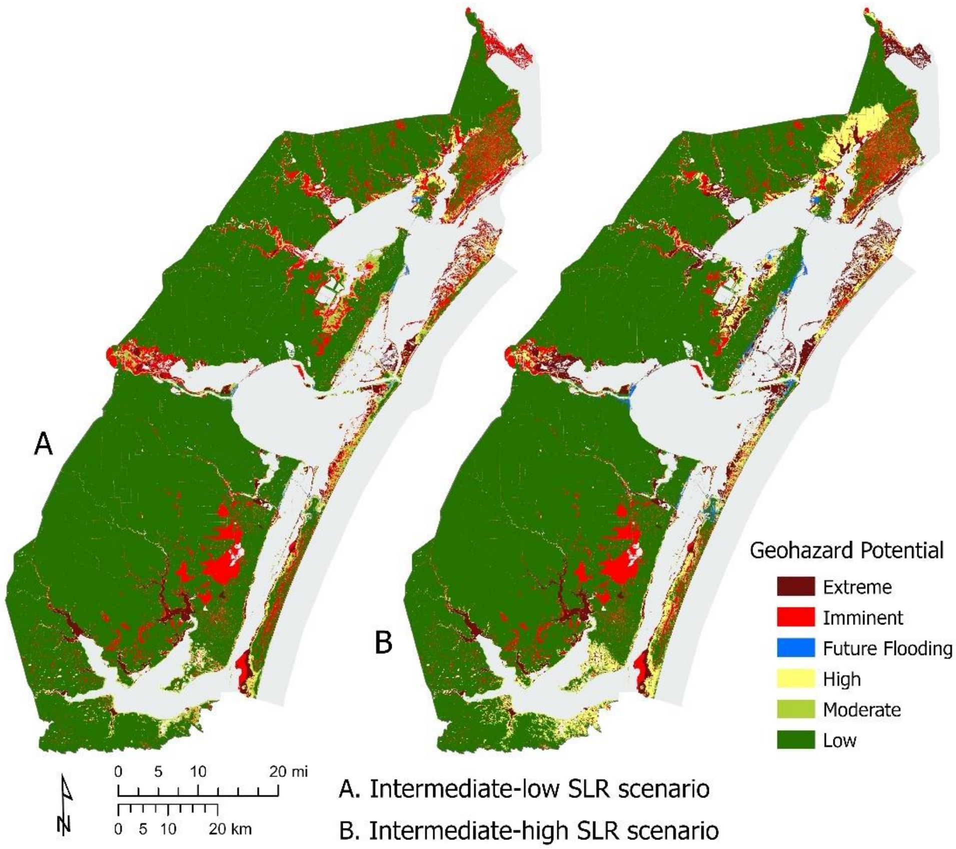


Figure 6-123. Map comparing geohazard potential category distribution in Regin 3 on (A) intermediate-low SLR scenario and (B) intermediate-high SLR scenario

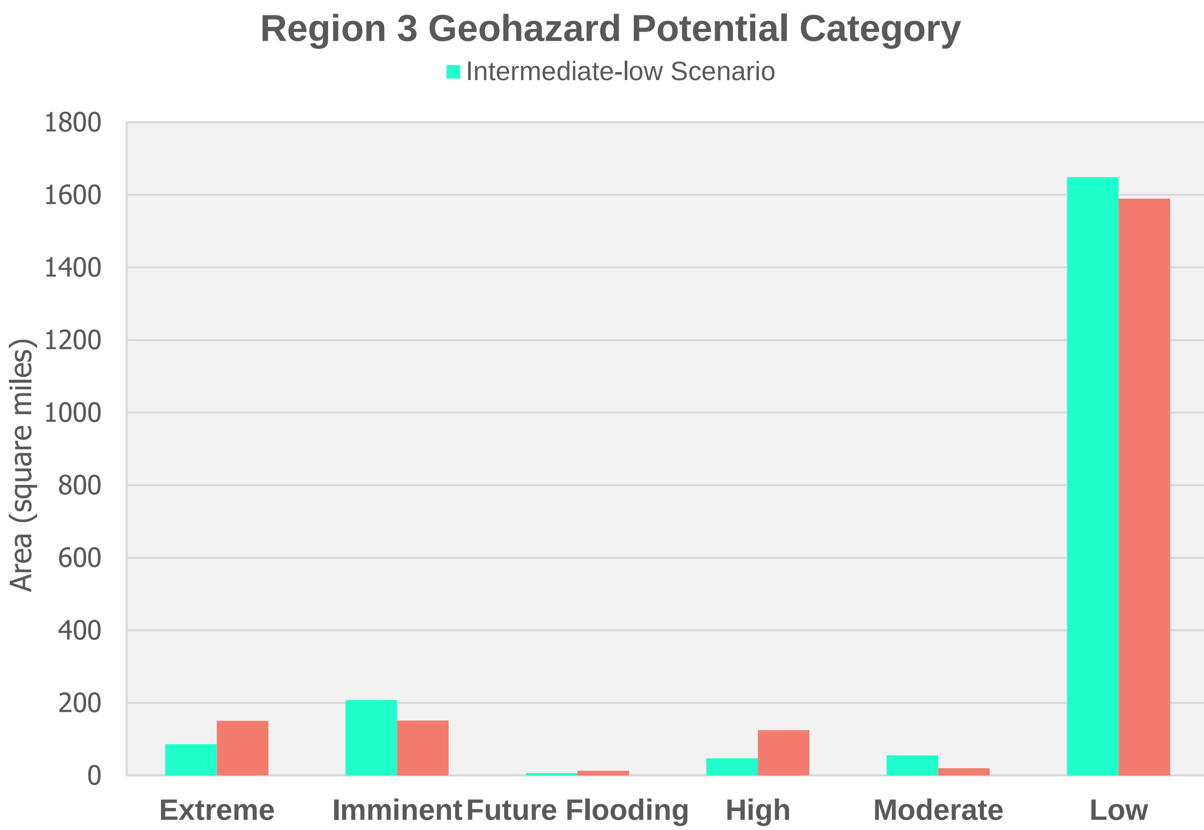


Figure 6-124. Graph comparing the geohazard potential category distribution in Region 3 on (A) the intermediate-low SLR scenario and (B) the intermediate-high SLR scenario

Table 6-42. Summary of geohazard potential category coverage in Region 3

	Intermediate-Low Scenario	Intermediate High Scenario
Extreme	4.2%	7.3%
Imminent	10.1%	7.4%
Future Flooding	0.3%	0.6%
High	2.3%	6.1%
Moderate	2.7%	1%
Low	80.4%	77.6%

Figure 6-125 shows a detailed view of Port Aransas/Redfish Bay area, displaying the distribution of geohazard potential categories in intermediate-low and intermediate-high SLR scenarios. This region is of significant economic importance as it serves as the mouth of the Corpus Christi Ship Channel, which connects to the Port of Corpus Christi - the largest port in the United States in terms of total revenue tonnage. The map depicts a substantial area with a higher geohazard potential in both SLR scenarios, covering a total of 70 sq. miles.

Under the intermediate-low scenario, nearly 17% of the mapped area falls under the Extreme geohazard potential category, which increases to 30% in the intermediate-high scenario. Notably, almost all the Harbor Island falls under the Extreme zone in both scenarios. The Imminent geohazard potential category covers roughly 14% of the mapped area in the intermediate-low scenario, primarily to the north of Aransas Pass, and the strip of beaches and foredunes on both the Gulf and bay side. However, this area decreases to 7% in the intermediate-high scenario, indicating that critical environments today will convert to open water with higher SLR. The Future Flooding zone increases from 207 hectares to 616 hectares between the intermediate-low and intermediate-high scenarios, with an increase visible in both Aransas Pass and Port Aransas.

The High geohazard potential category, which shows areas that will become imminent geohazard areas in 2100, covers 5% of the mapped area in the intermediate-low scenario and increases to 8% in the intermediate-high scenario. The Moderate geohazard category, which is concentrated in the back of the barrier island and along the bay shoreline of the Redfish Bay in the intermediate-low scenario, converts to higher geohazard potential in the intermediate-high scenario, thereby decreasing the area from 12% to 4% of the mapped area between these two scenarios. The remaining 50% of the mapped area falls under the Low geohazard potential in the intermediate-low scenario and includes upland areas where the ground elevation is generally higher. This area decreases slightly to 47% in the intermediate-high scenario and remains relatively stable. **Figure 6-126** shows the distribution of geohazard potential categories in Port Aransas/Redfish Bay area under both intermediate-low and intermediate-high SLR scenarios.

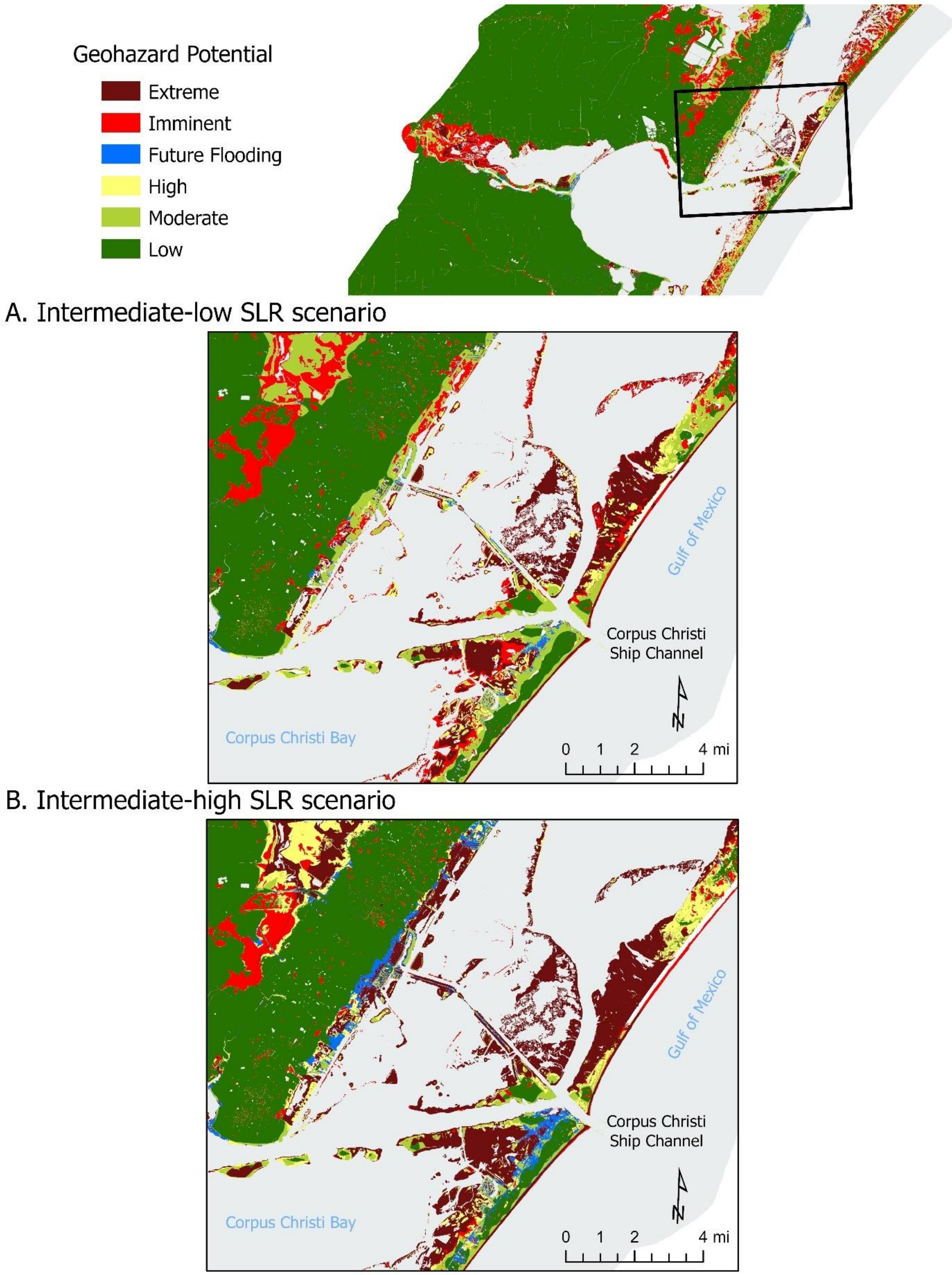


Figure 6-125. Map comparing geohazard potential category distribution around Port Aransas/Aransas Pass area on intermediate-low SLR scenario and intermediate-high SLR scenario

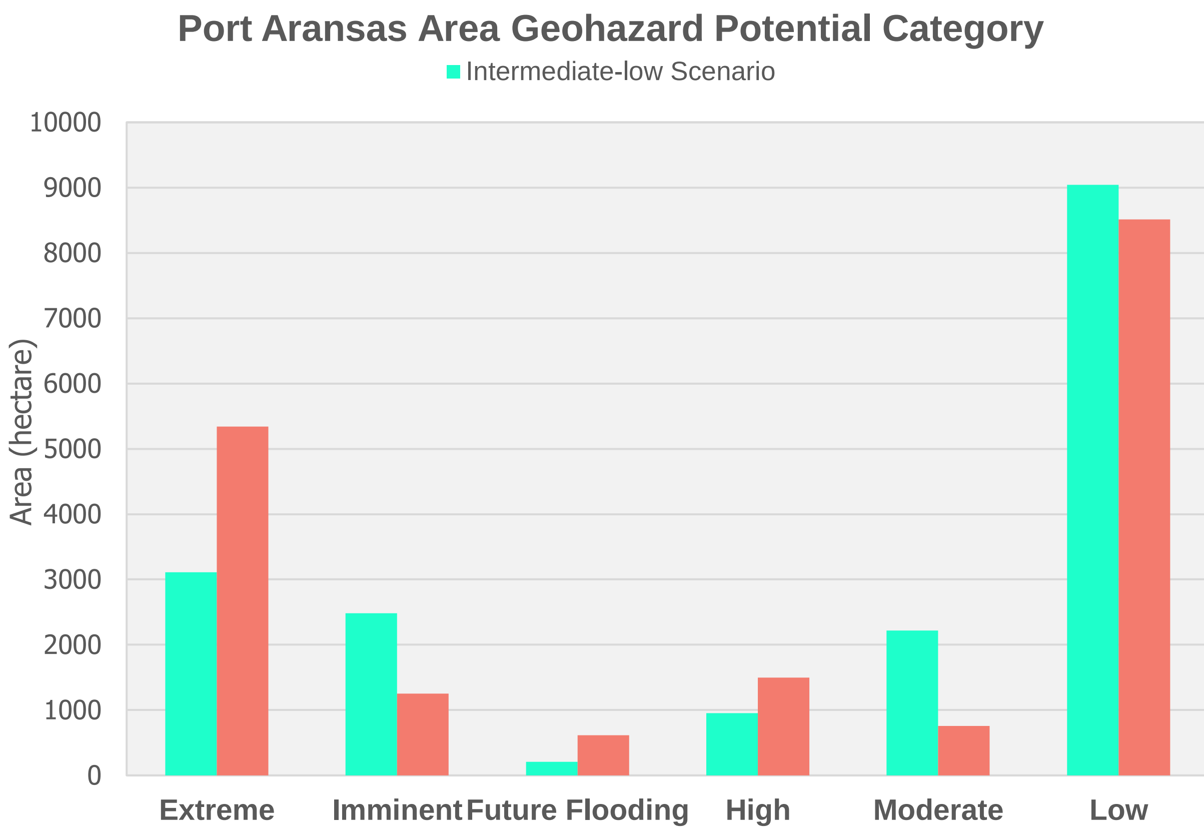


Figure 6-126. Graph comparing the geohazard potential category distribution in Port Aransas/Aransas Pass area shown in the map above on (A) the intermediate-low SLR scenario and (B) the intermediate-high SLR scenario

6.4.5 Region 4

The predicted effects of sea-level rise (SLR) are significant and expected to impact Region 4, leading to substantial changes in the landscape by 2100 based on landscape change modeling. The storm surge modeling shows that 14% of the land in Region 4 is highly vulnerable to storm surges, particularly along the backside of South Padre Island's shoreline and along the Lower Laguna Madre.. These findings are shown on the geohazards map of Region 4, as seen in **Figure 6-127** for intermediate-low and intermediate-high SLR scenarios, and **Figure 6-128** for geohazard potential category distribution under these scenarios. These maps show a similar trend in the changes in distribution as other regions in the upper coast.

Region 4 has the highest percentage of mapped area falling under the Extreme geohazard category among the four regions. Almost all of the tidal flats in the Laguna Madre lie in the Extreme zone. In the intermediate-low scenario, around 16.4% of the mapped area within Region 4 is categorized as Extreme, which increases to almost 19% in the intermediate-high scenario. Approximately 11.2% of the mapped area falls under the Imminent geohazard category in the intermediate-low scenario, primarily in the marshes and low-lying areas of the Lower Laguna, as well as along the bay shoreline of Laguna Madre. This percentage decreases to 9% in the intermediate-high scenario, mainly due to the transformation of present-day environments into open water.

In the intermediate-low scenario, a total of 1.7 square miles of an urban area and road, mainly in the South Padre Island and Port Isabel areas of Region 4, falls in the Future Flooding category, which increases to 2.9 square miles in the intermediate-high scenario. A significant portion of South Padre Island falls under the Future Flooding zone in the intermediate-high scenario. Additionally, about 2.3% of the mapped area in Region 4 is categorized as High geohazard potential category in the intermediate-low scenario, which increases to 5.3% in the intermediate-high scenario. These areas are expected to become imminent geohazard areas in 2100 and mainly located on the back side of the barrier island. As in other regions, the Moderate geohazard potential category decreases from 2.6% in the intermediate-low scenario to 0.8% in the intermediate-high scenario, as these areas are exposed to a higher geohazard potential with higher SLR. The remaining 67.4% of the mapped area fall under the Low geohazard potential category in the intermediate-low SLR scenario and it decreases slightly to 65.7% in the intermediate-high scenario.

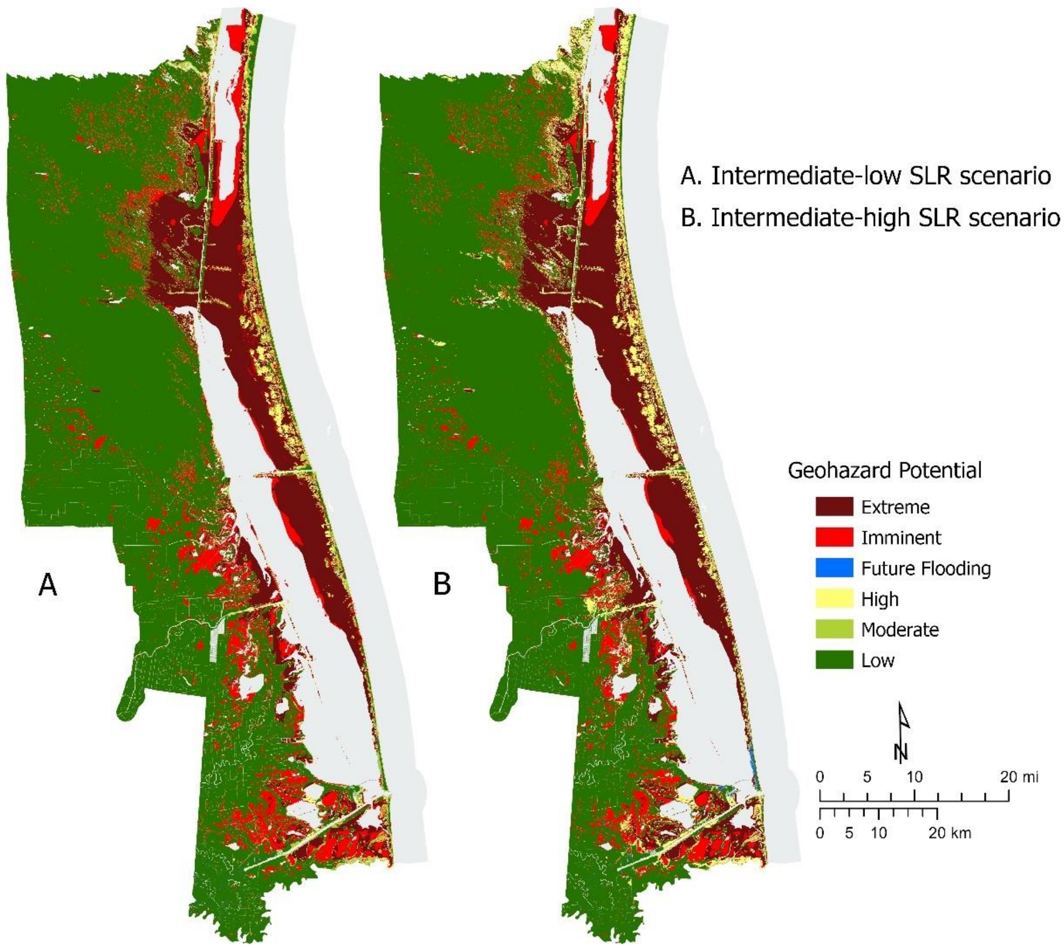


Figure 6-127. Map comparing geohazard potential category distribution in Regin 4 on (A) intermediate-low SLR scenario and (B) intermediate-high SLR scenario

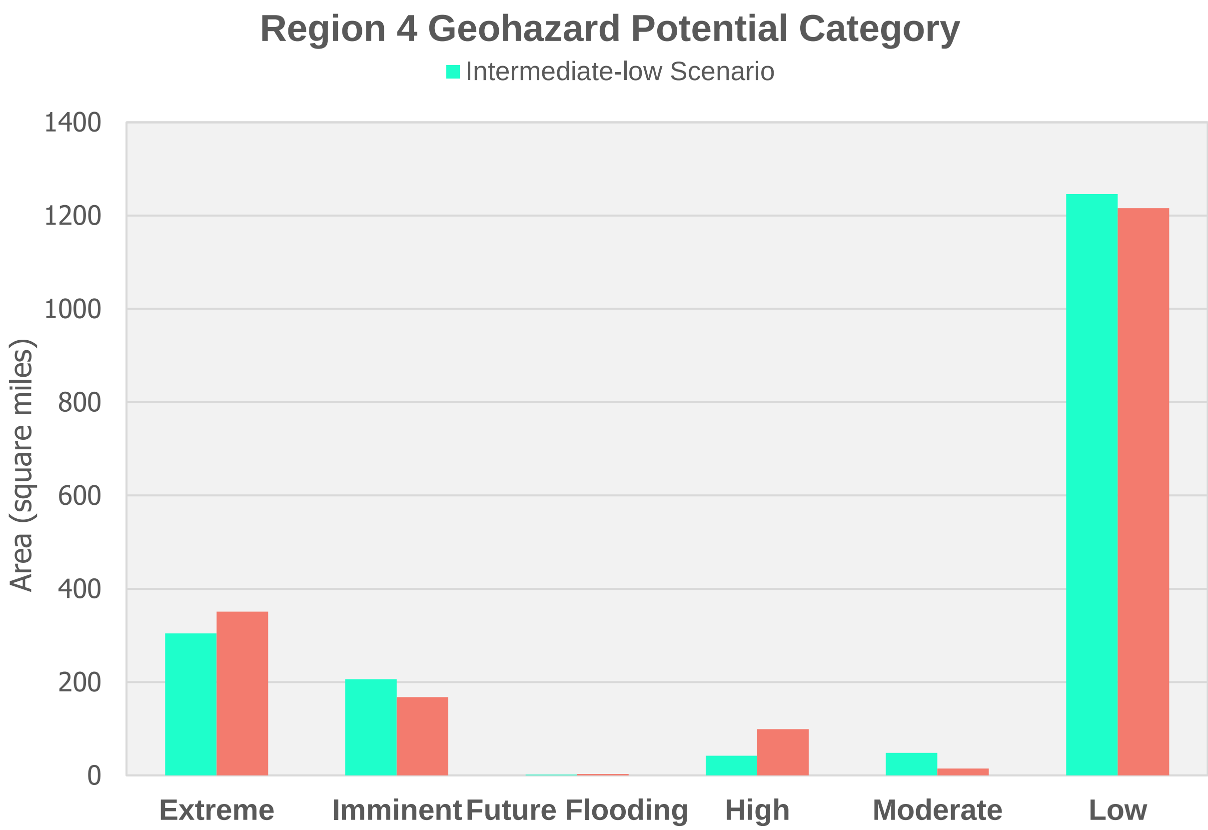


Figure 6-128. Graph comparing the geohazard potential category distribution in Region 4 on (A) the intermediate-low SLR scenario and (B) the intermediate-high SLR scenario

Table 6-43. Summary of geohazard potential category coverage in Region 4

	Intermediate-Low Scenario	Intermediate High Scenario
Extreme	16.4%	18.9%
Imminent	11.2%	9%
Future Flooding	0.1%	0.2%
High	2.3%	5.3%
Moderate	2.6%	0.8%
Low	67.4%	65.7%

Figure 6-129 provides a detailed view of South Padre Island showing the distribution of geohazard potential categories under intermediate-low and intermediate-high SLR scenarios. The maps reveal a substantial area of the island with a higher hazard potential in both SLR scenarios. The total area mapped covers 7.5 square miles.

In the intermediate-low scenario, nearly one-third of the mapped area falls under the Extreme geohazard potential category, increasing to almost half of the island in the intermediate-high scenario. Almost all the backside of the island in the north falls under the Extreme zone. The Imminent geohazard potential category covers about 7% of the mapped area in the intermediate-low scenario, mainly along the bay shoreline in the south of the island. However, this area decreases to 1% in the intermediate-high scenario.

The Future Flooding category, which represents areas at risk of flooding along the present-day urban areas and roads in the future, covers 2% of the mapped area in the intermediate-low scenario which increases to 13% in the intermediate-high scenario, flooding most of the South Padre Island. The High geohazard potential category, which are areas projected to become imminent geohazard areas in 2100, covers 5% of the mapped area in the intermediate-low scenario and increases to 15% in the intermediate-high scenario.

More than 31% of the mapped area falls under the Moderate geohazard potential category in the intermediate-low scenario. However, the Moderate category decreases significantly in the intermediate-high scenario, with a corresponding increase in the Extreme, Future Flooding, and High categories. The remaining 22% of the mapped area falls under the Low geohazard potential category in the intermediate-low scenario, covering developed areas on the south end of the Island and undeveloped areas with higher ground elevation. This area decreases to 15% in the intermediate-high scenario, changing to higher geohazard potential category. **Figure 6-130** displays the detail distribution of geohazard potential categories of the area under both intermediate-low and intermediate-high SLR scenarios. The maps highlight that a significant area of the island is exposed to a higher hazard potential in both scenarios, indicating the need for appropriate measures to mitigate the associated risks.

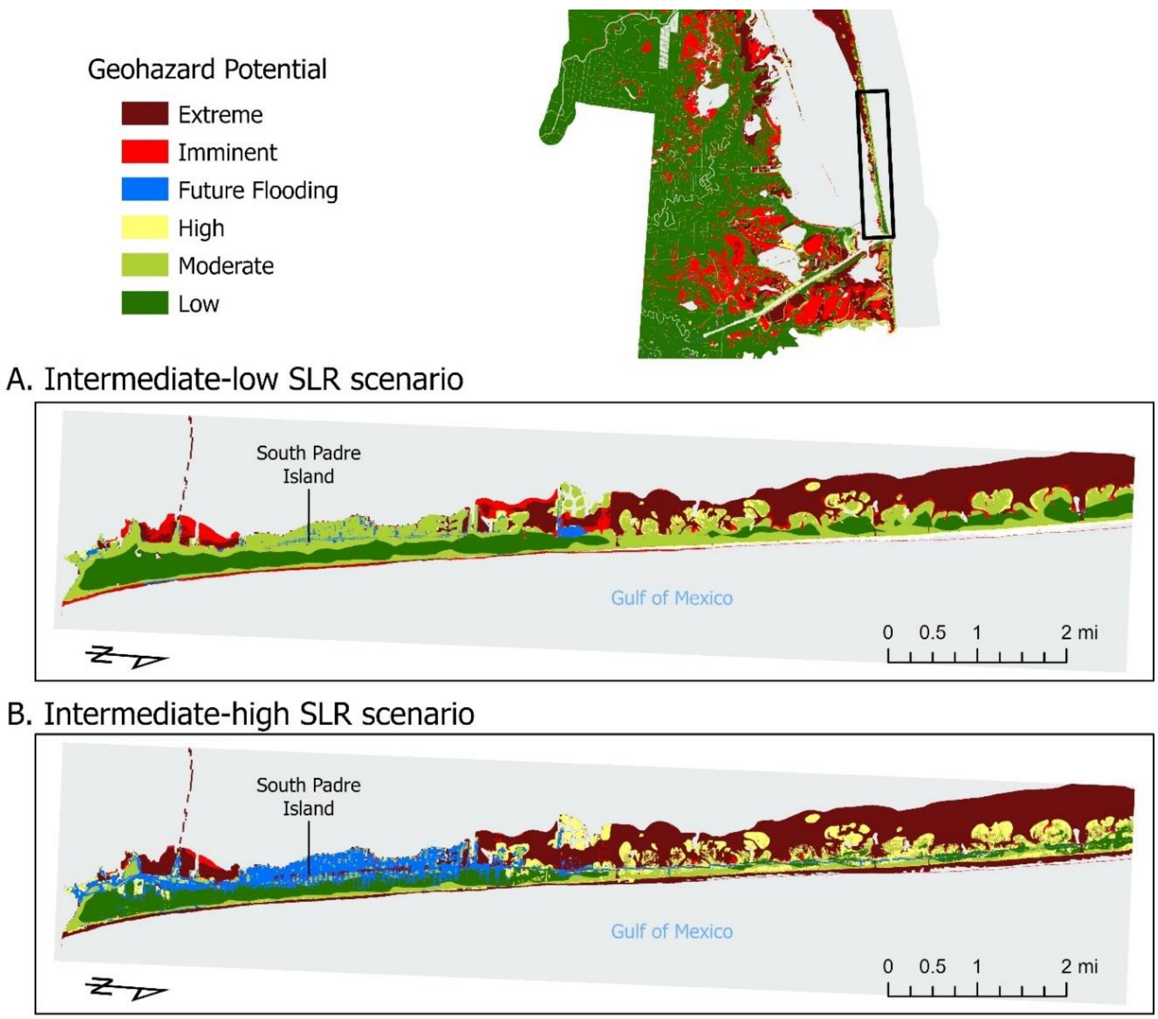


Figure 6-129. Map comparing geohazard potential category distribution in South Padre Island area on intermediate-low SLR scenario and intermediate-high SLR scenario

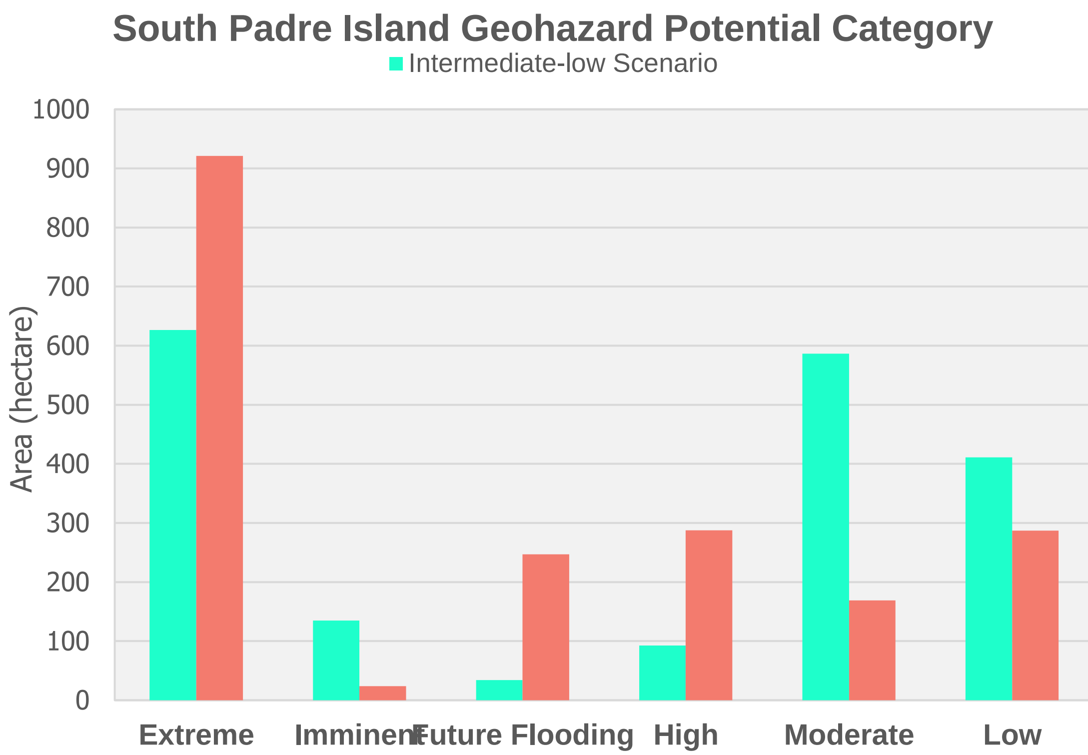


Figure 6-130. Graph comparing the geohazard potential category distribution in South Padre Island area shown in the map above on (A) the intermediate-low SLR scenario and (B) the intermediate-high SLR scenario

6.5 Conceptual Resiliency Projects Modeling

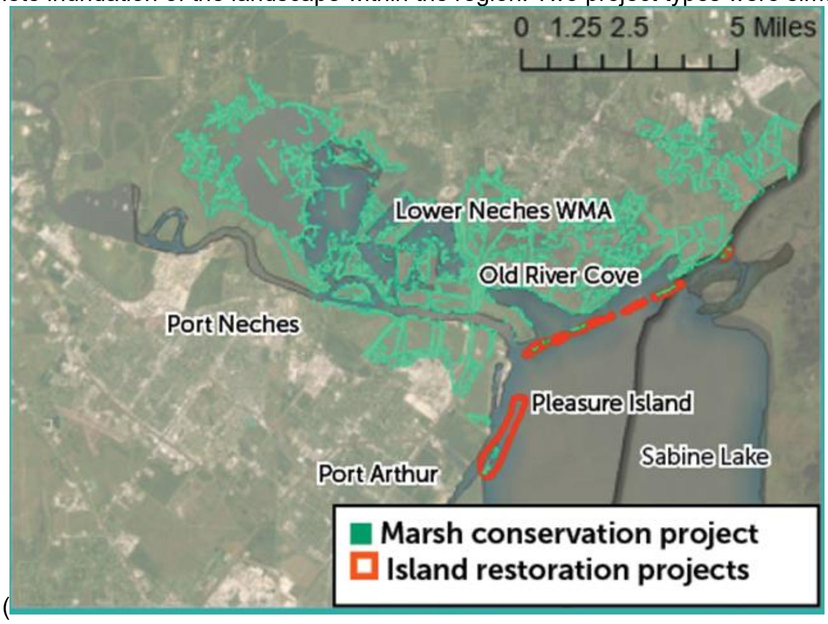
The conceptual resiliency project modeling results have shown that the beneficial use of dredged material (BUDM) can be an effective solution to mitigate the impacts of SLR on habitats. Furthermore, the implementation of living shorelines and island restoration can reduce the detrimental effects of storm surge and wave damage in the immediate vicinity. The outcomes of these modeling show that large-scale resiliency projects can decrease water depth and inundation caused by storm surge by acting as buffers, suppressing wave energy, and mitigating storm surge impact beyond the project area. The analysis suggests that combining multiple resiliency projects can effectively reduce wave energy and minimize storm surge impact in the area. Nevertheless, there are challenges associated with coordinating funding, dredge cycles, and interagency participation, which need to be addressed to implement such large-scale projects effectively.

6.5.1 Region 1

Landscape Change Modeling

The Sabine Lake/Port Arthur area was selected for with-project modeling due to the high vulnerability of the low-lying environments in Region 1A to inundation resulting from SLR and land surface subsidence, as well as the high social vulnerability and flood risk faced by communities within the region. Implementing projects in this area has the potential to enhance the resiliency of these vulnerable populations.

In the SLR modeling approach for the Sabine Lake area, the focus was on restoring and conserving the marshes around the Lower Neches WMA, utilizing the same SLAMM parameters from the subsite runs described in Section 6.3.1. The SLAMM model was executed solely for the intermediate-low SLR scenario, as the higher scenario would result in the complete inundation of the landscape within the region. Two project types were simulated: BUDM and



island restoration (

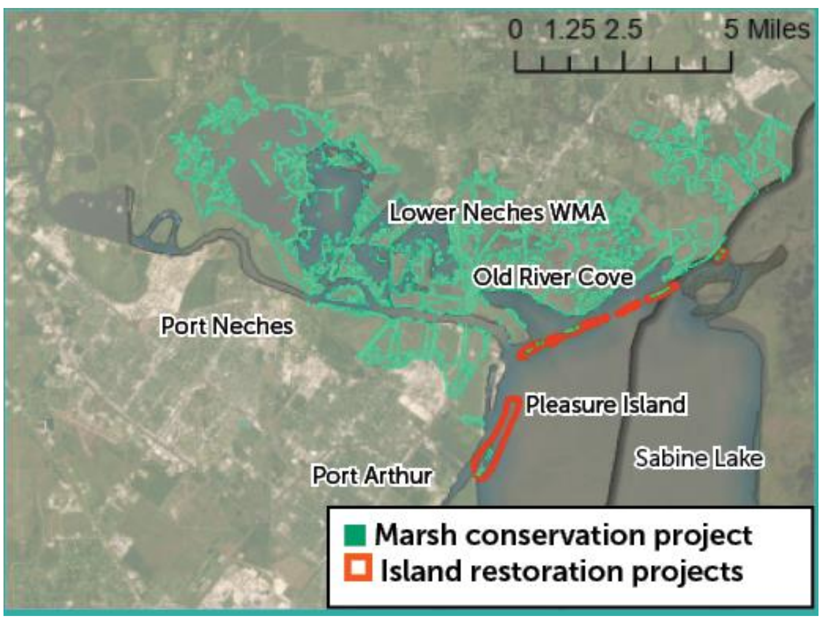


Figure 6-131 and **Figure** 6-132).

Project Concept	Locations	Desired Outcome	Models Used	Inputs Altered/Updated	Output Analysis
Dredge placement	All salt and brackish marshes, most located in Lower Neches WMA	Protect habitats from SLR by boosting elevation	SLAMM, SWAN	Elevation, slope, Mannings N, vertical accretion rates	Analysis of land cover changes, wave height and water surface elevation reduction

Island Creation	Pleasure Island, Old River Cove	Reduce flood risk	SLAMM, SWAN	Elevation, Mannings N, add structure in Surface-water Modeling System (SMS)	Analysis of wave height and water surface elevation reduction

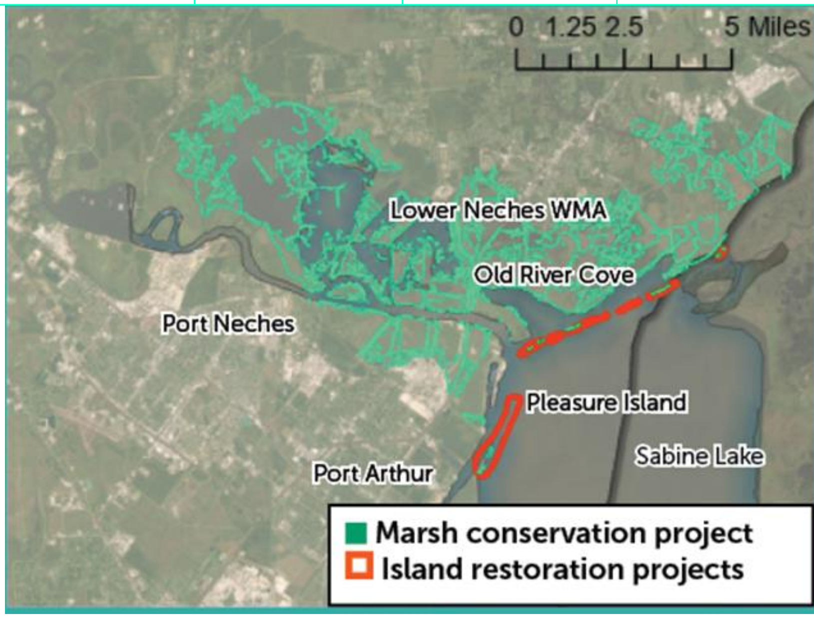


Figure 6-131 The project types modeled in Region 1A.

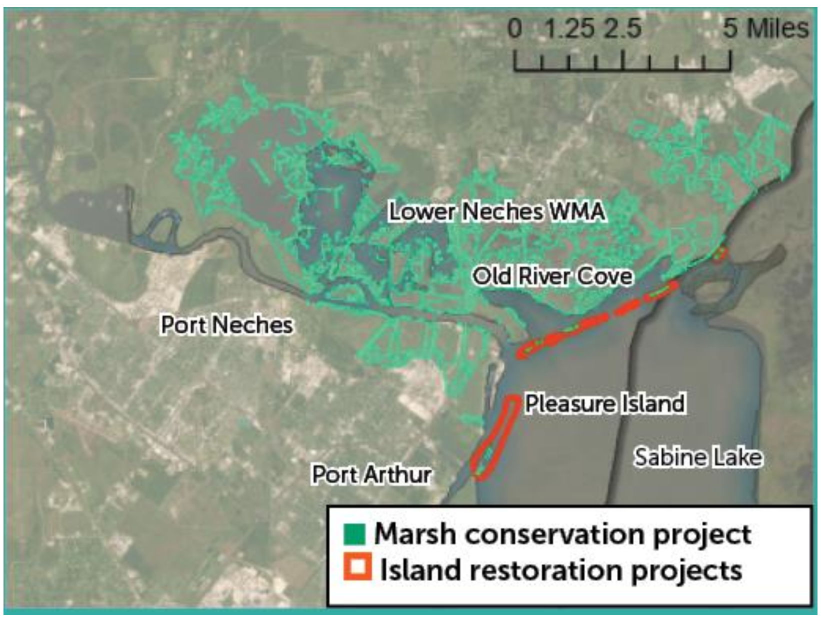


Figure 6-132 The locations of the conceptual projects modeled in SLAMM and ADCIRC+SWAN for Region 1A.

For the BUDM conceptual project, GIS was employed to identify all salt and brackish water marshes. During the SLAMM model simulation, the model was halted every 25 years to add 0.20m of elevation to these marsh areas, specifically at 2050 and 2075. This approach ensured that the marshes can maintain pace with the rate of rise in the intermediate-low SLR scenario. For island creation, the focus was on Old River Cove and Pleasure Island. Historical aerial imagery was examined to determine the former extent of the islands (Figure 6-133). In GIS, island elevations were raised to match existing islands, and the land cover type was altered to align with the surrounding islands. This approach aimed to restore these areas and provide additional protection against wave energy and storm surge. For Old River Cove, additional islands were created to maximize the wave buffering effects in the storm surge model (**Figure 6-134**).

Results show a considerable conservation of the low marshes in the Lower Neches WMA and the surrounding area, showing the efficacy of periodic elevation boosting in the SLAMM model (**Figure 6-135**). Output from the 2100 SLAMM model run was processed and prepared to be used in the ADCIRC+SWAN models.

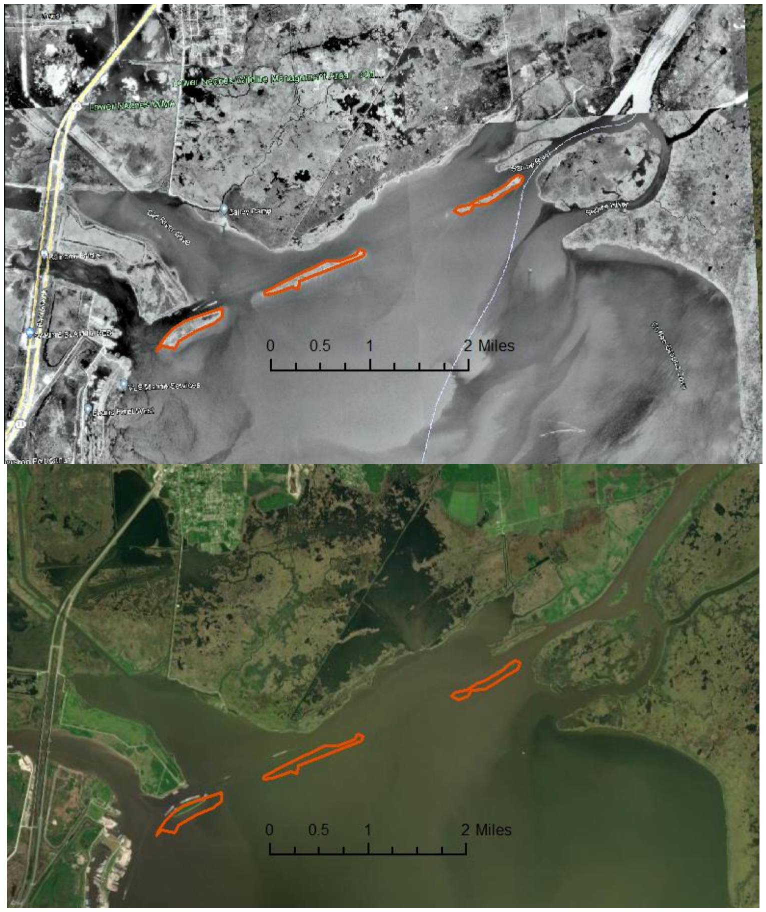


Figure 6-133 The outline of the historic islands around Old River Cove in 1989 (top) and present-day (below).

Figure 6-134 The full configuration of modeled islands.

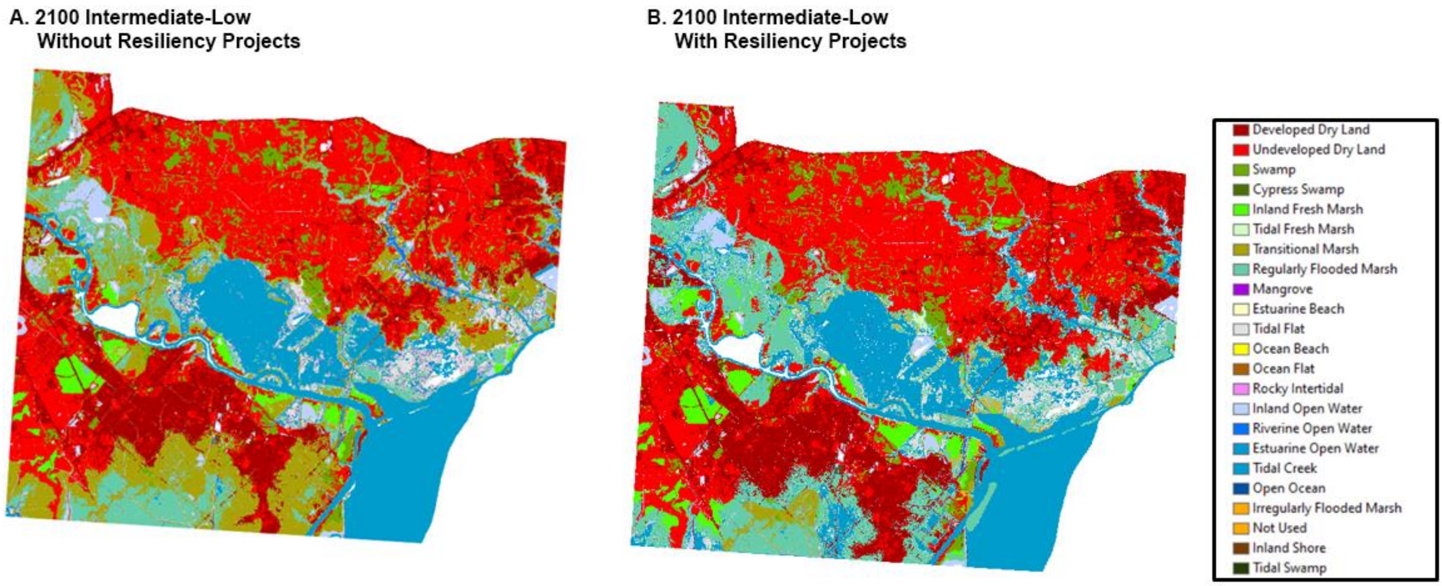


Figure 6-135 Comparison of land cover in 2100 on the future landscape with intermediate-low SLR scenario (A) without resiliency projects, and (B) with resiliency projects.

Storm Surge and Wave Modeling

Storm 160 was selected to investigate the impact of storm surge and wave with and without resiliency projects (marsh conservation and island restoration projects) in the future landscape under the intermediate-low SLR scenario. This storm made landfall on the eastward end of the Bolivar Peninsula near Rollover Pass as a Category 2 hurricane with a forward speed of 10 miles per hour and a maximum wind speed of 100 miles per hour (**Figure 6-12**).

Figure 6-136 shows the maximum water surface elevation due to Storm 160 with and without resiliency projects implemented in the future landscape with intermediate-low SLR scenario. Comparing the effect of resiliency projects on storm surge, the results showed that the large-scale marsh conservation projects in Lower Neches WMA act like buffers suppressing wave energy in turn reducing storm surge impact not only within the project area but also outside the project area. These projects also helped reduce the extent of storm surge inundation inland.

Figure 6-137 presents two maps showing the difference in extent of inundation and maximum water surface elevation due to Storm 160 with and without resiliency projects in place (top) and the difference in significant wave height with and without projects in place (bottom). The cool colors in the maps show an area with reduced water levels and wave height due to the presence of resiliency projects. Similarly, the purple color in the top map shows the area that is prevented from becoming inundation with the projects in place. It was found that more than 39 square miles of land in Orange and Jefferson counties did not get inundated with these resiliency projects in place.

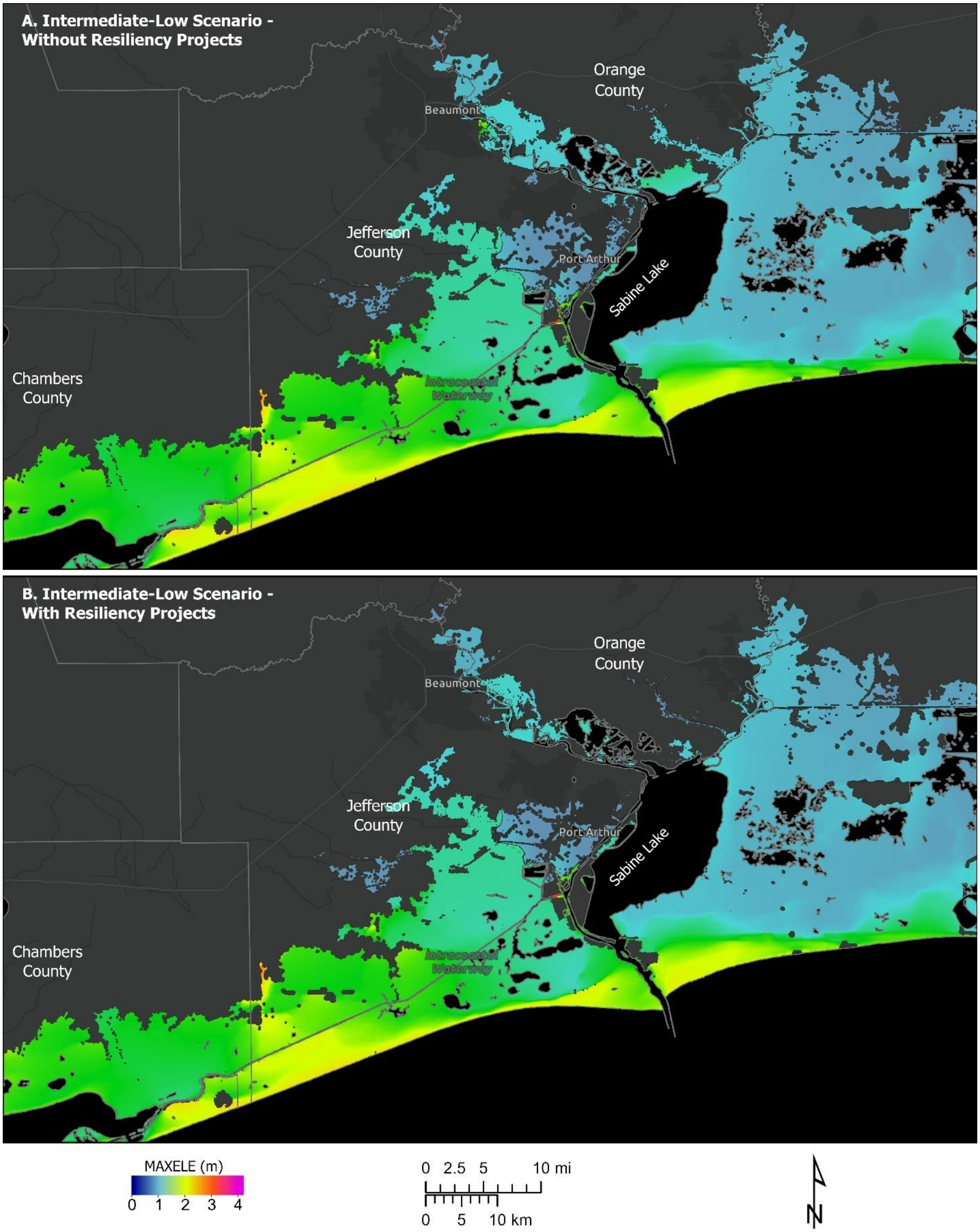


Figure 6-136. Comparison of maximum water surface elevation (MAXELE) due to Storm 160 in the future landscape with intermediate-low SLR scenario (A) without resiliency projects, and (B) with resiliency projects.

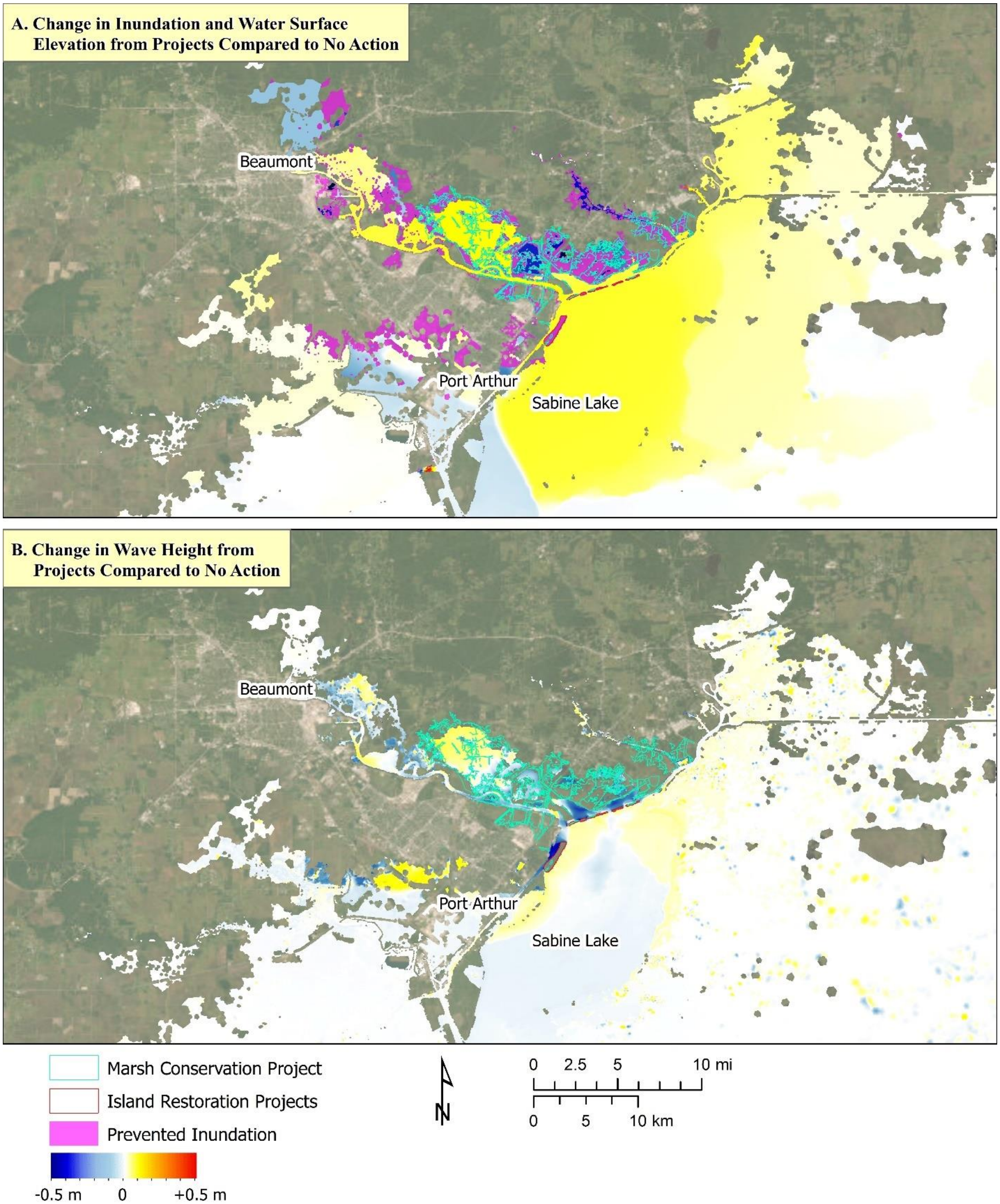


Figure 6-137. Difference maps showing (A) change in water surface elevation due to resiliency projects in place in the future landscape with intermediate-low SLR scenario, and (B) change in significant wave height due to the resiliency projects in place in the intermediate-low SLR scenario

6.5.2 Region 3

Landscape Change Modeling

Corpus Christi Bay presents a highly populated area encompassing diverse natural environments, such as barrier island brackish-salt marshes and fresh marshes along the Nueces River Delta. SLR modeling results indicate that these environments are at risk of conversion to open water by 2100. With-project modeling in this region concentrated on multiple projects dispersed across vulnerable locations with varying natural and built environment conditions, such as North Beach, Flour Bluff, and the backside of Mustang Island. The SLAMM model was executed solely for the intermediate-low SLR scenario, as higher scenarios would result in the complete inundation of the landscape within the region. The kinds of projects modeled include: BUDM, living shorelines, and shoreline armoring (**Figure 6-138** and **Figure 6-139**). These projects would represent a comprehensive approach to resiliency.

Project Concept	Locations	Desired Outcome	Models Used	Inputs Altered/Updated	Output Analysis
Living shoreline	Nueces River Delta, North Beach	Build a marsh and breakwaters to reduce wave energy and protect exposed and eroding habitats	SLAMM, SWAN	Land cover, elevation, slope, Mannings N	Analysis of wave height and water surface elevation reduction
Dredge placement	Nueces River Delta, Port Aransas Nature Preserve, Mustang Island, North Padre Island	Protect habitats from SLR by boosting elevation	SLAMM, SWAN	Elevation, slope, Mannings N, vertical accretion rates	Analysis of land cover changes, wave height and water surface elevation reduction
Shoreline armoring	Portland, Flour Bluff (Laguna Shores)	Protect communities and industry from flood risk	SLAMM,SWAN	Elevation, Mannings N, add structure in SMS	Analysis of wave height and water surface elevation reduction

Figure 6-138 The project types modeled in Region 3.

Figure 6-139 The locations of the conceptual projects modeled in SLAMM and ADCIRC+SWAN for Region 3.

In Region 3, various methods were applied for each project type, as described below:

1. Shoreline Armoring:
   - The digital elevation model (DEM) was altered to incorporate elevation changes resulting from the installation of breakwaters, sills, and other structures. The input dike file was also modified to represent the barrier.
2. Living Shorelines:
   - Potential project areas were identified using living shoreline site suitability approaches and analyzing land cover data. The DEM was altered to account for elevation changes due to breakwaters, sills, and other living shoreline components, similar to the shoreline armoring process. Additionally, low marsh land cover was added behind the barrier to the existing shoreline.
3. Dredge Placement and Wetland Restoration:
   - This method was applied similarly to the approach used in Region 1A, adding 0.2m of elevation every 25 years to wetland areas to allow them to keep pace with the rate of the intermediate-low SLR scenario.

Results show conservation of estuarine and freshwater wetlands around the Nueces River delta and the preservation of estuarine marshes, including mangroves, on the backsides of Mustang and North Padre Islands (Figure 6-140). Similar to Region 1's model results, simulating BUDM is shown to be efficacious in the SLAMM model by periodically boosting elevation. Output from the 2100 SLAMM model run was processed and prepared to be used in the ADCIRC+SWAN models.

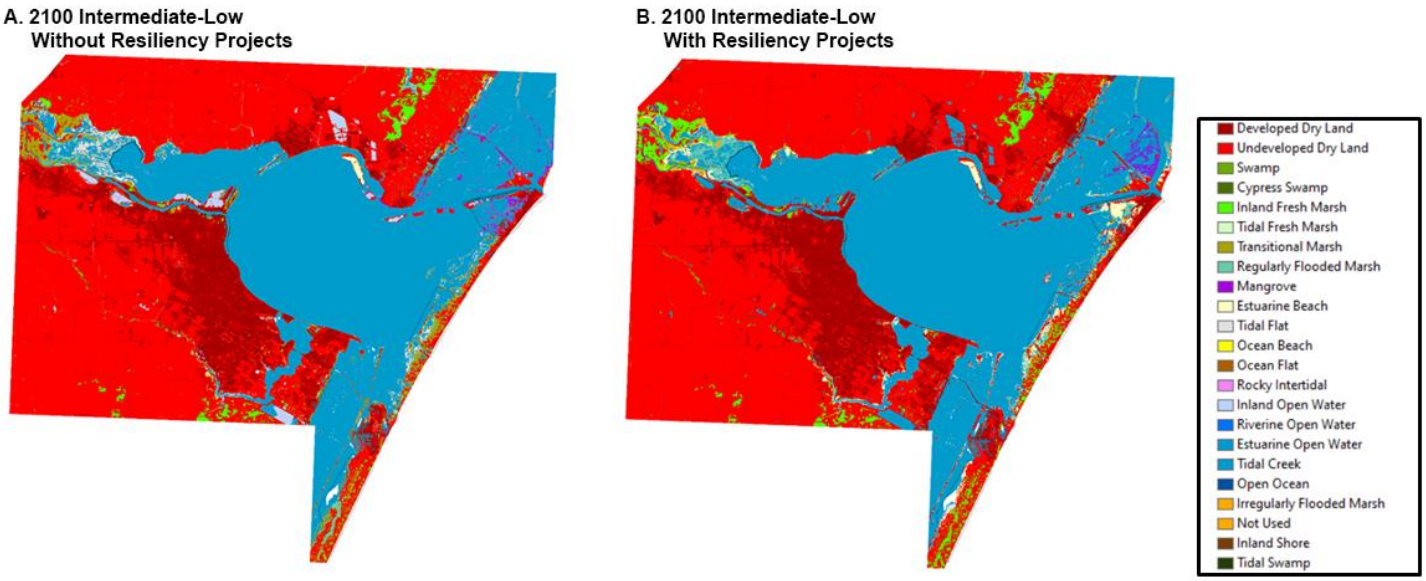


Figure 6-140 Comparison of land cover in 2100 on the future landscape with intermediate-low SLR scenario (A) without resiliency projects, and (B) with resiliency projects.

Storm Surge and Wave Modeling

Storm 416 was selected to investigate the impact of storm surge and wave with and without resiliency projects BUDM, living shoreline and shoreline armoring projects) in the future landscape under the intermediate-low SLR scenario. This storm made landfall on the northern end of the North Padre Island near Malaquite Beach as a Category 2 hurricane with a forward speed of 13 miles per hour and a maximum wind speed of 113 miles per hour (**Figure 6-12**).

Figure 6-141 shows the maximum water surface elevation due to Storm 416 with and without resiliency projects implemented in the future landscape with intermediate-low SLR scenario. Comparing the effect of resiliency projects on storm surge in Region 3, the results show not as much change in water surface elevation and extent of inundation as seen in Region 1 with Storm 160. However, the large-scale BUDM projects did succeed in reducing surge depth within the project site as well as the extent of inundation in Oso Bay and several areas around Corpus Christi Bay, e.g. North Beach and Nueces River Delta area.

Figure 6-142 has two maps showing the difference in maximum water surface elevation and extent of inundation due to Storm 416 with and without resiliency projects in place (top) and the difference in significant wave height with and without projects in place (bottom). The cool colors in the maps show an area with reduced water levels and wave height due to the presence of resiliency projects. Similarly, the purple color in the top map shows the area that is prevented from becoming inundation with the projects in place. The resiliency projects were able to reduce the wave the effects of storm surge and wave damage in the immediate area. E.g., The shoreline armoring project in Nueces River Delta was able to significantly reduce the wave height (bottom map in **Figure 6-142**).

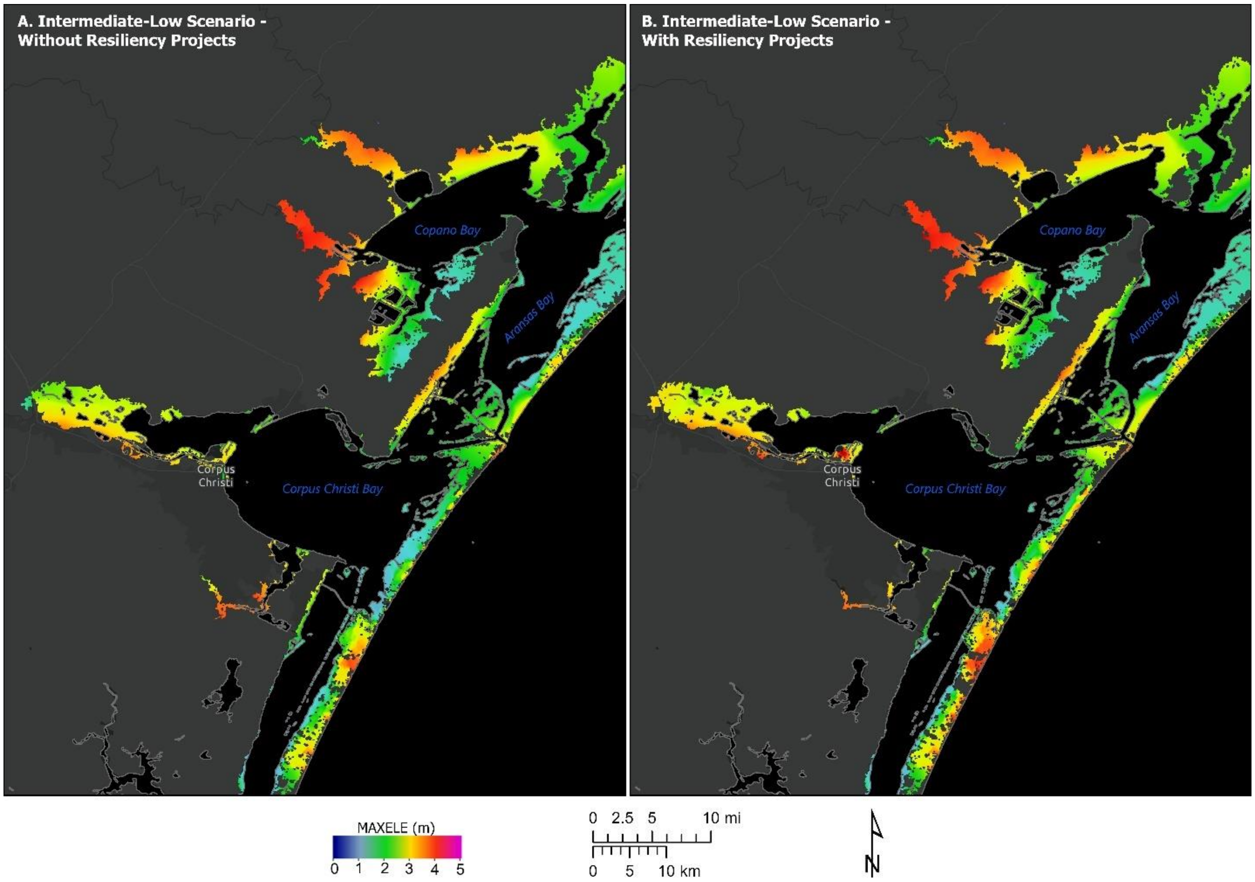


Figure 6-141. Comparison of maximum water surface elevation (MAXELE) due to Storm 416 in the future landscape with intermediate-low SLR scenario (A) without resiliency projects, and (B) with resiliency projects.

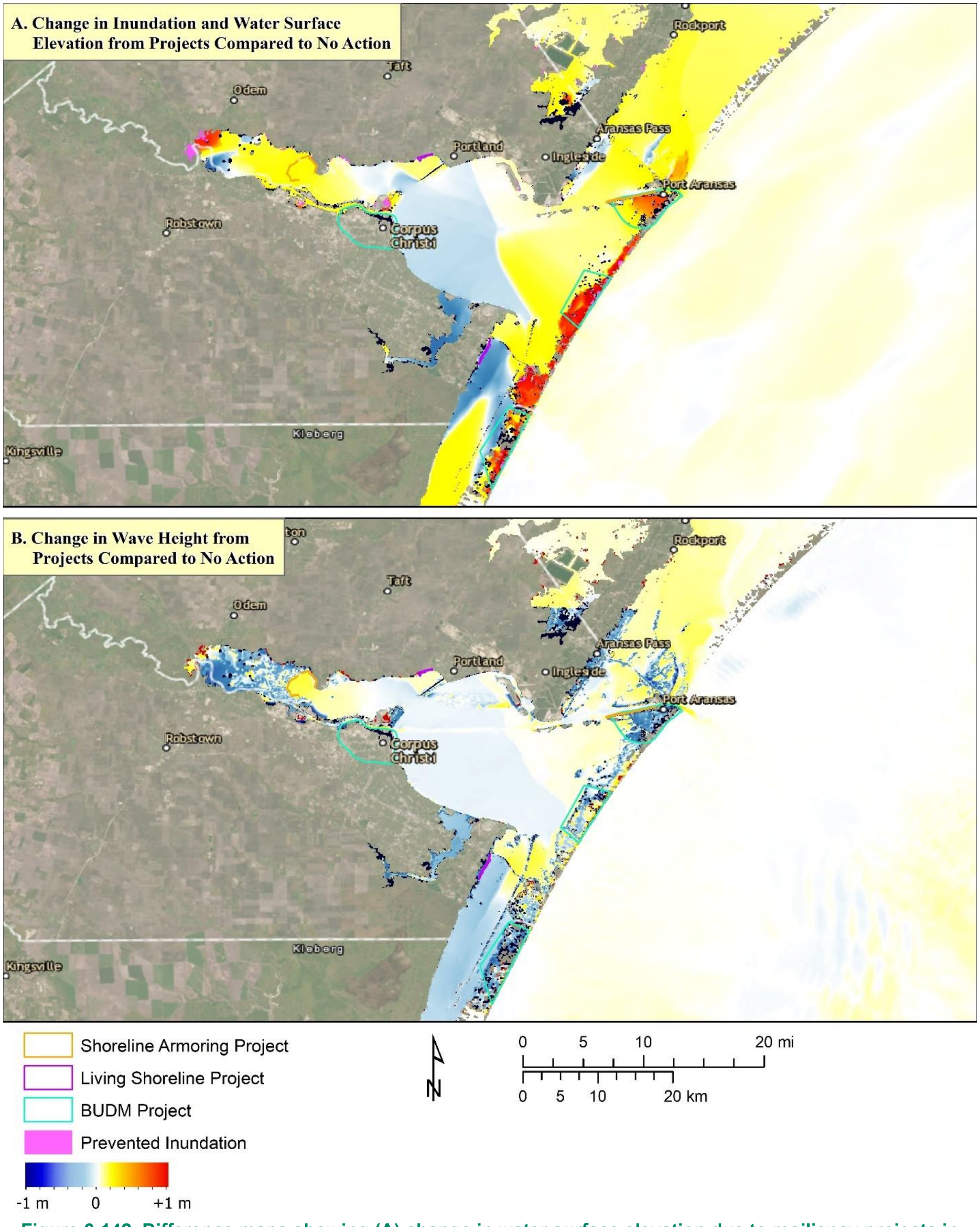


Figure 6-142. Difference maps showing (A) change in water surface elevation due to resiliency projects in place in the future landscape with intermediate-low SLR scenario, and (B) change in significant wave height due to the resiliency projects in place in the intermediate-low SLR scenario

7 Socioeconomics

7.1 Economic Characterization of the Texas Coast

The State of Texas through the GLO is assessing coastal vulnerability along its 367-mile coastline. Past experiences with the consequences of Hurricane's Rita and Ike along with continuing shoreline erosion and loss of natural coastal habitat have inspired the GLO to seek ways in which the State of Texas can protect, preserve, and restore valuable assets that are necessary to the safety and prosperity of Texas families.

Several efforts are underway, funded through the GLO, which focus on different aspects of coastal vulnerability. Storm surge and coastal flooding are being investigated by the GCCPRD through a grant by the GLO and by the USACE through GLO's cost-share of a hurricane protection feasibility study. The GCCPRD study has investigated large-scale structural means of protecting the built environment. The USACE study is looking at a variety of structural, nonstructural, and ecosystem measures that will protect the Texas coast and its diverse assets. Other work has been accomplished by the GLO that investigated coastal infrastructure needs and resiliency. By way of reference, these studies are included in the TCRMP.

This report complements the referenced actions by addressing the needs of the natural environment that are vital to the people and economy of Texas. This report builds upon what has been accomplished with other efforts. The alternatives developed in the Resiliency Plan have a foundation in the loss and degradation of the natural environment and the GLO's desire to preserve and protect the Texas coast's rich assets. While perhaps smaller in scale than the previously mentioned efforts, these actions are vital to the sustainability of the Texas coast's local and regional economies in which they are located.

Study Area

NOAA's Office of Coastal Management defines a county a Coastal Shoreline County if it is directly adjacent to the open ocean, major estuaries, or the Great Lakes. These counties are considered to be most directly affected by issues pertaining to the coast. This report adopts this perspective and defines its study area as the coastal shoreline counties (coastal counties) of Texas shown in **Table 7-1**.

Scope of Economic Report

This report begins with a characterization of the Texas coast, portraying the population who lives within the State's 18 coastal counties and presenting an overview of the counties' local and regional economies. A discussion of current and future coastal vulnerabilities follows that lays the foundation upon which the study's resiliency strategies are based.

7.1.1 Population and Growth Projections

The Texas coastline is a strong economic locus of our state. The coastline offers low-cost water transportation and abundant natural resources for commercial harvest and recreational enjoyment. Increasingly as more employment opportunities locate along the coast, more of our state's population moves there for jobs. As a result, more people and economic assets are exposed to the climatic and geophysical processes that threaten coastal low-lying areas.

Texas is experiencing the same growth pattern as that of the nation overall with urban populations concentrating along its 367-mile coastline. Texas's 18 coastal counties, shown in **Table 7-1**, make up less than 6 percent of the State's land area but contain 24 percent of the state's population. Texas's coastal counties had a population density of 464 persons/square mile in 2020 compared to the state's overall density of 109 persons/square mile, four times greater than that of the state as a whole. The population living within Texas's coastal counties is expected to increase from 6.1 million, in 2010, to 7.2 million in 2020 and to over 10 million by 2050 (Texas Demographer 2020). Ten of the eighteen counties along the Texas coast fall within major Metropolitan Statistical Areas (MSA) as designated by the U.S. Bureau of the Census. Recent population growth within Texas's coastal counties is displayed in **Table 7-2**, following county aggregations into regions as developed by the GLO in previous work, shown in **Table 7-1**.

Table 7-1. Coastal Regions Designations

Texas Coastal Region Designations	Texas Coastal Counties within Region
1a	Orange, Jefferson
1b	Harris, Galveston, Chambers, Brazoria
2	Matagorda, Jackson, Victoria, Calhoun
3	Refugio, Aransas, San Patricio, Nueces, Kleberg
4	Kenedy, Willacy, Cameron

Table 7-2. Texas Coastal Population Growth, 2010-2020

Region	County	Population (in 1000s)		Average Annual Percent Change	Percent of State Increase
		2020	2010	2010-2020	2010-2020
1a	Orange*	84.8	82.0	0.34%	0.07%
1a	Jefferson*	256.5	252.5	0.16%	0.10%
All 1a		341.3	334.5	0.20%	0.18%
1b	Chambers*	46.6	35.4	2.78%	0.29%
1b	Harris*	4,731.1	4,108.9	1.42%	15.96%
1b	Galveston*	350.7	292.6	1.83%	1.49%
1b	Brazoria*	372.0	314.5	1.70%	1.48%
All 1b		5,500.4	4,751.3	1.47%	19.21%
2	Matagorda	36.3	36.7	-0.13%	-0.01%
2	Jackson	15.0	14.1	0.63%	0.02%
2	Victoria	91.3	86.8	0.50%	0.11%
2	Calhoun	20.1	21.3	-0.59%	-0.03%
All 2		162.7	159.0	0.23%	0.09%
3	Refugio	6.7	7.4	-0.87%	-0.02%
3	Aransas*	23.8	23.2	0.27%	0.02%
3	San Patricio*	68.8	64.5	0.64%	0.11%
3	Nueces*	353.2	340.3	0.37%	0.33%
3	Kleberg	31.0	32.1	-0.33%	-0.03%
All 3		483.5	467.5	0.34%	0.41%
4	Kenedy	0.4	0.4	-1.76%	0.00%
4	Willacy	20.2	22.2	-0.96%	-0.05%
4	Cameron*	421.0	407.7	0.32%	0.34%
All 4		441.5	430.3	0.26%	0.29%
All Coastal Counties		6,929.5	6,142.6	1.21%	20.18%
Texas		29,145.5	25,245.7	1.45%	100.00%

*Metropolitan Area counties as designated by the U.S. Bureau of the Census
Source: U.S. Bureau of the Census

Texas's coastal counties added over 787,000 persons over the ten-year period 2010-2020 for an overall increase of 13 percent. Region 1b, which comprises four of the counties that make up the Houston-Sugar Land-Baytown Metropolitan Area, dominated growth within the coastal counties overall, capturing over 95 percent of coastal county growth between 2010-2020. Region 1a showed the least growth among the coastal regions. One fifth of Texas's population growth between 2010 and 2020 occurred in coastal counties.

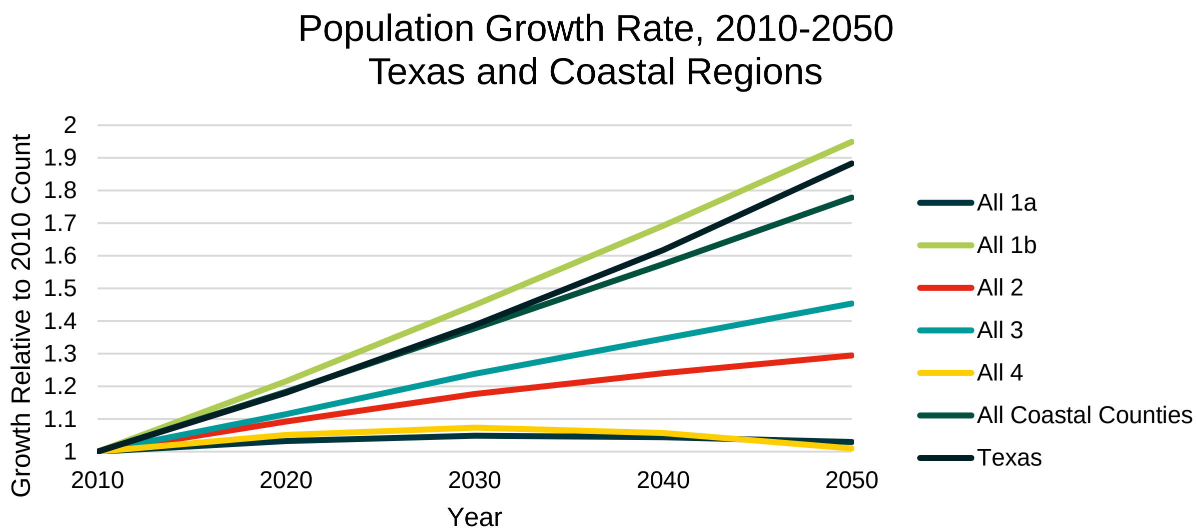
Expectation for future population growth is developed by the Texas State Data Center. For long-term planning purposes, the Texas State Demographer recommends adopting a mid-range growth projection scenario with net migration that is one-half the rate that was experienced in the post-2000 decade. **Table 7-3** shows the projections of growth for the State of Texas, the coastal counties and coastal regions. The State is expected to increase its population by over 17 million persons between 2020 and 2050. Of that number, close to 4 million will live in Texas's coastal counties. Region 1b is expected to capture 20 percent of State's population growth between 2020-2050 and over 95 percent of that growth along the Texas coast with an additional 3.5 million people (Texas Demographer 2020).

The forecast for future growth in coastal regions is shown in **Figure 7-1** which summarizes expectations for growth in Region 1b to be faster than other coastal regions and the State overall. By 2050, Region 1b is projected to grow its population by almost 60 percent over its 2020 projected level. Texas overall is expected to increase its total population by over 60 percent, over the same period.

Table 7-3. Population Growth Projections, Texas Coast, 2010-2050

Region	County	Census data, 2010 (in 1000s)	Census data, 2020 (in 1000s)	Projection, 2020 (in 1000s)	Projection, 2030 (in 1000s)	Projection, 2050 (in 1000s)	Average Annual Growth Rate, 2020-2050*	Population Change, 2020-2050* (in 1000s)	Percent of State Increase, 2020-2050*
1a	Orange	82.0	84.8	86.2	89.1	88.0	0.11%	1.8	0.01%
1a	Jefferson	252.5	256.5	258.7	261.3	256.1	-0.05%	-2.5	-0.01%
All 1a		334.5	341.3	344.8	350.4	344.1	-0.01%	-0.7	0.00%
1b	Chambers	35.4	46.6	42.3	52.6	77.5	3.07%	35.2	0.20%
1b	Harris	4,108.9	4,731.1	4,978.8	5,924.8	7,933.4	2.36%	2,954.6	16.73%
1b	Galveston	292.6	350.7	355.2	427.0	580.2	2.48%	225.1	1.27%
1b	Brazoria	314.5	372.0	375.9	452.5	632.1	2.63%	256.3	1.45%
All 1b		4,751.3	5,500.4	5,752.2	6,856.9	9,223.3	2.39%	3,471.2	19.65%
2	Matagorda	36.7	36.3	37.1	36.5	33.3	-0.53%	-3.8	-0.02%
2	Jackson	14.1	15.0	15.9	17.9	22.9	1.84%	7.0	0.04%
2	Victoria	86.8	91.3	97.7	109.0	125.7	1.26%	28.0	0.16%
2	Calhoun	21.3	20.1	22.8	23.7	23.9	0.24%	1.1	0.01%
All 2		159.0	162.7	173.5	187.1	205.8	0.86%	32.3	0.18%
3	Refugio	7.4	6.7	7.6	7.6	7.6	0.00%	0	0.00%
3	Aransas	23.2	23.8	27.7	33.1	46.2	2.60%	18.6	0.10%
3	San Patricio	64.5	68.8	71.3	78.2	86.4	0.96%	15.0	0.09%
3	Nueces	340.3	353.2	383.7	429.5	511.5	1.45%	127.7	0.72%
3	Kleberg	32.1	31.0	31.0	30.5	28.2	-0.47%	-2.8	-0.02%
All 3		467.5	483.5	521.3	579.0	679.8	1.34%	158.5	0.90%
4	Kenedy	0.4	0.4	0.5	0.5	0.6	0.71%	0.1	0.00%
4	Willacy	22.2	20.2	22.1	21.6	19.2	-0.70%	-2.9	-0.02%
4	Cameron	407.7	421.0	427.9	438.1	413.1	-0.18%	-14.7	-0.08%
All 4		430.3	441.5	450.5	460.3	432.9	-0.20%	-17.6	-0.10%
All Coastal Counties		6,142.6	6,929.5	7,242.4	8,433.7	10,885.9	2.06%	3,643.4	20.63%
Texas		25,245.7	29,145.5	29,677.7	34,894.5	47,342.1	2.36%	17,664.4	

* Estimations were done considering projected data.
Source: Texas Demographer 2020



Source: Texas Demographer 2020

Figure 7-1. Population Growth Rate, 2010-2050

7.1.2 Built Environment

Population growth is spurred by employment opportunities and locational amenities. Population growth brings with it residential development and associated commercial and industrial development. These actions transform the natural environment to one that supports human activity. All of the area and physical structures that have been created by people for use by people constitute the “built environment.” One estimate of the value of the built environment is the monetary value of real and personal property. This value is the basis for property tax assessments and is established by county appraisal districts consistently in every Texas County. Real property consists of all lands and all appurtenances to lands, such as buildings, crops, or mineral rights. Texas Tax Code Section 23.01 requires taxable property to be appraised at market value as of January 1 of the tax year. Except as provided by the Texas Constitution, all real and tangible personal property is taxed in proportion to its value, which is determined by law. The Texas Constitution provides certain exceptions to this rule, such as the use of productivity values for agricultural and timber land, which is appraised, based on productivity value rather than market value. This method tends to be lower than market value. Therefore, total market value of real property provides a conservative estimate of the value of a county’s economic assets but is presented here in lieu of more credible data. **Table 7-4** displays the market value of real property for 2021 for Texas’s coastal counties and regions. On a per square mile basis, the market value of real property in Texas coastal counties is over 4 times the value of an average Texas square mile overall (Texas Comptroller of Public Accounts, 2021).

In 2021, over $1,075 billion of real property was located in Texas’s 18 coastal counties, comprising 25 percent of the State’s total real property market value. Currently, coastal Region 1b dominates the coastal regions with 82 percent of the market value of built assets along the Texas coast.

Table 7-4. Estimate of the Value of the Built Environment, Texas Coastal Counties, 2021

Region	County	Total Market Value 2021 (in millions)	Percent of State Total 2021	Land Area Sq. Mi.	Value per Sq. Mi. 2021
1a	Orange	$8,705.2	0.20%	334	$26.1
1a	Jefferson	$36,134.8	0.84%	876	$41.3
All 1a		$44,840.0	1.04%	1,210	$37.1
1b	Chambers	$21,245.2	0.49%	597	$35.6
1b	Harris	$745,500.6	17.30%	1,704	$437.5
1b	Galveston	$54,596.7	1.27%	378	$144.4
1b	Brazoria	$64,907.9	1.51%	1,358	$47.8
All 1b		$886,250.4	20.57%	4,037	$219.5
2	Matagorda	$9,417.8	0.22%	1,100	$8.6
2	Jackson	$4,609.6	0.11%	829	$5.6
2	Victoria	$10,639.8	0.25%	882	$12.1
2	Calhoun	$6,520.9	0.15%	507	$12.9
All 2		$31,188.0	0.72%	3,319	$9.4
3	Refugio	$1,729.4	0.04%	770	$2.3
3	Aransas	$4,740.8	0.11%	252	$18.8
3	San Patricio	$23,481.4	0.54%	694	$33.8
3	Nueces	$47,597.0	1.10%	839	$56.7
3	Kleberg	$2,904.9	0.07%	881	$3.3
All 3		$80,453.5	1.87%	3,436	$23.4
4	Kenedy	$2,145.7	0.05%	1,458	$1.5
4	Willacy	$2,742.4	0.06%	591	$4.6
4	Cameron	$26,7764.4	0.62%	891	$30.1
All 4		$31,664.6	0.73%	2,940	$10.7
All Coastal Counties		$1,074,396.4	24.93%	14,941	$71.9
Texas		$4,309,432.6		261,233	$16.5

Source: Texas Comptroller of Public Accounts, 2021

7.1.3 Coastal Economy

Gross Domestic Product

A measure of Texas's financial wealth and well-being lies in its productivity as reflected in its Real gross domestic product (GDP). The GDP for private industry in the State of Texas was $1.7 trillion (chained 2012 dollars) in 2020, ranking second in the nation only behind California. GDP by state is the measure of the market value of all final goods and services produced within a state in a particular period of time. In concept, an industry's GDP by state, referred to as its "value added", is equivalent to its gross output (sales or receipts and other operating income, commodity taxes, and inventory change) minus its intermediate inputs (consumption of goods and services purchased from other U.S. industries or imported). GDP by state is the state counterpart of the Nation's GDP, the Bureau's featured and most comprehensive measure of U.S. economic activity (Bureau of Economic Analysis, 2020).

Table 7-5 presents the number of businesses, employment, wages, and GDP by industrial sector. In 2020, the largest contributor to Texas's financial wealth was mining, quarrying, and oil and gas extraction. This industry accounted for almost 13 percent of Texas's GDP. The second largest industry contributing to GDP was manufacturing with close to 13 percent of the GDP. Employment was highest within health care and social assistance, followed by retail trade, and accommodation and food service, respectively.

Table 7-5. Establishments, Employment, Wages, and GDP by Industry in Texas, 2020

NAICS** Sector	Annual Establishments	Annual Average Employment (in 1000s)	Total Annual Wages (in 1000s)	Annual Wages per Employee (in 1000s)	Real GDP chained 2012 $ (in millions)	Percent of Total Real GDP	Rank by Real GDP
NAICS 11 Agriculture, forestry, fishing and hunting	10,384	59.6	$2,437.0	$40.9	$11,322	0.65%	18
NAICS 21 Mining, quarrying, and oil and gas extraction	9,314	190.2	$26,81.8	$141.0	$227,457	13.12%	1
NAICS 22 Utilities	2,069	51.6	$5,944.1	$115.3	$27,582	1.59%	15
NAICS 23 Construction	55,014	737.1	$50,809.2	$68.9	$65,335	3.77%	10
NAICS 31-33 Manufacturing	26,257	867.8	$70,471.3	$81.2	$220,546	12.72%	2
NAICS 42 Wholesale trade	47,585	590.3	$52,947.8	$89.7	$127,408	7.35%	5
NAICS 44-45 Retail trade	79,965	1,281.8	$47,240.7	$36.9	$93,432	5.39%	7
NAICS 48-49 Transportation and warehousing	22,820	529.6	$32,439.4	$61.3	$49,263	2.84%	12
NAICS 51 Information	11,822	198.5	$20,414.9	$102.8	$79,528	4.59%	9
NAICS 52 Finance and insurance	43,525	559.7	$56,995.0	$101.8	$86,300	4.98%	8
NAICS 53 Real estate and rental and leasing	35,415	218.9	$15,003.3	$68.5	$189,242	10.91%	4
NAICS 54 Professional and technical services	102,502	831.6	$83,687.6	$100.6	$206,092	11.88%	3
NAICS 55 Management of companies and enterprises	3,786	141.0	$19,611.9	$139.1	$27,488	1.58%	16
NAICS 56 Administrative and waste services	40,350	786.4	$39,395.6	$50.1	$53,120	3.06%	12
NAICS 61 Educational services	8,764	172.8	$9,165.5	$53.0	$10,948	0.63%	19
NAICS 62 Health care and social assistance	89,917	1,473.4	$76,197.1	$51.7	$96,243	5.55%	6
NAICS 71 Arts, entertainment, and recreation	8,709	115.5	$4,641.1	$40.2	$39,533	2.28%	13
NAICS 72 Accommodation and food services	58,069	1,062.9	$22,464.4	$21.1	$31,827	1.84%	14
NAICS 81 Other services, except public administration	57,936	310.2	$13,667.9	$44.1	$26,714	1.54%	17
NAICS 99 Unclassified	5,865	5.4	$288.7	$53.8			20
Total	720,068	10,184.3	$650,640.3	$1,462.1	$1,734,321	100.00%	

*The public government sector is not included.
**NAICS: North American Industrial Classification System
Sources: Bureau of Economic Analysis, 2020 & Bureau of Labor Statistics, 2020.

Personal Income

Local area personal income statistics provide a framework for analyzing current conditions in local economies as a measure of wealth held by the local population. Personal income is the income received by, or on behalf of, all persons from all sources: from participation as laborers in production; from owning a home or unincorporated business; from the ownership of financial assets; and from government and business in the form of transfer receipts. It includes income from domestic sources as well as from the rest of the world. Personal income is the income that is available to persons for consumption expenditures, taxes, interest payments, transfer payments to governments and the rest of the world, or for saving.

Per capita personal income is calculated as the total personal income of the residents of a given area divided by the resident population of the area. Personal income is measured before the deduction of personal income taxes and other personal taxes and is reported in current dollars (no adjustment is made for price changes).

Table 7-6 presents 2020 personal income and per capita income for the coastal counties, coastal regions and the State as a whole. Altogether, the coastal counties contain both 24 percent of the State's population and the State's total personal income. However, the distribution of income is skewed along the Texas coast. With the exception of Region 1b, which is part of the Houston MSA, compared to the overall State, coastal regions fare below in terms of per capita personal income. The Region 1b population commands almost 84 percent of all the personal income within the coastal counties and has over one-fifth of all the personal income in the State.

Table 7-6. Personal Income and Per Capita Income, Coastal Counties, 2020

Region	County	Population 2020 (in 1000s)	Personal Income 2020 (in 1000s)	Per Capita Income 2020	Percent of State Total	
					Population	Personal Income
1a	Orange	84.8	$3,992,481	$48,173	0.29%	0.25%
1a	Jefferson	256.5	$11,642,671	$46,547	0.88%	0.72%
All 1a		341.3	$15,635,152	$94,720	1.17%	0.97%
1b	Chambers	46.6	$2,721,128	$59,687	0.16%	0.17%
1b	Harris	4,731.1	$285,160,839	$60,183	16.23%	17.62%
1b	Galveston	350.7	$19,994,969	$57,941	1.20%	1.24%
1b	Brazoria	372.0	$19,715,560	$51,812	1.28%	1.22%
All 1b		5,500.4	$327,592,496	$229,623	18.87%	20.24%
2	Matagorda	36.3	$1,768,294	$48,150	0.12%	0.11%
2	Jackson	15.0	$707,667	$47,642	0.05%	0.04%
2	Victoria	91.3	$4,953,641	$53,881	0.31%	0.31%
2	Calhoun	20.1	$1,095,838	$52,180	0.07%	0.07%
All 2		162.7	$8,525,440	$201,853	0.56%	0.53%
3	Refugio	6.7	$331,928	$48,266	0.02%	0.02%
3	Aransas	23.8	$1,294,859	$54,374	0.08%	0.08%
3	San Patricio	68.8	$3,245,531	$48,391	0.24%	0.20%
3	Nueces	353.2	$17,430,572	$47,999	1.21%	1.08%
3	Kleberg	31.0	$1,321,517	$43,560	0.11%	0.08%
All 3		483.5	$23,624,407	$242,590	1.66%	1.46%
4	Kenedy	0.4	$17,546	$46,296	0.00%	0.00%
4	Willacy	20.2	$671,018	$31,710	0.07%	0.04%
4	Cameron	421.0	$14,290,654	$33,690	1.44%	0.88%
All 4		441.5	$14,979,218	$111,696	1.51%	0.93%
All Coastal Counties		6,929.5	$390,356,713	$880,482	23.78%	24.12%
Texas		29,145.5	$1,618,635,133	$55,129		

Source: Bureau of Economic Analysis, 2020

Employment, Businesses and Wages

As of 2020, Texas possessed 8.6 percent of the total U.S. employment with 10.1 million persons working in the labor force. Texas has a strong export economy based in the oil and gas industry for not only oil and gas extraction but also product manufacturing. Over one-half of the nation's employment in oil and gas extraction is located in Texas. Texas also has a diversified employment base and has a higher employment percentage in the construction, wholesale trade, transportation and warehousing, and real estate industries, compared to the overall U.S. (BLS, 2020).

Table 7-7 displays the total employment, establishment count, and total wages for the coastal counties for 2020. Over one-quarter of the State's employment is located within the 18 coastal counties along with nearly 22 percent of all business establishments. Harris County in Region 1b dominates the coastal counties with employment and business establishments.

Wages are one component of personal income. Cumulatively, the total wages across the coastal counties is higher than the State wages, capturing almost 28 percent of all wages in the State. Consequently, the annual average wages per employee is 10 percent higher along the coast with Harris, Kenedy, Calhoun, and Chambers Counties all having higher wages per employee than the overall State average.

Table 7-7. Annual Average Employment, Business Establishments, and Wages Coastal Counties, 2020

Region	Coastal County	Total Employment			Business Establishment Count			Total Wages			Pay		
		Annual Average	Percent of State	Percent of Coastal County	Annual Average	Percent of State	Percent of Coastal County	Annual Average (in 1000s)	Percent of State	Percent of Coastal County	Annual Average (in 1000s) ^1	Percent of State	Percent of Coastal County
1a	Jefferson	96,851	0.95%	3.79%	5,692	0.79%	3.52%	$5,752.3	0.88%	3.21%	$59.4	92.97%	84.58%
1a	Orange	17,482	0.17%	0.68%	1,352	0.19%	0.84%	$1,033.6	0.16%	0.58%	$59.1	92.54%	84.19%
All 1a		114,333			7,044			$6,785.8			$59.5		
1b	Harris	1,939,150	19.0%	75.9%	120,071	16.67%	74.21%	$147,670.7	22.70%	82.35%	$76.1	119.20%	108.44%
1b	Galveston	77,027	0.8%	3.0%	6,294	0.87%	3.89%	$3,955.3	0.61%	2.21%	$51.3	80.38%	73.12%
1b	Chambers	14,439	0.1%	0.6%	735	0.10%	0.45%	$991.1	0.15%	0.55%	$68.6	107.45%	97.75%
1b	Brazoria	91,123	0.9%	3.6%	6,135	0.85%	3.79%	$5,672.5	0.87%	3.16%	$62.2	97.44%	88.65%
All 1b		2,121,739			133,235			$158,289.6			$74.6		
2	Matagorda	7,787	0.08%	0.30%	773	0.11%	0.48%	$487.3	0.07%	0.27%	$62.5	97.95%	89.11%
2	Jackson	4,624	0.05%	0.18%	390	0.05%	0.24%	$227.1	0.03%	0.13%	$49.1	76.89%	69.95%
2	Victoria	29,446	0.29%	1.15%	2,373	0.33%	1.47%	$1,406.6	0.22%	0.78%	$47,8	74.77%	68.02%
2	Calhoun	11,172	0.11%	0.44%	607	0.08%	0.38%	$871.2	0.13%	0.49%	$78.0	122.07%	111.05%
All 2		53,029			4,143			$2,992.1			$56.4		
3	Refugio	1,493	0.01%	0.06%	163	0.02%	0.10%	$62.3	0.01%	0.03%	$41.7	65.31%	59.42%
3	Aransas	4,365	0.04%	0.17%	592	0.08%	0.37%	$170.3	0.03%	0.09%	$39.0	61.09%	55.58%
3	San Patricio	14,575	0.14%	0.57%	1,088	0.15%	0.67%	$767.3	0.12%	0.43%	$52.6	82.40%	74.96%
3	Nueces	124,996	1.23%	4.89%	8,209	1.14%	5.07%	$6,306.9	0.97%	3.52%	$50.5	78.98%	71.85%
3	Kleberg	7,300	0.07%	0.29%	550	0.08%	0.34%	$281.4	0.04%	0.16%	$38.6	60.35%	54.90%
All 3		152,729			10,602			$7,588.3			$49.7		
4	Kenedy	325	0.00%	0.01%	24	0.00%	0.01%	$25.5	0.00%	0.01%	$78.9	123.13%	112.01%
4	Willacy	2,557	0.03%	0.10%	271	0.04%	0.17%	$100.1	0.02%	0.06%	$39.2	61.30%	55.77%
4	Cameron	109,003	1.07%	4.27%	6,486	0.90%	4.01%	$3,550.2	0.55%	1.98%	$32.6	50.98%	46.38%
All 4		111,885			6,781			$3,675.9			$32.9		
Coastal Counties		2,553,715	25.07%		161,805	22.47%		$179,331.7	27.56%		$70.2		
Texas Statewide		10,184,330			720,066			$650,640.3			$63.9		

^1: Total Wages divided by Total Employment
Source: Bureau of Labor Statistics, 2020

Location Quotients and Industry Concentrations

The employment distribution within industrial sectors for each coastal county was compared against employment within industrial sectors Statewide. This comparison resulted in location-quotient calculations that indicate where the county's industrial focus lies based on employment. Any county location quotient over 1.0 indicates that proportionately more employment is found in that industrial sector than at the State level and that county's industrial sector supports an export economy. Location quotients that are very high (>10) indicate a heavy concentration of employment in that industry within the county. In general, diversified economies are more resilient ones, being able to better withstand market fluctuations that can adversely affect one industry. Local economies that are dominated by very few industries have difficulty maintaining stability when those industries suffer downturns. **Table 7-8** displays the location quotients for each county by coastal region and industrial subsector.

Region 1a. As shown in **Table 7-8**, Region 1a has an economy dominated by manufacturing, especially petroleum products in Jefferson County and chemicals in Orange County. Pipeline transportation and support services in construction also contribute to a strong manufacturing-based economy for Region 1a.

Region 1b. The diverse economy of an urban Harris County dominates Region 1b with export economies in a wide range of industrial sectors. Additional significant employment sectors are crude petroleum and natural gas extraction; pipeline transportation of oil and gas; oil and gas field machinery and equipment manufacturing; geophysical surveying and mapping services, and support activities for mining. Galveston County has strong economies for employment in navigational services to shipping; marine cargo handling; seafood processing; petroleum refining; and cruise ship and tourism industries. Chambers County's employment is concentrated in the pipeline construction, fishing and hunting industries, heavy construction activities, and chemical manufacturing. Brazoria County's economy is concentrated in petrochemical manufacturing and heavy construction activities, more specifically, oil and gas pipeline and industrial building construction.

Region 2. Victoria County reflects the diversified economy of its urban center Victoria with export employment across many sectors that support the regional demand for human services such as health, food services, and mobility. Construction equipment merchant wholesalers; chemical manufacturing; and heavy machinery rental and leasing are high employment sectors in Victoria County. Region 2's Matagorda County has very high employment in pipeline transportation of natural gas; shellfish fishing and seafood processing; and rice and tree farming. Calhoun County's employment is almost totally concentrated in chemical manufacturing. Other significant sectors include heavy construction, and specialty trade.

Region 3. San Patricio County, in Region 3, has very high employment in oil and gas extraction; industrial building construction activities; oil and gas pipeline construction and operations; water transportation; and cotton farming and ginning. Nueces County's employment reflects its urban center Corpus Christi with a diverse economy supporting many service needs. Nueces County also possesses a very high concentration of employment in petroleum refineries, pipeline transportation of oil and gas and support activities; and scenic and sightseeing transportation. Refugio has a high concentration of employment in private home services; gasoline stations; and farming, ranching, and agricultural support services. Kleberg County has a high percentage of employment in animal production and aquaculture; building material stores and downstream oil and gas.

Region 4. Kenedy County's employment is totally concentrated in ranching while Willacy County's employment is very high for farming and agriculture support activities. Employment in Cameron County reflects its urban center of Brownsville with a wide variety of employment across many sectors that support human consumption and needs. Cameron County also has a high percentage of employment in farming and shellfish fishing.

Table 7-8. Location Quotients for the Texas Coastal Counties

Region	1a		1b				2				3					4		
Industry	**Jefferson**	**Orange**	**Harris**	**Galveston**	**Chambers**	**Brazoria**	**Matagorda**	**Jackson**	**Victoria**	**Calhoun**	**Refugio**	**Aransas**	**San Patricio**	**Nueces**	**Kleberg**	**Kenedy**	**Willacy**	**Cameron**
Base Industry: Total, all industries	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
NAICS 111 Crop production	0.12	-	0.06	0	0.18	0.66	6.54	3.17	0.14	0.47	2.72	-	2.29	0.43	0.25	-	9.09	0.47
NAICS 112 Animal production and aquaculture	0.18	0	0.12	0.22	0.56	0	4.4	2.81	1.5	1.79	5.27	0	0	0	16.21	57.68	7.04	0.16
NAICS 113 Forestry and logging	0	-	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAICS 114 Fishing, hunting and trapping	0	-	0.15	6.6	28.31	0	25.15	0	-	0	-	-	0	0	0	-	0	5.22
NAICS 115 Agriculture and forestry support activities	0.15	0	0.08	0	0.44	0.22	3.21	2.39	0.24	0	4.44	0	3.07	0.28	0	-	9.83	0.48
NAICS 211 Oil and gas extraction	0	1.12	15.42	1.93	3.13	0	3.14	1.15	0	0	0	0	18.7	2.15	0	-	0	-
NAICS 212 Mining, except oil and gas	0	0	0.33	-	-	0	-	-	0	-	-	-	0	0.72	0	-	-	0.38
NAICS 213 Support activities for mining	1.4	0	6.33	3.9	3.25	1.48	6.13	26.76	17.67	0	0	0	0	6.55	6.61	0	-	0.13
NAICS 221 Utilities	0.82	1.69	1.67	0.85	0	0.65	0	0	3.14	0	0	0	1.64	1.25	0	0	0	0.65
NAICS 236 Construction of buildings	3.58	1.39	1.47	1.4	1.14	3.09	0	4.13	0.66	1.96	0	1.18	4.55	2.6	0	-	0	0.34

Region	1a		1b				2				3					4		
Industry	Jefferson	Orange	Harris	Galveston	Chambers	Brazoria	Matagorda	Jackson	Victoria	Calhoun	Refugio	Aransas	San Patricio	Nueces	Kleberg	Kenedy	Willacy	Cameron
NAICS 237 Heavy and civil engineering construction	4.19	5.19	2.06	1.48	21.57	8.56	0	7.32	1.47	6.19	0	1.69	14.79	2.01	0	-	0	0.55
NAICS 238 Specialty trade contractors	1.19	1.06	1.17	0.93	0.22	1.16	0.33	1.48	1.04	5.06	2.44	1.38	1.65	1.06	0.4	-	0.27	0.48
NAICS 311 Food manufacturing	0.41	0.06	0.3	0.25	0.62	0.26	0.71	-	0.21	0	-	0	0	0.6	0.23	-	0	0.78
NAICS 312 Beverage and tobacco product manufacturing	0.26	-	0.76	0.33	0	0.13	-	0	0	0	0	0	-	0.66	-	-	-	0.2
NAICS 313 Textile mills	-	-	0.15	0.11	0	0	-	-	-	-	-	-	-	-	-	-	-	0
NAICS 314 Textile product mills	1.02	-	0.62	0.31	0	0.55	0	0	0.58	-	-	1.02	-	0.16	-	-	-	0.77
NAICS 315 Apparel manufacturing	-	0	0.37	0	-	0	-	-	-	-	-	-	-	0.05	-	-	-	0
NAICS 316 Leather and allied product manufacturing	-	-	0.51	0	0	0	-	-	-	-	-	-	-	-	0	-	0	-
NAICS 321 Wood product manufacturing	0.63	0	0.43	0.13	-	0.2	0	-	0	-	-	0	-	0.13	-	-	-	0
NAICS 322 Paper manufacturing	-	0	0.23	-	-	0	-	-	-	-	-	-	-	-	-	-	-	0.51

Region	1a		1b				2				3					4		
Industry	**Jefferson**	**Orange**	**Harris**	**Galveston**	**Chambers**	**Brazoria**	**Matagorda**	**Jackson**	**Victoria**	**Calhoun**	**Refugio**	**Aransas**	**San Patricio**	**Nueces**	**Kleberg**	**Kenedy**	**Willacy**	**Cameron**
NAICS 323 Printing and related support activities	0.41	0.21	0.62	0.12	-	0.27	0	0	0.54	0	-	0.48	0	0.17	0	-	0	0.16
NAICS 324 Petroleum and coal products manufacturing	54.09	-	3.04	0	-	0	-	-	-	0	0	-	1.38	20.63	-	-	-	0
NAICS 325 Chemical manufacturing	5.51	14.51	1.85	1.96	16.07	11.2	0	-	3.03	40.94	-	-	3.75	0.88	0	-	0	0.53
NAICS 326 Plastics and rubber products manufacturing	0	0	0.67	0	-	0.24	-	0	0	0	-	-	-	0	-	-	-	0.44
NAICS 327 Nonmetallic mineral product manufacturing	0.46	-	0.69	0.46	0	0.68	0	-	0.95	-	-	-	1.83	0.49	0	-	-	0.7
NAICS 331 Primary metal manufacturing	0.42	0	0.47	0	0	0.19	-	-	0	0	-	-	0	0	-	-	0	0
NAICS 332 Fabricated metal product manufacturing	2.1	2.91	1.73	0.58	2.73	1.51	0.49	0	0.64	0	-	0.26	0.16	0.74	0	0	-	0.38
NAICS 333 Machinery manufacturing	1.69	0	2.15	0.31	0.3	0.63	-	0	1.36	0	-	-	0.69	0.26	0	-	-	0.5
NAICS 334 Computer and electronic product manufacturing	0	-	0.6	0.21	0	0.45	0	0	0	0	0	-	-	0.2	0	0	-	0.16

Region	1a		1b				2				3					4		
Industry	Jefferson	Orange	Harris	Galveston	Chambers	Brazoria	Matagorda	Jackson	Victoria	Calhoun	Refugio	Aransas	San Patricio	Nueces	Kleberg	Kenedy	Willacy	Cameron
NAICS 335 Electrical equipment and appliance manufacturing	0.17	0	0.78	0	-	1.06	-	0	-	-	-	-	-	0	-	-	-	1.18
NAICS 336 Transportation equipment manufacturing	0.39	1.88	0.15	0.1	-	0.11	0.3	-	0	0.59	-	0	0.52	0.1	0	-	-	0.89
NAICS 337 Furniture and related product manufacturing	0.34	0	0.35	0.16	-	0	-	-	0.18	-	-	-	0	0.05	-	-	-	0.14
NAICS 339 Miscellaneous manufacturing	0.25	0	0.58	0.16	-	0.08	-	-	0.21	-	-	-	-	0.44	0	-	0	0.07
NAICS 423 Merchant wholesalers, durable goods	1.03	1.3	1.67	0.49	1	0.82	0.26	0	1.56	0.4	0	0.6	0.37	0.96	0.08	-	0	0.6
NAICS 424 Merchant wholesalers, nondurable goods	0.84	0.21	1.22	0.64	0.47	0.6	0.52	1.01	1.4	0.19	1	0	0	0.85	0.03	-	0.27	0.5
NAICS 425 Electronic markets and agents and brokers	0.36	0.09	0.91	0.37	0	0.27	0	0	0.4	0.63	-	0	0	0.29	0	-	0	0.23
NAICS 441 Motor vehicle and parts dealers	1.19	1.18	1	1.3	0.59	1.11	0.89	0.59	1.78	1.47	0	1.74	1.51	1.15	1.73	-	0.74	1.29

Region	1a		1b				2				3					4		
Industry	Jefferson	Orange	Harris	Galveston	Chambers	Brazoria	Matagorda	Jackson	Victoria	Calhoun	Refugio	Aransas	San Patricio	Nueces	Kleberg	Kenedy	Willacy	Cameron
NAICS 442 Furniture and home furnishings stores	1.03	0.41	1.04	0.67	0.46	0.87	0.67	0	1.07	0	-	1.7	0	0.94	0	-	0	1.02
NAICS 443 Electronics and appliance stores	2.53	0.75	1.09	0.67	0	1.1	0.63	0	1.32	0	0	0	0	0.95	0.59	-	-	1.21
NAICS 444 Building material and garden supply stores	1.17	1.76	0.7	1.28	0.59	1.4	0.86	0.8	1.79	0.89	0	0.95	1.83	1.15	1.98	-	1	1.07
NAICS 445 Food and beverage stores	1.02	1.33	0.93	1.35	0.38	1.16	1.92	0	1.09	0.7	0	2	1.57	0.98	1.17	0	0	0.94
NAICS 446 Health and personal care stores	1.11	1.34	0.76	0.99	0.23	1.09	0.9	0	1.01	0.32	0	0.77	0.76	1.08	0.94	-	1.5	0.88
NAICS 447 Gasoline stations	1.21	2.76	0.74	1.21	1.66	1.81	1.63	5.72	2.08	1.05	7.63	2.71	2.07	1.36	2.11	-	3.26	1.62
NAICS 448 Clothing and clothing accessories stores	1.04	0.65	1.08	1.17	0.25	1.01	0.49	0.25	1.2	0	0	0.69	0.09	1.15	0.14	-	-	1.01
NAICS 451 Sports, hobby, music instrument, book stores	1.3	0.6	0.86	1.28	0	1.14	0	0	1.79	0.42	-	0	1.31	1.43	0.65	-	0	1.04
NAICS 452 General merchandise stores	0.98	2.05	0.76	1.41	1.24	1.58	1.73	0	1.63	1.13	0	2.24	1.57	1	1.64	-	0.5	1.46
NAICS 453 Miscellaneous store retailers	1.12	0.69	0.74	0.99	0.49	0.74	0.46	0	1.6	0	-	0.7	0.4	0.86	0.55	-	-	0.6

Region	1a		1b				2				3					4		
Industry	Jefferson	Orange	Harris	Galveston	Chambers	Brazoria	Matagorda	Jackson	Victoria	Calhoun	Refugio	Aransas	San Patricio	Nueces	Kleberg	Kenedy	Willacy	Cameron
NAICS 454 Nonstore retailers	0.36	0.17	0.24	0.36	0.49	0.55	0	0	0.41	0.11	0	0.79	0	0.19	0	-	0	0.55
NAICS 481 Air transportation	0.09		2.51	0.34	0	0	-	-	0	-	-	0	0	0.24	-	-	-	0.25
NAICS 482 Rail transportation	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAICS 483 Water transportation	1.44	0	3.46	3.92	-	1.81	0	-	-	0	-	0	9.83	0	-	-	-	-
NAICS 484 Truck transportation	0.6	0.52	0.94	0.21	2.49	0.87	0.25	0.48	1.51	0.27	0	-	0.61	0.7	0.12	-	0.33	0.99
NAICS 485 Transit and ground passenger transportation	0.55	0	0.41	0.37	-	0.14	-	0	0.53	0	0	-	0	0.47	0	-	0	0.11
NAICS 486 Pipeline transportation	9.36	5.55	13.16	0	83.51	3.75	31.54	16.08	23.95	-	0	-	2.65	8.33	0	-	-	0
NAICS 487 Scenic and sightseeing transportation	0	-	0	4.04	-	0	-	-	-	-	-	14.8	2.75	6.27	-	-	-	3.91
NAICS 488 Support activities for transportation	3.4	2.05	2.4	3.34	1.42	2.14	0.22	0	0.55	0.65	0	0	0	1.89	0.82	-	0	1.7
NAICS 491 Postal service	-	-	2.34	-	-	0	0	-	0	-	-	-	-	0	-	-	-	0
NAICS 492 Couriers and messengers	0.89	-	0.74	0	0	0.44	0	-	1.15	-	-	-	0	0.59	-	-	-	0.64
NAICS 493 Warehousing and storage	0.23	0.61	0.76	0.19	0	0.35	0	-	0.39	0	-	-	-	0.18	-	-	0	0.41

Region	1a		1b				2				3					4		
Industry	**Jefferson**	**Orange**	**Harris**	**Galveston**	**Chambers**	**Brazoria**	**Matagorda**	**Jackson**	**Victoria**	**Calhoun**	**Refugio**	**Aransas**	**San Patricio**	**Nueces**	**Kleberg**	**Kenedy**	**Willacy**	**Cameron**
NAICS 511 Publishing industries, except Internet	0.18	0	0.42	0.24	-	0.14	0	0	0	0.2	0	0.5	0	0.12	0	-	0	0.15
NAICS 512 Motion picture and sound recording industries	0	-	0.32	0.2	-	0.25	0	0	0	0	-	0	0	0.32	0	-	-	0.3
NAICS 515 Broadcasting, except Internet	0.96	0	0.62	0	-	0	0	-	1.23	0	-	-	0	0	-	-	-	0.25
NAICS02 516 Internet publishing and broadcasting	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAICS 517 Telecommunications	0.57	0.14	0.97	0.54	0	0.39	0.32	1.75	0.76	0.16	-	0.45	1.26	0.78	0	-	0	0.3
NAICS 518 Data processing, hosting and related services	0.04	0	0.46	0	-	0.03	0	-	0	0	-	0	-	0	-	-	0	0
NAICS 519 Other information services	0	0	0.16	0.18	0	0	0	-	0	-	-	0	0	0.21	-	-	-	0
NAICS 521 Monetary authorities - central bank	-	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NAICS 522 Credit intermediation and related activities	0.77	0.9	0.77	0.91	0.28	0.66	0.72	0.57	0.99	0.62	0.65	0.59	0.58	0.96	1.02	-	0.55	0.71

Region	1a		1b				2				3					4		
Industry	Jefferson	Orange	Harris	Galveston	Chambers	Brazoria	Matagorda	Jackson	Victoria	Calhoun	Refugio	Aransas	San Patricio	Nueces	Kleberg	Kenedy	Willacy	Cameron
NAICS 523 Securities, commodity contracts, investments	0	0.15	1.16	0	0.18	0	0.2	1.68	0	0.65	0	0	0	0	0	0	0	0
NAICS 524 Insurance carriers and related activities	0.4	0.37	0.68	1.3	0.11	0.28	0.18	0.19	0.31	0	0	0.84	0.24	0.45	0.16	-	0	0.47
NAICS 525 Funds, trusts, and other financial vehicles	0	-	0	0	-	0	-	-	0	0	-	0	0	0	0	-	-	0
NAICS 531 Real estate	0.82	0.44	1.34	0.9	0.16	0.75	0.38	0.61	0.53	0.17	0	1.64	0.63	0.87	0.49	-	0	0.66
NAICS 532 Rental and leasing services	0	0	1.86	0	2.31	1.62	2.34	-	2.33	1.4	0	0.48	0	2.46	0.76	-	0	0
NAICS 533 Lessors of nonfinancial intangible assets	0	0	1.1	0	-	0.3	-	-	-	-	-	-	0	-	-	-	-	0
NAICS 541 Professional and technical services	0.69	0.56	1.26	0.51	0.55	0.49	0	0	0.36	1	0.1	0.68	0.4	0.71	0	-	0	0.25
NAICS 551 Management of companies and enterprises	0.38	0.19	1.03	0.09	0.56	0.36	0	0	0.16	0	0	0	0.17	0.36	0	-	-	0.33
NAICS 561 Administrative and support services	0.67	0.3	1.23	0.58	0.41	0.61	0	0	0.48	0.7	0	0.54	0.38	0.68	0.48	0	0	1.12

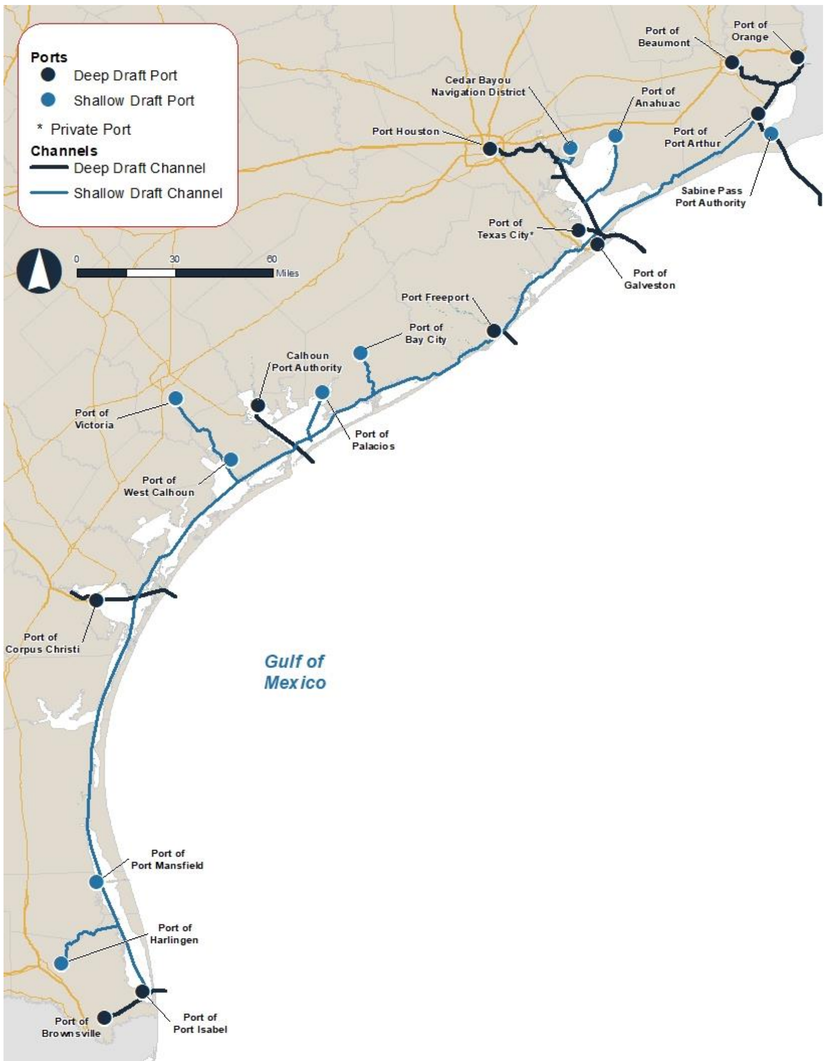
Region	1a		1b				2				3					4		
Industry	**Jefferson**	**Orange**	**Harris**	**Galveston**	**Chambers**	**Brazoria**	**Matagorda**	**Jackson**	**Victoria**	**Calhoun**	**Refugio**	**Aransas**	**San Patricio**	**Nueces**	**Kleberg**	**Kenedy**	**Willacy**	**Cameron**
NAICS 562 Waste management and remediation services	2.27	1	1.22	0.48	2.1	1.46	0	-	1.05	0	-	0	2.14	2.14	-	0	-	0.53
NAICS 611 Educational services	0.41	0.18	0.98	0.36	0.08	0.34	-	0	0.31	0.04	0	0	0.2	0.24	0	-	-	0.73
NAICS 621 Ambulatory health care services	1.38	0.63	1.03	0.72	0.28	1.14	1.01	0.14	1.18	0.23	0.11	0.77	0.53	1.93	1.44	0	1.32	2.59
NAICS 622 Hospitals	1.1	-	0.93	0.37	0	0.29	0	-	0.99	0	0	-	0	1.26	0	-	-	0.77
NAICS 623 Nursing and residential care facilities	0.75	0.65	0.41	0.77	0	0.64	0.9	1.25	1.75	0	1.98	1.14	0	0.8	0.67	-	0	1.75
NAICS 624 Social assistance	0.37	0.48	0.56	0.66	0.3	0.68	0	0	0.64	0.29	0.08	0	0.36	0.73	0.55	-	0	2.85
NAICS 711 Performing arts and spectator sports	0.16	0	0.81	0.48	0	0.74	0	-	0.3	0.13	-	-	0	0.38	0	-	0	0.05
NAICS 712 Museums, historical sites, zoos, and parks	0.65	0	1.05	5.86	0	0.23	0	-	1.07	-	-	2.29	-	2.05	-	-	-	1.19
NAICS 713 Amusements, gambling, and recreation	0.42	0.35	0.62	1.04	0	0.78	0.52	0.1	0.68	0.28	0	2	0	0.68	0	0	0	0.61
NAICS 721 Accommodation	0.65	0.82	0.71	1.53	0.55	0.57	1.56	0.62	0.91	1.31	0	4.14	1.52	1.22	0.56	0	0.7	1.03

Region	1a		1b				2				3					4		
Industry	**Jefferson**	**Orange**	**Harris**	**Galveston**	**Chambers**	**Brazoria**	**Matagorda**	**Jackson**	**Victoria**	**Calhoun**	**Refugio**	**Aransas**	**San Patricio**	**Nueces**	**Kleberg**	**Kenedy**	**Willacy**	**Cameron**
NAICS 722 Food services and drinking places	1.15	1.37	1.07	1.8	1.03	1.36	1.25	0.73	1.28	0.78	1.45	2.61	1.57	1.47	1.68	-	1.36	1.27
NAICS 811 Repair and maintenance	1.41	1.65	1.31	1.95	1.16	1.39	1.37	2.06	1.41	0.51	0	1.6	1.15	1.18	1.31	0	0	0.51
NAICS 812 Personal and laundry services	0.86	0.92	1.04	1.24	0.37	0.95	0.76	0.33	1.16	0.42	0	1.17	0.43	1.03	0.48	0	1.64	0.61
NAICS 813 Membership associations and organizations	0.43	0.11	0.46	0.51	0.07	0.44	0.45	0.26	0.7	0.51	0.36	0.73	0.27	0.56	0.33	-	0.4	0.7
NAICS 814 Private households	0.43	0.44	1.68	0.64	0.19	0.52	0.75	2	1.92	0.66	15.88	0.71	0.97	0.9	0.39	0	0	0.65
NAICS 999 Unclassified	0.11	0.23	0.38	0.46	0	0.38	0	0.35	0.23	1.21	0	1.87	0.27	0.18	0.09	0	0	0.19

-Highlighted cells indicate very high concentrations of employment
Source: Bureau of Labor Statistics, 2020

Texas Maritime Transportation System (MTS)

Access to water transport and to deep water opened the State to trade with the rest of the world. TxDOT Maritime Division promotes the development and intermodal connectivity of Texas ports, waterways and marine infrastructure and operations. Texas's MTS shown in **Figure 7-2**, consists of waterways, ports, and intermodal landside connectors. Together, the components of the MTS facilitate the movement of goods and people over water. In Texas, 11 commercial ports are served by channels with a draft of more than 30 ft (deep-draft ports). There are six other ports that handle commercial cargoes with channel depths less than a 30-foot draft (shallow-draft ports). The remaining shallow-draft ports are used for commercial fishing and recreational purposes and do not handle commercial cargoes. Texas's ports are connected by an extensive shallow-draft channel called the GIWW in Texas, an integral component of the state's vast petrochemical and manufacturing supply chains (TxDOT, 2021).



Source: TxDOT, 2022

Figure 7-2. Texas Maritime Transportation System

Texas ports play a critical role in the state's transportation system and are a key part of the state's economy.

- Texas Gulf Coast ports handle more than 607 million tons of foreign and domestic cargo each year — 27 percent of all U.S. port tonnage (USACE, 2020).

- Seven Texas ports rank in the top 50 of all U.S. ports in terms of annual 2020 tonnage: Houston (1st), Corpus Christi (3rd), Beaumont (8th), Port Arthur (15th), Port Freeport (16th), Texas City (20th), and Galveston (46th); (USACE, 2021).
- The tons of cargo moving via Texas ports generate 128,848 jobs directly related to marine cargo activities (Texas Ports Association, 2019).
- Texas ports generate over $449.6 billion in economic activity and $7.8 billion in state and local taxes per year (Texas Ports Association, 2019).
- Texas port activities represent approximately 25% of the total State GDP (Texas Ports Association, 2019).
- The use of Texas waterways is forecasted to continue to increase — fueled by the expansion of the Panama Canal, the surge in the state's population, and increasing worldwide waterborne trade.

Table 7-9 displays select ports within Texas listed by tonnage moved. The Port of Houston (Region 1b) is the first in the nation in terms of port activity. In terms of tonnage, around 40% of all the United States' foreign trade moves through Texas ports.

Table 7-10 presents commodity movements along the State's waterways based upon tonnage. Crude petroleum and petroleum products make up over 80 percent of all commodity movements on Texas waterways as of 2020. Crude petroleum and petroleum products comprise 68 percent of commodities destined for Texas ports. Petroleum products and chemicals comprise three-fourths of the tonnage shipped from Texas ports. Waterway traffic within the State is dominated by crude petroleum and petroleum products, making up over three-quarters of all commodities moved within the State's waterway system. Importing goods into Texas ports is critical to the state's economy and provides the necessary inputs for value-added manufacturing activities that generate wealth for the state.

Table 7-11 presents the value of commodities moved through Texas ports. Texas ports moved $101 billion of imports and $207 billion in exports in 2021. This volume makes up nearly 8 percent of the value of our nation's imports and over 33 percent of our nation's exports. The Port of Houston ranks first in the nation in value of exports and fifth in the nation in value of imports. China is the top trading partner for imports, based upon a variety of different import commodities. The value of crude oil imports is the largest for a single commodity.

Table 7-9. 2020 Commodity Tonnage Moved at Select Ports in Texas

Port Name	Total	Domestic	Foreign	Imports	Exports
	Tonnage in 1,000s of Short Tons				
Houston, TX	275,940,289	79,177,826	196,762,463	56,970,738	139,791,725
Beaumont, TX	70,567,386	24,785,761	45,781,625	16,170,960	29,610,665
Corpus Christi, TX	150,755,485	25,056,307	125,699,178	17,606,086	108,093,092
Texas City, TX	33,721,312	12,540,971	21,180,341	7,601,309	13,579,032
Port Arthur, TX	41,222,200	17,297,108	23,925,092	7,316,835	16,608,257
Freeport, TX	38,748,662	4,171,925	34,576,737	6,560,377	28,016,360
Matagorda, Port Lavaca, Point Comfort, TX	4,279	2,554	1,726	506	1,220
Galveston, TX	11,945,182	5,242,679	6,702,503	1,525,032	5,177,471
Brownsville, TX	6,781,993	2,777,097	4,004,896	3,696,342	308,554
Victoria, TX	2,032,848	2,032,848	-	-	-
Total Tonnage, Texas Ports	*607,805,000*	*46,801,000*	*346,068,000*	*26,099,000*	*118,158,000*
All Tonnage, All U.S. Ports	*2,226,442,000*	*492,230,000*	*845,511,000*	*492,230,000*	*637,601,000*
Texas Tonnage as Percent of U.S.	*27%*	*10%*	*41%*	*5%*	*19%*

Source: USACE, 2020

Table 7-10. Commodity Movements to and from Texas on Texas Waterways, 2020

Commodity	Origin Shipping		Destination Receiving		Intrastate		Total	
	Short Tons (1000s)	Percent	Short Tons (1000s)	Percent	Short Tons (1000s)	Percent	Short Tons (1000s)	Percent
Chemical Fertilizers	287.2	0.0%	1,395.8	0.7%	30.2	0.1%	1,713.2	0%
Chemicals and Related Products	73,977.6	10.1%	9,838.6	4.6%	6,584.2	22.1%	90,400.4	9%
Coal, Lignite & Coal Coke	317.1	0.0%	10.7	0.0%	-	0.0%	327.8	0%
Crude Materials, Inedible Except Fuels	1,674.0	0.2%	3,249.6	1.5%	-	0.0%	4,923.6	1%
Crude Petroleum	281,107.4	38.3%	103,654.8	48.3%	1,998.7	6.7%	386,760.9	40%
Food and Farm Products	30,031.3	4.1%	4,688.8	2.2%	119.3	0.4%	34,839.4	4%
Iron Ore, Iron, and Steel Waste and Scrap	817.9	0.1%	4,570.9	2.1%	.9	0.0%	5,389.6	1%
Lumber, Logs, Wood Chips, and Pulp	1,266.6	0.2%	809.4	0.4%	4.8	0.0%	2,080.8	0%
Manufactured Goods	18,369.9	0	21,210.2	0	4.7	0	39,584.8	0
Non-Ferrous Ores and Scrap	565.0	0.1%	511.8	0.2%	-	0.0%	1,076.8	0%
Petroleum and Petroleum Products	321,528.1	44%	43,384.6	20.2%	20,896.2	70.2%	385,809.0	39%
Primary Metal Products	2,963.0	0.4%	11,164.6	5.2%	1.0	0.0%	14,128.7	1%
Sand, Gravel, Shells, Clay, Salt, and Slag	730.6	0.1%	9,829.2	4.6%	-	0.0%	10,559.7	1%
Unknown or Not Elsewhere Classified	389.7	0.1%	202.1	0.1%	-	0.0%	591.7	0%
Grand Total	734,025.5	100.0%	214,520.9	100.0%	29,745.8	100.0%	978,292.2	100%
Overseas in 1,000s	710,499.0	96%	207,381.2	96%				

Source: USACE, 2020

Table 7-11. Value of Commodity Imports and Exports, Port Rank, Trade Countries, and Top Trade Commodities, 2021

	Total Vessel Value (in billions)		US Port Rank by Value		Top Trade Countries		Top Trade Commodities	
Port Name	**Imports**	**Exports**	**Imports**	**Exports**	**Imports**	**Exports**	**Imports**	**Exports**
Houston, TX	$ 74.9	$ 94.7	5	1	China	Mexico	Crude Oil from Petroleum and Bituminous Materials	Crude Oil from Petroleum and Bituminous Materials
Beaumont, TX	$ 1.1	$ 16.1	57	12	Mexico	India	Crude Oil from Petroleum and Bituminous Materials	Crude Oil from Petroleum and Bituminous Materials
Corpus Christi, TX	$ 5.2	$ 51.5	29	2	Russia	Korea, South	Crude Oil from Petroleum and Bituminous Materials	Crude Oil from Petroleum and Bituminous Materials
Texas City, TX	$ 3.3	$ 4.5	38	33	Mexico	Mexico	Crude Oil from Petroleum and Bituminous Materials	Crude Oil from Petroleum and Bituminous Materials
Port Arthur, TX	$ 8.6	$ 11.3	22	16	Saudi Arabia	Canada	Crude Oil from Petroleum and Bituminous Materials	Crude Oil from Petroleum and Bituminous Materials
Freeport, TX	$ 3.3	$ 15.7	39	13	Mexico	China	Crude Oil from Petroleum and Bituminous Materials	Crude Oil from Petroleum and Bituminous Materials
Port Lavaca, TX	$ 0.3	$ 1.2	75	51	Trinidad and Tobago	Korea, South	Inorganic Chemicals; Compounds of Precious metals; Rare Earth Metals; etc.	Organic Chemicals
Sabine, TX	$ 0.0	$ 9.1	124	21	Canada	Korea, South	Salt, Sulphur; Earths & Stone; Plastering Materials	Crude Oil from Petroleum and Bituminous Materials
Galveston, TX	$ 4.0	$ 2.5	34	41	Germany	Brazil	Machinery and Mechanical appliances; Boilers; etc.	Crude Oil from Petroleum and Bituminous Materials
Brownsville, TX	$ 0.6	$ 0.4	68	65	South Africa	Bahamas	Aluminum and articles	Crude Oil from Petroleum and Bituminous Materials
Orange, TX	$ 0.0	$ 0.0	161	148	Germany	India	Electrical Machinery & Equipment and parts; Sound Recorders and Reproducers; etc.	Soap; Organic Surface-active agents; Prepared Waxes; Polishes; etc.
Total Value, Texas Ports	$ 101.3	$ 207.0						
All Value, All U.S. Ports	$ 1,252.2	$ 635.1			China	China	Machinery and Mechanical appliances; Boilers; etc.	Crude Oil from Petroleum and Bituminous Materials
Texas Tonnage Value as Percent of U.S.	8%	33%						

GIWW in Texas

The GIWW is the portion of the Intracoastal Waterway located along the Gulf Coast of the United States. It is a navigable inland waterway running approximately 1,050 mi (1,690 km) from Carrabelle, Florida, to Brownsville, Texas. In Texas, the GIWW is 406 miles long. The waterway provides a channel with a controlling depth of 12 ft, designed primarily for barge transportation. One of the initial functions of the GIWW was to provide protected inland transportation of goods and troops during World War II. It has since evolved into a multipurpose waterway used by recreational and commercial interests. Recreational uses include fishing, skiing, sightseeing and traveling protected water transportation routes along the coast. Commercial uses include the movement of domestic and international cargo, harvesting fish and shellfish, and servicing the Gulf and coastal oil and gas industry.

The GIWW is used to link Texas ports together which increases the efficiency of deep draft transportation. It further links Texas to the U.S. inland navigation system. The GIWW is used to transport large quantities of liquid bulk, including crude oil, petroleum products, and chemicals between Texas ports and to ports throughout the South and Midwest. The GIWW is the nation's third busiest inland waterway, with the Texas portion handling two-thirds of its traffic (TxDOT, 2013).

Motorized towboats push one or more non-motorized barges along the waterway and comprise a barge fleet or tow. The tow moves along the waterway passing under bridges and through locks and floodgates to their destination. Because the bottom of the GIWW is soft sand and silt, very few groundings occur. A barge fleet can carry the equivalent of 16 railcars or 70 trucks and has the least environmental impact per ton and transports commodities with the greatest safety and least hazard to the general public. Efficient use of the GIWW alleviates highway congestion in coastal Texas and rail bottlenecks in metropolitan Houston. The Texas GIWW Master Plan developed several infographics to display these environmental and safety advantages.

Table 7-12, **Figure 7-3**, and **Figure 7-4** display the efficiencies of GIWW transportation in Texas as determined by this Master Plan (Kruse et al., 2014).

Figure 7-3. Ton-Miles Traveled per Gallon of Fuel

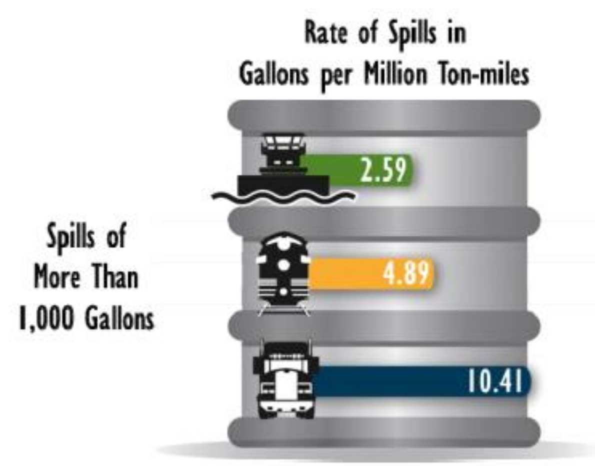


Figure 7-4. Rate of Spills in Gallons per Million Ton-Miles

Table 7-12. Summary of Emissions (Grams per Ton-Mile), 2019

Mode	Emission (grams/ton-mile)				
	Hydrocarbons or Volatile Organic Compounds (VOC) for Truck	Nitrogen Oxides (NOx)	Particle Matter (PM-10)	Carbon Monoxide (CO)	Carbon Dioxide (CO_2)
Truck	0.0221	0.4487	0.0191	0.1898	140.7023
Railroad	0.0083	0.2182	0.0053	0.0564	21.5678
Inland Towing	0.0058	0.1526	0.0037	0.0394	15.0815

Source: Center for Ports and Waterways, Texas A&M Transportation Institute, January 2022

The GIWW is also used to efficiently transport oversize equipment to industrial facilities. Large components are typically transported by barge to industrial facilities such as refineries, chemical plants, mineral processors, and paper mills, and then wheeled the final short distance to their permanent location. These components, whether imported by ship from overseas, or fabricated domestically, would need to be disassembled for transport by rail or truck, if possible. This ability to transport equipment by barge is one reason most industrial facilities are located adjacent to waterways. Within Texas, many petrochemical facilities were constructed and continue to be upgraded with equipment transported by barge.

Offshore petroleum exploration and production is facilitated by the GIWW, as major components of offshore structures are transported by barge to fabrication facilities in Brownsville, Ingleside, and Galveston. These fabrication facilities compete worldwide, largely with fabrication facilities in East Asia and Europe, and employ thousands of Texans in shipyards. As such, an increase in the transportation cost from switching transportation modes could impact the economic viability of these facilities. As an example, the Keppel-Amfels shipyard at the Port of Brownsville has fabricated jack-up rigs for Gulf of Mexico offshore petroleum exploration with large components shipped by barge from Vicksburg to Brownsville.

The GIWW provides more versatility for shipping liquid bulk than pipelines. Barges can be efficiently cleaned to transport most liquid bulk commodities, including petrochemicals, in quantities of 1 million gallons. Although pipelines can transport multiple types of liquid bulk, switching between different commodities is more complicated and much larger quantities are needed to justify shipping a particular chemical by pipeline.

Table 7-13 presents tonnage movements on the GIWW in Texas in 2020. Most of this cargo moves on the segment from the Sabine River to Galveston Bay and most of the cargo on the GIWW is petroleum and chemical-related products.

The National Waterways Foundation funded the study, “Inland Navigation of the United States, An Evaluation of Economics Impacts and the Potential Effects of Infrastructure Investment,” prepared by the University of Kentucky and the University of Tennessee, November 2014. This study investigated the regional and national impacts of losing the inland navigation system using the Regional Economic Models, Inc. proprietary software. The segment of the nation that was predicted to be impacted most significantly was the GIWW system. Moving the chemical petroleum products that tend to dominate industrial production within this region is relatively expensive compared with other industries. Also, the availability of alternative transportation of any kind is very limited for many chemical producers and refiners, as many may not have sufficient rail or truck loading facilities to compensate for a loss of barge transportation. Most coastal refineries have traditionally been supplied by imported crude petroleum and for this reason are not supplied by pipeline nor do they have rail service. Therefore, many chemical facilities rely primarily upon the GIWW to ship inputs and outputs. And finally, the vitality of the overall regional economy is very closely tied to these industries. Therefore, the strength of the State’s petroleum and petrochemical refining economy is closely aligned to the availability of water-based transportation efficiencies provided by the GIWW in Texas.

Table 7-14 presents businesses, employment and income from the marine transportation industry within the 18-coastal counties. Within the State, over $1 billion in wages is earned by 15,429 workers in the industry per year. Region 1b dominates the industry with 82 percent of the employment and 83 percent of the wages earned from marine transportation.

Table 7-13. Tonnage Moved on the GIWW, Texas Segments, 2020

	Inbound Receiving		Outbound Shipping		Local		Through		Grand Total
TX GIWW Segment	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound	Upbound	Downbound	
Sabine River to Galveston	2,713	3,371	974	2,595	67	23	23,045	27,062	59,849
Galveston to Corpus Christi	174	161	371	9	1	-	13,515	8,317	22,548
Corpus Christi to Mexican border	-	1	-	-	-	-	404	3,407	3,812
Total	2,887	3,533	1,345	2,604	68	23	36,963	38,787	86,210

In 1,000 Tons; Upbound: north or east; Downbound: south or west
Source: USACE, 2022

Table 7-14. Marine Transportation Industries, Annual Average Employment, Business Establishments, and Wages in Coastal Counties, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	43	667	$39,452	$59.1
1a	Orange	9	4	$1,354	$338.5
All 1a		52	671	$40,806	$60.8
1b	Harris	209	10,480	$763,020	$72.8
1b	Galveston	45	16,08	$89,069	$55.4
1b	Chambers	2	D	D	D
1b	Brazoria	18	541	$15,703	$29.0
All 1b		274	12,629	$867,792	$68.7
2	Matagorda	3	D	D	D
2	Jackson	1	D	D	D
2	Victoria	N/A	N/A	N/A	N/A
2	Calhoun	5	35	$2,470	$70.6
All 2		9	35	$2,470	$70.6
3	Refugio	N/A	N/A	N/A	N/A
3	Aransas	2	D	D	D
3	San Patricio	6	D	D	D
3	Nueces	32	510	$32,698	$64.1
3	Kleberg	N/A	N/A	N/A	N/A
All 3		40	510	$32,698	$64.1
4	Kenedy	N/A	N/A	N/A	N/A
4	Willacy	1	D	D	D
4	Cameron	N/A	N/A	N/A	N/A
All 4		1			
Coastal Counties		376	13,845	$582,532	$68.2
Coastal Counties % of State		76%	90%	56%	
Texas Statewide		494	15,429	$1,042,108	$67.5

*NAICS codes: 4831, 4832, 4883.
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Economic Impact of the US Military in Texas

Texas is home to 15 active-duty military installations and ranks second only to California in number of active duty and reserve members of the military with over 165,000 personnel as of September 2020. Another 47,600 civilians work for the military in Texas. In total, over 213,000 U.S. military personnel across all branches of service are stationed in Texas as shown in **Table 7-15** (“Military Active-Duty Personnel,” 2020).

Table 7-15. Active Military Personnel in Texas, September 2020

Branch of Service	Active Duty	Reserves	Government Civilians	Total
Army	72,947	18,333	24,900	116,180
Navy	5,903	5,723	1,435	13,061
Marine Corps	2,252	3,445	30	5,727
Air Force	34,472	9	16,850	51,331
Coast Guard	-	334	-	334
Air National Guard	-	3,390	-	3,390
Army Guard	-	18,617	-	18,617
Defense Dept.	-	-	4,379	4,379
Total	**115,574**	**49,851**	**47,594**	**213,019**

Source: Defense Manpower Data Center: Active Duty Master Personnel File, Reserve Components Common Personnel Data System and U.S. Office of Personnel Management

In 2019, the Texas Comptroller of Public Accounts estimated the contribution of U.S. Department of Defense installations to the Texas's economy as shown in **Table 7-16**. In total over 600,000 persons are employed in military installation earning nearly $40 billion in personal income. The U.S. military presence in Texas generates $123.6 billion in economic output to the State and contributes $75.3 billion to the State's GDP.

Table 7-16. Economic Impact of Military Installations in Texas and in Texas's Coastal Regions, 2019

	Statewide Total	Coastal Region 1	Coastal Region 3
Total Employment	633,892	2,323	20,364
Output to the Texas Economy (in Billions)	$123.6	$0.47	$5.43
GDP (in Billions)	$75.3	$0.29	$2.85
Disposal Personal Income (in Billions)	$39.20	$0.14	$1.90

Source: Texas Comptroller of Public Accounts, 2019

Four Department of Defense installations are located within Texas's coastal counties:

1. EF JRB in Harris County (Region 1);

Ellington Airport is a joint use civil and military airport that supports multiple tenants including the Texas Air and Army National Guard, hence the name EF JRB. EF JRB is notable for having troop presences from all five of the U.S. Armed Forces: Army, Navy, Marines, Air Force and Coast Guard. The major units at EF JRB are tasked with reconnaissance and Air Sovereignty alert missions and with providing support for natural disasters among many other missions supporting Texas. The 147th Reconnaissance Wing is under the Texas Air National Guard. Additional units at EF JRB include the United States Coast Guard Houston, Naval Operations Support Center Houston and the 1st Battalion, 23rd Marines.

Personnel: 753

2. NAS, Kingsville, in Kleberg County (Region 3);

The primary mission of NAS Kingsville is to provide facilities and support for Training Air Wing Two in training undergraduate jet/strike pilots for the U.S. Navy and U.S. Marine Corps. NAS Kingsville trains 50% of the Navy and Marine Corps' jet/strike pilots each year.

Personnel: 1,647

3. NAS, Corpus Christi, in Nueces County (Region 3);

NAS Corpus Christi is primarily focused on pilot training. Training Air Wing Four is comprised of four individual units: two primary training squadrons and two squadrons that provide advanced multi-engine training to Navy, Marine, Coast Guard and foreign pilots. Training Air Wing Four provides over 600 new, highly qualified aviators every year. The Chief of Naval Air Training is headquartered at NAS Corpus Christi and oversees all aviation training for the U.S. Navy.

Personnel: 4,782

4. Corpus Christi Army Depot in Nueces County (Region 3).

Corpus Christi Army Depot is the industry leader in repair and overhaul for helicopters, engines, and components for Army aviation assets. Corpus Christi Army Depot is the largest rotary wing repair facility in the world and supports multiple government agencies in addition to the Department of Defense.

Personnel: 3,658

The economic contribution of these installations is displayed by region and is included in the statewide total in **Table 7-16**. Within Texas's coastal counties, the U.S. military presence employs over 20,000 persons generating $2 billion in personal income. The economic contribution of these facilities to the state is $5.9 billion and the contribution to the state's GDP is estimated at $3.1 billion (Texas Comptroller of Public Accounts, 2019).

The Coast Guard is ubiquitous along the Texas Gulf Coast with more than 2,000 personnel stationed at operational facilities from Port Arthur to South Padre Island. The Coast Guard is both a federal law enforcement agency and a military force. In times of peace, the Coast Guard operates as part of the Department of Homeland Security enforcing the nation's laws at sea, protecting the marine environment, guarding the nation's coastline and ports, and performing vital lifesaving missions. In times of war, or at the direction of the President, the Coast Guard serves as part of the Navy Department, defending the nation against terrorism and foreign threats (U.S. Coast Guard, 2017; Smith 2016).

Coastal Commerce

Access to low-cost water transportation and access to open bay and Gulf waters support economic diversity and prosperity along the Texas coast. Activities that rely upon coastal features, resources, and amenities include waterborne commerce, commercial and recreational fishing, tourism including ecotourism, petroleum exploration and refining, and petroleum and chemical product manufacturing.

Ocean Economy

The National Ocean Economics Program (NOEP) and NOAA, Economics: National Ocean Watch, have designated major industrial sectors as "Ocean" sectors, signifying that those industries are completely dependent upon their proximity to water and shoreline amenities and resources (Colgan, 2007). These sectors are ship building and marine passenger and freight transportation. The NOEP also identified other industrial sectors that are not solely dependent upon their near shore location but, because of their proximity to water and near shore amenities, are included in the Ocean economy. These include marine construction, tourism and recreation, offshore minerals, and living resources sectors. The "Ocean" industrial sectors developed by NOEP and NOAA are listed in **Table 7-17** with their associated industries.

Table 7-17. Industrial Sectors in the Ocean Economy

Sector	Industry	Sector	Industry
Living Resources	Fish Hatcheries and Aquaculture	**Ship and Boat Building**	Boat Building and Repair
	Fishing		Ship Building and Repair
	Seafood Processing	**Tourism and Recreation**	-
	Seafood Markets		Boat Dealers
Marine Construction	Marine Related Construction		Eating and Drinking Places
Marine Transportation	Deep Sea Freight		Hotels and Lodging
	Marine Passenger Transportation		Marinas
	Marine Transportation Services		RV Parks and Campsites
	Search and Navigation Equipment		Scenic Water Tours
	Warehousing ^1		Sporting Goods
Mineral Resources	Limestone, Sand, and Gravel		Amusement and Recreation Services
	Oil and Gas Exploration and Production		Zoos and Aquaria

^1 Location specific; Source: Colgan, 2007

Building upon the work of NOEP and NOAA, Ocean Economy sectors were modified to better reflect the economic contributions of additional industrial sectors that derive benefit from proximity to the amenities and opportunities found along the Texas coast. Inland navigation was included because of the presence of the GIWW. Also, because the energy industry is so active in Texas and especially along the coast, these industrial sectors were included as Ocean sectors.

Table 7-18 displays the sector, industry, and associated NAICS codes of Texas's ocean economy. **Table 7-19** presents the contribution of different industries to the coastal economy. The petroleum industry in Harris County provides a large employment base with high wages that significantly increase the average annual wage per employee for the Texas Coastal Region.

Table 7-18. Texas Ocean Economy Industrial Sectors

Sector	Industry	NAICS Sector
Living Resources	Fish Hatcheries and Aquaculture	1125
	Fishing	1141
	Seafood Processing	311710
	Seafood Markets	445220
Marine Construction	Marine Related Construction	237990
Marine Transportation	Deep Sea and Coastal Transportation	4831
	Inland Water Transportation	4832
	Support Activities for Water Transport	4883
Ship and Boat Building	Ship Building and Repair	336611
	Boat Building and Repair	336612
Leisure and Hospitality	Arts, Entertainment, and Recreation	71
	Accommodations and Food Services	72
Mineral Exploration and Extraction	Crude Petroleum Extraction	211111

Sector	Industry	NAICS Sector
	Natural Gas Liquid Extraction	211112
	Construction Sand and Gravel Mining	212321
	Industrial Sand Mining	212322
	Drilling Oil and Gas Wells	213111
	Support Activities for Oil and Gas Operations	213112
	Geophysical Surveying and Mapping Services	541360
Petroleum Refining and Chemical Manufacturing	Petroleum and Coal Products Manufacturing	3241
	Chemical Manufacturing	325
	Plastics and Rubber Products Manufacturing	326
Oil and Gas Pipeline Construction	Oil and Gas Pipeline and Related Structures Construction	237120
Pipeline Transportation	Pipeline Transportation	486

Table 7-19. Ocean Economy - Annual Average Employment, Business Establishments, and Wages in Texas Coastal Counties, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	751	23,773	$1,828,554	$76.9
1a	Orange	209	5,107	$383,778	$75.1
All 1a		960	28,880	$2,212,332	$76.6
1b	Harris	13,193	300,213	$18,012,745	$60.0
1b	Galveston	1,007	21,532	$783,495	$36.4
1b	Chambers	175	5,458	$478,456	$87.7
1b	Brazoria	916	26,761	$1,886,276	$70.5
All 1b		15,291	353,964	$21,160,972	$59.8
2	Matagorda	167	1,262	$33,514	$26.6
.42	Jackson	68	600	$25,602	$42.7
2	Victoria	334	4,821	$177,145	$36.7
2	Calhoun	131	4,058	$388,410	$95.7
All 2		700	10,741	$624,671	$58.2
3	Refugio	39	D	D	D
3	Aransas	130	1,360	$29,879	$22.0
3	San Patricio	214	3,288	$129,480	$39.4
3	Nueces	1,244	25,963	$1,183,751	$45.6
3	Kleberg	98	1,428	$23,131	$16.2
All 3		1,725	32,039	$1,366,241	$42.6
4	Kenedy	6	D	D	D
4	Willacy	37	383	$5,225	$13.6
4	Cameron	903	15,361	$352,867	$23.0
All 4		946	15,744	$358,092	$22.8
Coastal Counties		19,622	441,368	$25,722,308	$58.3
Coastal Counties % of State		25%	28%	40%	
Texas Statewide		79,413	1,550,591	$64,446,656	$41.6

*The data shown in this table is for the NAICS codes listed in Table 7-18

The Energy Industry

When looking at the driving factors that comprise the Texas economy, the energy industry is the major contributor to State wealth and activity. Industrial sectors based in energy include not only resource exploration and recovery; but also, transportation of materials; product manufacturing; and construction of pipelines, refineries, ships, offshore platforms and barges.

Mineral Resources Extraction

Mineral resource extraction industries include those listed in **Table 7-20**. **Table 7-18** of the industrial sectors in the Ocean Economy: limestone, sand, and gravel mining and oil and gas exploration and production. The oil and gas extraction industry in Texas accounts for 54 percent of the nation's value added for that industrial sector. Support activities for mining in Texas accounts for 42 percent of the nation's value added from that sector.

Table 7-20 presents these industries as they are represented on the Texas Gulf coast. Texas's coastal counties account for 20 percent of the businesses, 25 percent of the employment, and 10 percent of the wages for the mineral extraction industries in Texas as a whole.

Table 7-20. Mineral Resource Extraction - Annual Average Employment, Business Establishments, and Wages, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	18	273	$22,522	$82.5
1a	Orange	4	D	D	D
All 1a		22	273	$22,522	$82.5
1b	Harris	888	26,659	$3,892,425	$146.0
1b	Galveston	36	695	$55,730	$80.2
1b	Chambers	16	D	D	D
1b	Brazoria	75	D	D	D
All 1b		1,015	27,354	$3,948,155	$144.3
2	Matagorda	7	D	D	D
2	Jackson	20	D	D	D
2	Victoria	65	D	D	D
2	Calhoun	2	D	D	D
All 2		94	D	D	D
3	Refugio	13	D	D	D
3	Aransas	7	D	D	D
3	San Patricio	25	233	$16,460	$70.7
3	Nueces	122	1,617	$148,226	$91.7
3	Kleberg	9	D	D	D
All 3		176	1,850	$164,686	$89.0
4	Kenedy	2	D	D	D
4	Willacy	1	D	D	D
4	Cameron	9	30	$1,273	$42.4
All 4		12	30	$1,273	$42.4
Coastal Counties		1,319	29,507	$1,218,824	$41.3
Coastal Counties % of State		20%	25%	10%	
Texas Statewide		6,629	120,393	$12,213,724	$101.4

*NAICS codes: 212321, 212322, 211111, 211112, 213111,213112, and 541360.
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Petroleum Refining, Petrochemical, Chemical, and Plastics Manufacturing

While the petroleum refining and petrochemical manufacturing industries are not directly linked to the Ocean economy as defined by the NOEP (2007), the nation's concentration of these industries is near or on the coast. Texas's petrochemical facilities are clustered near deep water harbors at the Sabine/Neches River, the Houston Galveston Bay Region, Freeport, and the Corpus Christi Bay and at the shallow-draft Victoria Channel. The proximity to open water for deep-draft shipping and low-cost water transportation along the coast and the GIWW supports these industries in Texas. Historically, the bulk of petroleum needed for national consumption has been imported from foreign sources. With foreign imports, coastal ports were the more efficient location for development of refining and manufacturing facilities of crude petroleum. Also, offshore oil and natural gas exploration and recovery has been supported by the proximity of refining facilities proximate to the shore.

Petroleum product, chemical, and plastics manufacturing supports a strong economy on the Texas coast. **Table 7-21** provides establishments, employment and wages for the following industrial sectors: petroleum and coal products (including petroleum refineries); chemical manufacturing (including petrochemicals); and plastics and rubber manufacturing. Coastal counties account for 33 percent of the businesses and 47 percent of the employment in these high-paying industrial sectors in Texas.

Table 7-21. Petroleum Product, Chemical, and Plastics Manufacturing - Annual Average Employment, Business Establishments, and Wages, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	70	8,610	$1,212,737	$140.9
1a	Orange	14	1,903	$264,205	$138.8
All 1a		84	10,513	$1,476,942	$140.5
1b	Harris	707	37,650	$4,734,525	$125.8
1b	Galveston	32	1,263	$186,819	$147.9
1b	Chambers	11	1,649	$228,043	$138.3
1b	Brazoria	63	7,682	$1,065,869	$138.7
All 1b		813	48,244	$6,215,256	$128.8
2	Matagorda	4	D	D	D
2	Jackson	3	D	D	D
2	Victoria	12	721	$76,772	$106.5
2	Calhoun	13	3,113	$368,916	$118.5
All 2		32	3,834	$445,688	$116.2
3	Refugio	1	D	D	D
3	Aransas	1	D	D	D
3	San Patricio	10	422	$58,316	$138.2
3	Nueces	31	3,298	$427,676	$129.7
3	Kleberg	1	D	D	D
All 3		44	3,720	$485,992	$130.6
4	Kenedy	N/A	N/A	N/A	N/A
4	Willacy	1	D	D	D

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
4	Cameron	19	745	$76,865	$103.2
All 4		20	745	$76,865	$103.2
Coastal Counties		993	67,056	$8,700,743	$129.8
Coastal Counties % of State		33%	47%	58%	
Texas Statewide		2988	143,871	$14,903,011	$103.6

*NAICS codes: 3241, 325, and 326
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Oil and Gas Pipeline Construction (NAICS 237120)

The oil and gas industries in Texas are evident in a variety of industrial sectors. Oil and gas pipeline construction includes construction of oil refineries and petrochemical plants, construction of storage tanks for oil and natural gas and construction of gathering and distribution pipelines. As **Table 7-22** shows, about 52 percent of the State's employment in this sector is located in coastal counties.

Table 7-22. Oil and Gas Pipeline Construction - Annual Average Employment, Business Establishments, and Wages, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	15	2,916	$278,640	$95.6
1a	Orange	6	762	$62,882	$82.5
All 1a		21	3,678	$341,522	$92.9
1b	Harris	137	10,808	$1,082,228	$100.1
1b	Galveston	8	713	$74,182	$104.0
1b	Chambers	14	1,830	$169,743	$92.8
1b	Brazoria	26	5,902	$533,071	$90.3
All 1b		185	19,253	$1,859,224	$96.6
2	Matagorda	2	D	D	D
2	Jackson	4	235	$14,683	$62.5
2	Victoria	2	D	D	D
2	Calhoun	5	D	D	D
All 2		13	235	$14,683	$62.5
3	Refugio	2	D	D	D
3	Aransas	1	D	D	D
3	San Patricio	7	200	$8,931	$44.7
3	Nueces	14	1,100	$132,955	$120.9
3	Kleberg	1	D	D	D
All 3		25	1,300	$141,886	$109.1
4	Kenedy	N/A	N/A	N/A	N/A
4	Willacy	N/A	N/A	N/A	N/A

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
4	Cameron	2	D	D	D
All 4		2	D	D	D
Coastal Counties		246	24,466	$2,357,315	$96.4
Coastal Counties % of State		34%	52%	57%	
Texas Statewide		720	47,284	$4,120,138	$87.1

*NAICS code 237120
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Pipeline Transportation

Transportation of petroleum, natural gas, and products by pipeline supports the energy and manufacturing industries and contributes to the coastal economy. **Table 7-23** shows that two-thirds of the employment in this support service is located along the Texas coast where products are moved to and from ports and manufacturing plants.

Table 7-23. Pipeline Transportation Industry - Annual Average Employment, Business Establishments, and Wages, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	16	390	$41,659	$106.8
1a	Orange	3	44	$7,480	$107.3
All 1a		19	434	$49,139	$113.2
1b	Harris	142	10,728	$1,983,861	$184.9
1b	Galveston	2	D	D	D
1b	Chambers	16	518	$53,940	$104.1
1b	Brazoria	13	153	$17,497	$114.4
All 1b		173	11,399	$2,055,298	$180.3
2	Matagorda	9	118	$12,265	$103.9
2	Jackson	7	34	$5,881	$170.9
2	Victoria	13	314	$29,902	$95.2
2	Calhoun	N/A	N/A	N/A	N/A
All 2		29	466	$48,048	$103.1
3	Refugio	2	D	D	D
3	Aransas	D	D	D	D
3	San Patricio	3	18	$3,464	$188.9
3	Nueces	20	465	$54,034	$116.1
3	Kleberg	1	D	D	D
All 3		26	483	$57,498	$119.0
4	Kenedy	N/A	N/A	N/A	N/A
4	Willacy	N/A	N/A	N/A	N/A
4	Cameron	1	D	D	D

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
All 4		1	D	D	D
Coastal Counties		248	12,782	$2,209,983	$172.9
Coastal Counties % of State		33%	67%	72%	
Texas Statewide		759	18,991	$3,049,705	$160.6

*NAICS code 486
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Ship Building and Repairs

As part of the Ocean Economy, the ship building, parts, and repairs industries support offshore mineral exploration and extraction activities as well as commercial fishing and waterborne transportation along the GIWW and the open waters of the Gulf. Construction and repair of barges, ships, commercial fishing boats, towboats and offshore oil and gas floating platforms are integral enterprises of the Texas coastal economy and are part of this industrial sector. **Table 7-24** shows the contribution of ship building and repairs to the economy of the Texas coast.

Table 7-24. Ship and Boat Building Industry - Annual Average Employment, Business Establishments, and Wages, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	7	497	30,859	$62.1
1a	Orange	8	D	D	D
All 1a		15	497	30,859	$62.1
1b	Harris	24	D	D	D
1b	Galveston	8	D	D	D
1b	Chambers	N/A	N/A	N/A	N/A
1b	Brazoria	3	D	D	D
All 1b		35	D	D	D
2	Matagorda	4	D	D	D
2	Jackson	N/A	N/A	N/A	N/A
2	Victoria	1	D	D	D
2	Calhoun	4	D	D	D
All 2		9	D	D	D
3	Refugio	N/A	N/A	N/A	N/A
3	Aransas	1	D	D	D
3	San Patricio	2	D	D	D
3	Nueces	4	D	D	D
3	Kleberg	N/A	N/A	N/A	N/A
All 3		7	D	D	D
4	Kenedy	N/A	N/A	N/A	N/A
4	Willacy	N/A	N/A	N/A	N/A
4	Cameron	13	D	D	D

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
All 4		13	D	D	D
Coastal Counties		79	497	30,859	$62.1
Coastal Counties % of State		53%	9%	8%	
Texas Statewide		150	5,756	396,466	$68.8

*NAICS code: 336611 and 336612
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Marine Construction

The BLS includes marine construction within the sector code 237990 which includes other heavy and civil engineer construction. Marine construction includes construction of breakwaters, bulkheads, channels and canals, harbors, jetties, and other marine structures. Because marine construction is not differentiated among many other forms of heavy construction, the contribution of the industry to the ocean economy may be overstated for the coastal counties. Nearly one-third of the State's employment in heavy construction is found in the 18-coastal county area, as shown in **Table 7-25**.

Table 7-25. Marine Construction Industry - Annual Average Employment, Business Establishments, and Wages, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	8	66	$4,193	$63.5
1a	Orange	2	D	D	D
All 1a		10	66	$4,193	$63.5
1b	Harris	113	4,179	$367,553	$88.0
1b	Galveston	12	331	$26,832	$81.0
1b	Chambers	1	D	D	D
1b	Brazoria	8	306	$22,938	$75.0
All 1b		134	4,816	$417,323	$86.7
2	Matagorda	1	D	D	D
2	Jackson	2	D	D	D
2	Victoria	1	D	D	D
2	Calhoun	2	D	D	D
All 2		6	D	D	D
3	Refugio	N/A	N/A	N/A	N/A
3	Aransas	4	42	$2,560	$61.0
3	San Patricio	6	D	D	D
3	Nueces	6	109	$10,101	$92.7
3	Kleberg	2	D	D	D
All 3		18	151	$12,661	$83.8
4	Kenedy	N/A	N/A	N/A	N/A
4	Willacy	N/A	N/A	N/A	N/A

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
4	Cameron	4	97	$4,974	$51.3
All 4		4	97	$4,974	$51.3
Coastal Counties		172	5,130	$439,151	$85.6
Coastal Counties % of State		28%	29%	29%	
Texas Statewide		619	17,959	$1,519,782	$84.6

*NAICS code: 237990
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Commercial Fishing

The marsh systems and coastal bays along Texas's coastline and the adjacent Gulf waters provide a bounty of aquatic resources and an abundance of fishing opportunities. Commercial fishing is an important component of the coastal economy but is highly vulnerable to the health of the ecosystems that provide harvestable resources.

Overall, in 2020, Texas commercial fishermen landed 72.3 million pounds of seafood valued at over $195 million. The leading 10 species landed by weight and value are shown in **Table 7-26** (NOAA, 2020). The shrimp harvest ranked highest in both weight and value, comprising 82 percent of the total landed weight and 73 percent of the landed value, oysters following at $30 million landed value. Texas routinely accounts for about a quarter of the red snapper harvested in the Gulf and a third of the Gulf's shrimp landings based on pounds. In 2020, about 21 percent of all domestic shrimp landed in the United States came from Texas (NOAA, 2020).

Table 7-26. 2020 Top Commercial Fish Species Landed by Weight and Value, Texas

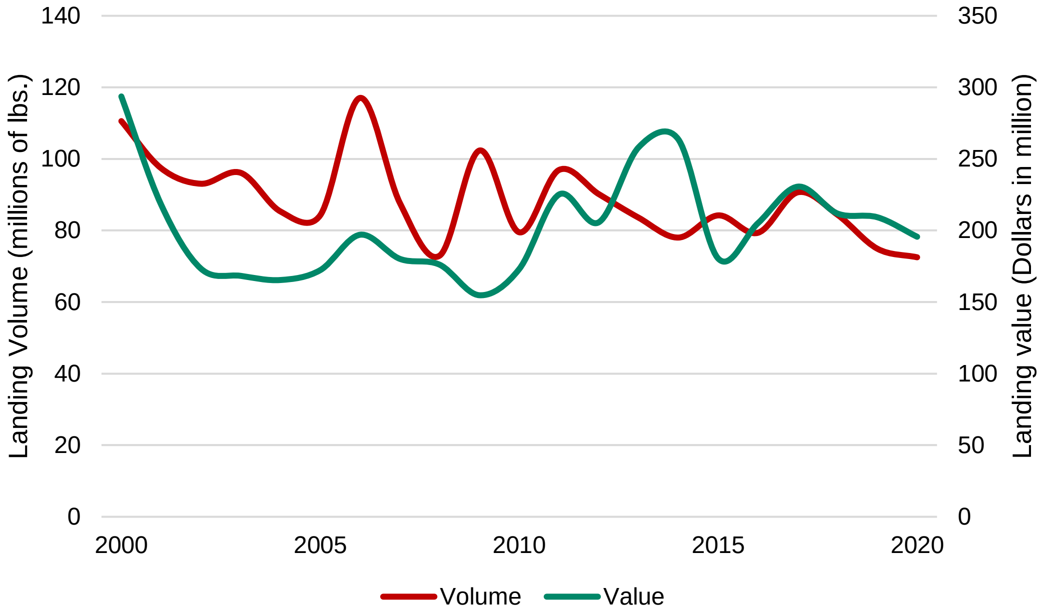
Rank	Ranked by Volume		Rank	Ranked by Value	
	Species	Pounds Caught		Species	Value (in million)
1	Shrimp*	59.27	1	Shrimp*	$142.9
2	Oyster	5.3	2	Oyster	$30.6
3	Blue crab	3.4	3	Red snapper	$12.1
4	Red snapper	2.75	4	Blue crab	$5.0
5	Black drum	1.07	5	Black drum	$1,4
6	Mullets	0.155	6	Atlantic croaker	$1,3
7	Atlantic croaker	0.12	7	Mullets	$0.5
8	Yellowedge grouper	0.11	8	Yellowedge grouper	$0.5
9	Blue catfish	0.11	9	Vermillion snapper	$0.2
10	Vermillion snapper	0.09	10	Striped mullet	$0.1
ALL LANDED SPECIES		**72.33**	**TOTAL VALUE**		**195.0**

* Includes all the species
Source: NOAA Fisheries, 2020

Texas's historical landing, shown in **Figure 7-5**, shows a decline in landed volume for the last 20 years. In 2020, the volume landed was the lowest recorded in the last 2 decades and it was 38% lower than in 2006, the peak landing weight (117 million pounds). This trend is explained by the decreased in the volume of landed shrimp, which has accounted, on average, for more than 80 percent of Texas's total landed weight since 2000. Although, commercial fishing landing revenues have remained relatively stable due to higher prices.

Commercial fishing is currently threatened by declining stocks as a result of overfishing, loss of habitat, and water pollution. In the future, climate change may exacerbate many stressors on fish populations, including changes in ocean pH and salinity and an increase in water temperature. Together, these shifting ocean conditions and species diversity will likely impact commercial fishing, and adaptation to these changes will be key for the commercial fishing industry moving forward.

Commercial Fishery Landings by Weight and Value, Texas 2000-2020



Commercial Fishery Landings by Selected Species, Texas 2000-2020

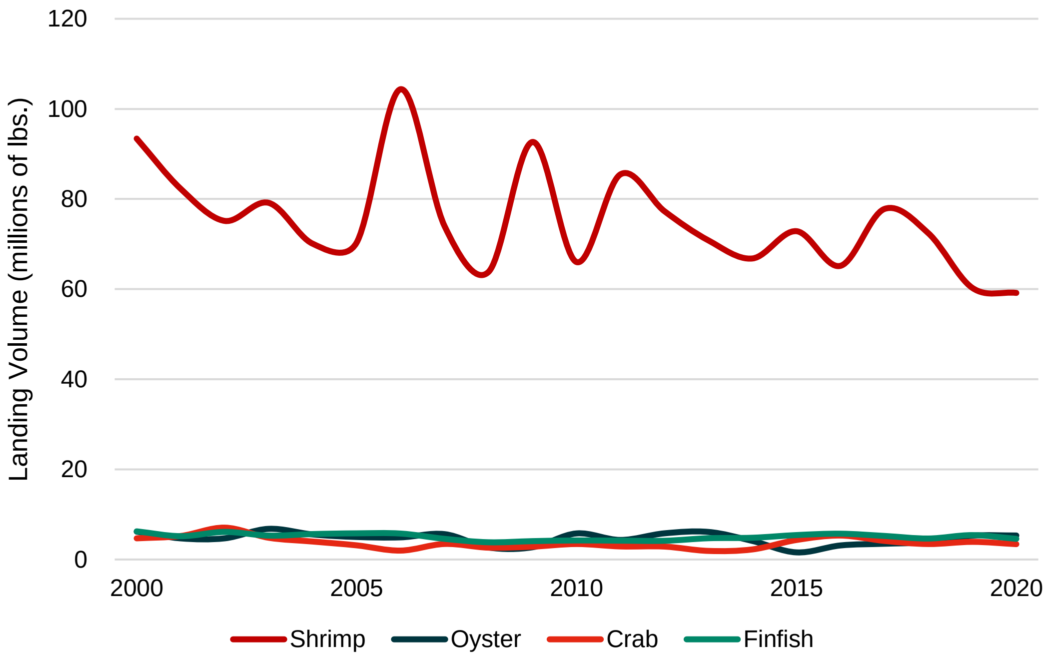


Figure 7-5. Total Landings in Texas, 2000-2020

Source: NOAA Fisheries, 2020

The leading Texas ports in 2020 for commercial fisheries landings are presented in **Table 7-27**. The ports of Brownsville-Port Isabel and Galveston ranked highest in weight and value of commercial fishery harvests.

Table 7-27. Top Texas Ports for Commercial Fishery Landings, 2020

Rank	Port	Weight in pounds (in million)	Rank	Port	Landed Value (in million)
1	Brownsville-Port Isabel, TX	17.2	1	Galveston, TX	$51.2
2	Galveston, TX	15.5	2	Brownsville-Port Isabel, TX	$46.4
3	Port Arthur, TX	14.1	3	Palacios, TX	$31.9
4	Palacios, TX	13.6	4	Port Arthur, TX	$29.1

Source: NOAA Fisheries, 2020

The commercial fisheries industry supports not only the commercial harvesters but also seafood processors, seafood distributors, grocers, and restaurants. NOAA's National Marine Fisheries Service Seafood Industry Input/ Output Model estimates economic impacts for fishery products as they work their way through the entire economy from harvesting to the final users. The impact of the commercial fisheries is shown in **Table 7-28** and are confined to the domestic harvest and the indirect effects to the processing, wholesale, and retail sectors. The estimates for a specific state measure only the impacts that occurred within that state from the seafood industry activities in that state. For the commercial harvester's sector, the harvesting activity is attributed to the state where the fish were landed. Economic contributions from interstate commerce and imported harvests are not reflected in the statistics presented in **Table 7-28**. The most current estimates of the commercial fisheries contribution to the Texas's economy are for the year 2020 when a total of 72.3 million pounds of fish were landed in Texas valued at $195 million. The economic contribution of the commercial fishery industry to the Texas coastal counties is shown in **Table 7-29**.

Table 7-28. Economic Impacts to Texas from the Domestic Seafood Industry Production, 2019

Category	Impact (in 1000s)
Employment, jobs	16.5
Income	$426,016
Sales	$1,152,738
Value Added (GDP contribution)	$593,688
Landed Fisheries Volume, 2020 (lbs)	72,330
Landed Fisheries Value, 2020	$195,029

Includes direct, indirect, and induced effects.
Sources: NOAA Fisheries, 2020

Table 7-29. Commercial Fishing Industry - Annual Average Employment, Business Establishments, and Wages, 2020

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
1a	Jefferson	19	D	D	D
1a	Orange	2	D	D	D
All 1a		21	D	D	D
1b	Harris	40	225	$10,246	$45.5
1b	Galveston	17	226	$7,443	$32.9
1b	Chambers	10	28	$909	$32.4
1b	Brazoria	8	D	D	D

Region	Coastal County	Establishments	Employment	Annual Wages (in 1000s)	Average Wage per Employee (in 1000s)
All 1b		75	479	$18,598	$38.8
2	Matagorda	29	46	$1,777	$38.6
2	Jackson	2	D	D	D
2	Victoria	1	D	D	D
2	Calhoun	15	33	$1,494	$45.2
All 2		47	079	$3,271	$41.4
3	Refugio	1	D	D	D
3	Aransas	3	D	D	D
3	San Patricio	N/A	N/A	N/A	N/A
3	Nueces	5	D	D	D
3	Kleberg	1	D	D	D
All 3		10	D	D	D
4	Kenedy	N/A	N/A	N/A	N/A
4	Willacy	N/A	N/A	N/A	N/A
4	Cameron	49	D	D	D
All 4		49	D	D	D
Coastal Counties		202	558	$21,869	$39.2
Coastal Counties % of State		73%	23%	$0	
Texas Statewide		276	2,452	$96,264	$39.3

*NAICS code: 31170, 1125, 1141, 445220
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Recreation and Tourism/Leisure and Hospitality

Recreational activities and tourism are important industrial sectors to the coastal economy and include sightseeing, beach-going, wildlife watching, fishing, boating, and other forms of recreation and leisure time activities.

Table 7-30 displays the combination of leisure and hospitality industrial sectors to the local and regional economies in 2020. 15.7% of total employment in Region 3 is in the leisure and hospitality industrial sectors, much of this is driven by Aransas County, which has 30.2% of total employment within the leisure and hospitality industry.

Table 7-30. Recreation and Tourism Representation in Coastal Counties, 2020

Region	Coastal County	Leisure and Hospitality Establishments	Percent of Coastal Counties' Establishments in Sector	Leisure and Hospitality Sector Employment (in 1000s)	Percent of Coastal Counties' Employment in Sector	Leisure and Hospitality Sector Wages (in 1000s)	Percent of All Coastal Counties' Wages in Sector
1a	Jefferson	555	3.5%	10.3	3.6%	$198,492	2.9%
1a	Orange	161	1.0%	2.4	0.8%	$47,857	0.7%
All 1a		716	4.5%	12.8	4.4%	$246,349	3.6%
1b	Harris	10,933	68.4%	199.4	69.4%	$5,178,887	75.3%
1b	Galveston	847	5.3%	16.7	5.8%	$343,420	5.0%
1b	Chambers	105	0.7%	1.4	0.5%	$25,821	0.4%
1b	Brazoria	702	4.4%	12.1	4.2%	$231,198	3.4%
All 1b		12,587	78.7%	229.8	79.9%	$5,779,326	84.0%
2	Matagorda	108	0.7%	1.1	0.4%	$19,472,	0.3%
2	Jackson	29	0.2%	0.3	0.1%	$5,038	0.1%
2	Victoria	239	1.5%	3.7	1.3%	$70,471	1.0%
2	Calhoun	85	0.5%	0.8	0.3%	$15,530	0.2%
All 2		461	2.9%	6.0	2.1%	$110,511	1.6%
3	Refugio	20	0.1%	D	D	D	D
3	Aransas	111	0.7%	1.3	0.5%	$27,319	0.4%
3	San Patricio	155	1.0%	2.4	0.8%	$42,309	0.6%
3	Nueces	1,010	6.3%	18.8	6.6%	$378,061	5.5%
3	Kleberg	83	0.5%	1.4	0.5%	$23,131	0.3%
All 3		1,379	8.6%	24.0	8.4%	$470,820	6.8%
4	Kenedy	4	0.0%	D	D	D	D
4	Willacy	34	0.2%	0.4	0.1%	$5,225	0.1%
4	Cameron	806	5.0%	14.5	5.0%	$269,755	3.9%
All 4		844	5.3%	14.8	5.2%	$274,980	4.0%
Coastal Counties		15,987	100.0%	287.5	100.0%	$6,881,986	100.0%
Texas Statewide		66,778		1,178.4		$27,105,458	

*NAICS Super Sector 70, includes NAICS 71, Entertainment, Arts and Recreation and NAICS 72, Accommodation and Food Services
D = Disclosure issues prevent this data from being presented; N/A: No data available
Source: Bureau of Labor Statistics, 2020

Marine Recreational Boating and Fishing

NOAA Fisheries Service estimates annual marine recreational fishing trip expenditures and durable equipment expenditures for Texas. Marine recreational expenditures are categorized into the following expenditure types: for-hire trips, private boat trips, shore trips and durable equipment expenditures related to marine recreational fishing, which include expenditures on fishing tackle and gear, fishing related equipment, boats, vehicles, and second homes. The USFWS estimates annual saltwater anglers, trips and days of fishing for Texas. **Table 7-31** presents marine recreational fishing expenditures and saltwater fishing pressure for Texas for 2018. In 2018, fisherman made 1.2 million fishing trips. Recreational expenditures for marine fishing averaged $233 per trip in 2018. The most popular types of saltwater fish caught in Texas waters are redfish, flounder and seatrout.

Table 7-31. Annual Marine Recreational Angler Trip & Durable Equipment Expenditures, Texas

2018	Total (in million)
Durable Equipment	$1,362.1
For-Hire Boat	$118.7
Private Boat	$159.6
Shore Fishing	NA
Total Trip Expenditures	$278.4
Trips	1.2*
Average Expenditure per Trip	$233

*Shore Fishing and Durable Equipment not included in Trip Total
Source: Fisheries Economics of the United States, 2018

Marine recreational fishing impacts to the Texas economy are presented in **Table 7-32**. Marine recreational fishing supported close to 14,000 jobs in 2018 and provided $681 million in income to full and part-time workers. Over $1.1 billion in value added was contributed to the GDP of the state.

Table 7-32. Economic Impacts to Texas from Marine Recreational Fishing, 2018

2018	Employment	Income (1000s of dollars)	Sales (1000s of dollars)	Value Added (1000s of dollars)
Durable Equipment	10,610	$533,956	$1,373,030	$870,403
For-Hire Boats	1,768	$67,723	$200,685	$120,852
Private Boat	1,848	$79,495	$256,168	$155,454
Shore Fishing	NA	NA	NA	NA
Total	**14,226**	**$681,174**	**$1,829,883**	**$1,146,709**

Includes direct, indirect, and induced effects.
Sources: National Marine Fisheries Services, 2018

Boat Registration Data

Boat registration data was pulled from the State of Texas through the TPWD in April 2022. The dataset is a population set and categorized their unique TX Number. Boater registration data was pulled from this database and analyzed for the Texas Coast. From this dataset, there are 133,536 registered boats whose owners reside on the Texas coast, making up 20% of the total 682,518 registered boats in Texas. **Table 7-33** below shows the distribution of boat owners by region. Region 1 has the largest number of registered boat owners for the Texas coast with Harris County making up 41% of the total number of boats registered.

Table 7-33. Boat Distribution by Region/County

County of Residence	# of Registered Boats	% of Total
Region 1		
Harris	54,970	41%
Galveston	15,049	11%
Brazoria	11,847	9%
Jefferson	8,289	6%
Orange	7,614	6%
Chambers	2,458	2%
Region 1 Subtotals	*100,227*	*75%*
Region 2		
Victoria	3,601	3%
Matagorda	2,554	2%
Calhoun	2,124	2%
Jackson	947	1%
Region 2 Subtotals	*9,226*	*7%*
Region 3		
Nueces	9,914	7%
San Patricio	3,479	3%
Aransas	2,891	2%
Kleberg	640	0%
Refugio	429	0%
Region 3 Subtotals	*17,353*	*13%*
Region 4		
Cameron	6,222	5%
Willacy	494	0%
Kenedy	14	0%
Region 4 Subtotal	*6,730*	*5%*
Texas Coast Totals	**133,536**	**100%**

Source: Texas Registered Boats, 2022

The size of vessels for the Texas coast dataset ranges from less than 16 ft to 112 ft in length. Over 90 percent of the registered boats fall within Class A and Class I at less than 26 ft long. **Table 7-34** below shows the vessel class distribution for the Texas coast dataset by vessel class and its percentage of the total.

Table 7-34. Vessel Class by Boat Length

Vessel Class	Count	% Total
Class A (less than 16')	35,444	26.5%
Class I (16 ft to less than 26 ft)	89,764	67.2%
Class II (26 ft to less than 40 ft)	6,416	4.7%
Class III (40 ft to less than 65 ft)	1,478	1.2%
Small Research Vessel	434	0.4%
Total Vessel Count	**133,536**	**100%**

Source: Boat Classification Data provided by NOAA, 2015

The vessel usage for the majority of the registered boats is for pleasure; however, usage along the Texas coast includes commercial, government, and charter activities as well. **Table 7-35** below shows the count and percentage of vessel usage for those registered within the Texas coast.

Table 7-35. Registered Vessel Use by Category

Vessel Category	Count	% Total
Pleasure	131,319	98.3%
Other Commercial	609	0.5%
Commercial Fishing	893	0.7%
Government/Political Subdivision	352	0.3%
Boat Charter	259	0.2%
Charter Fishing	76	0.1%
Commercial Passenger	28	0.0%
Total Vessel Count	**133,536**	**100%**

Source: Texas Registered Boats, 2022

Cruise Ship Industry

Galveston County and Galveston Island, in particular, have become popular tourist destinations, not only because of the Island's beaches and its historic and recreational attractions, but also for its cruise ship industry. Proximity to open, deep water has buoyed this growing industry on the Island. The Port of Galveston is ranked as the nation's fourth-largest cruise market based on embarkations, with an unprecedented number of cruise ship calls (297), representing a 10.8% increase on the previous record of 268 calls in 2018, as shown in **Table 7-36**. At 1.1 million, embarkations are 76% higher than the 2006 peak of 617,000. Cruise activity generated $71.5million in passenger on-shore spending and another $23.4 million in services in 2019 (Galveston Island Convention & Visitors Bureau, 2019).

Table 7-36. The Port of Galveston, Cruise Ship Industry, 2017-2019

Year	Total Cruise Ship Calls	Annual Growth Rate
2017	255	8.5%
2018	268	5.1%
2019	297	10.8%

Source: The Port of Galveston, 2022

As a result of the COVID-19 pandemic and the many infected ships in the first quarter of 2020, the entire cruise industry was stopped and a prohibition on resuming this industry was imposed worldwide. COVID-19 restrictions have canceled hundreds of sailings out of Galveston this year, costing the Port of Galveston millions of dollars in lost revenue: the cruise ship calls were reduced by 78% and there were more than 1.7 million less cruise passengers in

2020. The Port of Galveston operating revenue decreased 88% in 2020, from $51.8 million to $27.4 million, followed by four years with an average growth rate of 12%.

The Port of Galveston Strategic Master Plan establishes policies and guidelines to direct the future development of the Port in the terms of conceptual port infrastructure. The port has projected roughly $20 million for pier repairs, site work, utilities and additional cruise parking. Furthermore, the construction of the Port of Galveston's third cruise terminal is a game-changer for the port and regional economy. Opening in late 2022, the new terminal will be a major revenue generator for the port. It is creating $1.4 billion in local business services revenue, $5.6 million in state and local taxes, and incredible business development opportunities (The Port of Galveston, 2022).

Coastal State Parks

Each year over 8 million people visit Texas State Parks, a number that continues to increase. Texas State Parks provide more than just recreation but also help enhance the well-being of Texans. Studies have shown that time spent outdoors can help improve mood, problem-solving abilities and physical health.

Texas State Parks are a major economic engine for Texas. The recreational industry, of which Texas State Parks are a significant part, generate 115,511 jobs and $40.2 billion to the Texas economy. According to Texas Parks and Wildlife Foundation, the state parks generated close to $13 million in sales activity, had a $3.5 million impact on the incomes of Texas residents, and supported an estimated 143 jobs throughout the state in 2018, as shown in **Table 7-37**.

Table 7-37. Economic Impacts to Texas from Coastal State Parks, 2018

State Park	Park Revenues (in 1000s)	Total day visitor days	Total overnight visitor days	Impact on labor income (in 1000s)	Impact on output (in 1000s)	Number of jobs created
Mustang Island	$272	42,095	26,876	$1,014	$4,113	40.4
Goose Island	$329	26,063	38,701	$555	$2,656	28.6
Galveston Island	$865	95,974	49,806	$1,621	$5,264	63.3
Sea Rim	$223	18,654	46,342	$306	$926	10.5
Total	$1,689	182,786	161,725	$3,496	$12,959	142.8

Source: Jeong & Crompton, 2019

7.2 Boat Ramp Use Memo

AECOM conducted an initial data analysis of the Texas Coastal Boat Ramp data provided by the GLO to support work on the 2023 TCRMP. In addition, this analysis included an overview of boat registration within the state of Texas. The analysis conducted gives a general idea of the overall boat ramp and bay use activity within the coastal bay areas. For the 139 boat ramps in the database, using data available from 2021 only, there is an average of 89 days of survey data for each ramp.

With the data that is available, general assumptions could be made for the boat ramp and bay use. Below is a summary that describes the boat ramp performance. While the data is not complete, it does give a general idea of the activity for each of the bays and their value to the Texas Coast. It also gives a general idea of the county of residence where bay-use activity originates for each bay system.

Boat Registration Data

Boat registration data was pulled from the State of Texas through the TPWD. The dataset is a population set and categorized their unique TX Number. Boater registration data was pulled from this database and analyzed for the Texas Coast. From this dataset, there are 133,536 registered boats whose owners reside on the Texas Coast, making up 20% of the total, 682,518, registered boats in Texas. The below table (**Table 7-38**) shows the distribution of boat owners by region. Region 1 has the largest number of registered boat owners for the Texas Coast with Harris County making up 41% of the total number of boats registered by owners in the Texas Coast.

Table 7-38. Boat Distribution by Region/County

County of Residence	# of Registered Boats	% of Total
Region 1		
Harris	54,970	41%
Galveston	15,049	11%
Brazoria	11,847	9%
Jefferson	8,289	6%
Orange	7,614	6%
Chambers	2,458	2%
Region 1 Subtotals	*100,227*	*75%*
Region 2		
Victoria	3,601	3%
Matagorda	2,554	2%
Calhoun	2,124	2%
Jackson	947	1%
Region 2 Subtotals	*9,226*	*7%*
Region 3		
Nueces	9,914	7%
San Patricio	3,479	3%
Aransas	2,891	2%
Kleberg	640	0%
Refugio	429	0%
Region 3 Subtotals	*17,353*	*13%*
Region 4		
Cameron	6,222	5%
Willacy	494	0%
Kenedy	14	0%
Region 4 Subtotal	*6,730*	5%
Texas Coast Totals	**133,536**	**100%**

Source: Texas Registered Boats, 2022

The size of vessels for the Texas Coast dataset ranges from less than 16 ft to 112 ft in length. Over 90 percent of the registered boats fall within Class A and Class I at less than 26 ft long. The below table (**Table 7-39**) shows the vessel class distribution for the Texas Coast dataset by vessel class and its percentage of the total.

Table 7-39. Vessel Class by Length

Vessel Class	Count	% Total
Class A (less than 16’)	35,444	26.5%
Class I (16 ft to less than 26 ft)	89,764	67.2%
Class II (26 ft to less than 40 ft)	6,416	4.7%
Class III (40 ft to less than 65 ft)	1,478	1.2%

Vessel Class	Count	% Total
Small Research Vessel	434	0.4%
Total Vessel Count	133,536	100%

Boat Classification Data provided by NOAA, 2015

The vessel usage for majority of the registered boats is for pleasure, however, usage along the Texas Coast includes commercial, government, and charter activities as well. The table below (**Table 7-40**) shows the count and percentage of vessel usage for those registered within the Texas Coast.

Table 7-40. Vessel Use by Activity

Vessel Use	Count	% Total
Pleasure	131,319	98.3%
Other Commercial	609	0.5%
Commercial Fishing	893	0.7%
Government/Political Subdivision	352	0.3%
Boat Charter	259	0.2%
Charter Fishing	76	0.1%
Commercial Passenger	28	0.0%
Total Vessel Count	133,536	100%

Overall Coastal Environment Data

Top Bay Use

This data shows the distribution of visitors for each of the bays with the given sample. The assumption is that the sample is random and gives an overall picture of annual activity. Based on the data, the bay with the most boating activity is Aransas Bay (**Table 7-41**).

Table 7-41. Top Bay Use for Boating Activity

Bay	% of Recorded Activity
Aransas Bay	17%
Upper Laguna Madre	16%
Matagorda Bay	15%
San Antonio Bay	14%
Corpus Christi Bay	13%
Galveston Bay	11%
Lower Laguna Madre	10%
Sabine Lake	5%

Top Activity Codes

Fishing, both Sport Fishing and Party-Boat Fishing, respectively, have the greatest participation rate, making up over 80% of all activity. **Table 7-42** below is the list of activities from the dataset by percent of recorded boat ramp activity. Those activities not listed were either below 1% of the total sample or indicated no activity.

Table 7-42. Top Boating Activity Codes

Activity	% of Recorded Activity
Sport Fishing	65%
Party-Boat Fishing	16%
Sailing/Pleasure Riding	7%
Other	6%
Work Boat	2%
Tournament Fishing	2%
Hunting	1%
Commercial Crabbing	1%
Commercial Finfish Fishing	1%

Data Analysis (By Bay)

Using the sample data provided, general conclusions can be made for each bay area. This analysis includes the distribution of counties of residences for boat ramp goers, their destination (which bay was visited), and the activity performed; tables are shown below by bay **(Table 7-43** through **Table 7-50**). Sport Fishing is the most popular activity for each of the bay areas with varying counties of residence for each bay area. Because the data was a sample, percentage data was most appropriate to express the characteristics of the dataset.

Table 7-43. Aransas Bay Boating Use by County of Residence and Top Activities

County of Residence	% of Total
Aransas	16%
Bexar	12%
San Patricio	6%
Travis	5%
Nueces	5%
Harris	4%
Comal	4%

Activity	Participation %
Sport Fishing	63%
Party-Boat Fishing	18%
Sailing/Pleasure Riding	7%
Other	6%

Table 7-44. Upper Laguna Madre Boating Use by County of Residence and Top Activities

County of Residence	% of Total
Nueces	34%
Bexar	12%
Harris	3%
San Patricio	3%
Kleberg	3%
Travis	3%
Comal	3%
Jim Wells	2%
Wilson	2%
Guadalupe	2%
Hays	2%

Activity	Participation %
Sport Fishing	60%
Party-Boat Fishing	22%
Other	7%
Sailing/Pleasure Riding	5%
Work Boat	2%
Tournament Fishing	2%
Hunting	1%
Commercial Finfish Fishing	1%

Table 7-45. Matagorda Bay Boating Use by County of Residence and Top Activities

County of Residence	% of Total
Harris	12%
Matagorda	12%
Fort Bend	10%
Wharton	7%
Brazoria	5%
Calhoun	5%
Victoria	4%
Montgomery	3%
Travis	2%
Austin	2%
Colorado	2%

Activity	Participation %
Sport Fishing	62%
Party-Boat Fishing	19%
Sailing/Pleasure Riding	7%
Other	5%
Tournament Fishing	2%
Hunting	1%
Work Boat	1%
Commercial Bait Shrimping	1%
Commercial Crabbing	1%

Table 7-46. San Antonio Bay Boating Use by County of Residence and Top Activities

County of Residence	% of Total
Calhoun	15%
Victoria	11%
Harris	8%
Travis	5%
Bexar	4%
Williamson	3%
Lavaca	3%
Guadalupe	3%
Comal	3%
Fort Bend	2%

Activity	Participation %
Sport Fishing	70%
Party-Boat Fishing	10%
Other	7%
Sailing/Pleasure Riding	7%
Hunting	3%
Tournament Fishing	2%
Commercial Crabbing	1%
Work Boat	1%

Table 7-47. Corpus Christi Bay Boating Use by County of Residence and Top Activities

County of Residence	% of Total
San Patricio	14%
Nueces	12%
Bexar	11%
Aransas	6%
Travis	4%
Comal	3%
Harris	3%
Wilson	3%

Activity	Participation %
Sport Fishing	69%
Party-Boat Fishing	13%
Other	7%
Sailing/Pleasure Riding	6%
Work Boat	3%
Tournament Fishing	2%
Hunting	1%

Table 7-48. Galveston Bay Boating Use by County of Residence and Top Activities

County of Residence	% of Total
Harris	30%
Galveston	20%
Brazoria	14%
Fort Bend	7%
Montgomery	5%
Chambers	4%
Liberty	2%
Tarrant	1%

Activity	Participation %
Sport Fishing	62%
Party-Boat Fishing	21%
Sailing/Pleasure Riding	7%
Other	5%
Tournament Fishing	2%
Work Boat	2%
Commercial Crabbing	1%

Table 7-49. Lower Laguna Madre Boating Use by County of Residence and Top Activities

County of Residence	% of Total
Cameron	32%
Hidalgo	27%
Willacy	10%
Harris	3%
Bexar	2%
Nueces	1%
Hays	1%

Activity	Participation %
Sport Fishing	70%
Party-Boat Fishing	10%
Other	7%
Sailing/Pleasure Riding	5%
Commercial Finfish Fishing	2%
Work Boat	2%
Hunting	1%
Commercial Crabbing	1%
Tournament Fishing	1%

Table 7-50. Sabine Lake Boating Use by County of Residence and Top Activities

County of Residence	% of Total
Jefferson	33%
Orange	26%
Hardin	8%
Harris	7%
Louisiana	6%

Activity	Participation %
Sport Fishing	62%
Sailing/Pleasure Riding	14%
Other	6%
Work Boat	5%
Sport Crabbing	3%
Commercial Crabbing	3%
Hunting	3%

7.3 Fishing License Memo

AECOM analyzed the recreational saltwater fishing license data provided by the TPWD, comparing fishing license holders and their places of residence. Texas sells recreational fishing licenses for freshwater fishing, saltwater fishing, or a combination of both. The below map (**Figure 7-6**) shows in yellow the location of the artificial reef structures in Texas that provide habitat for marine life along the Gulf coast, which provide saltwater fishing opportunities for anglers.

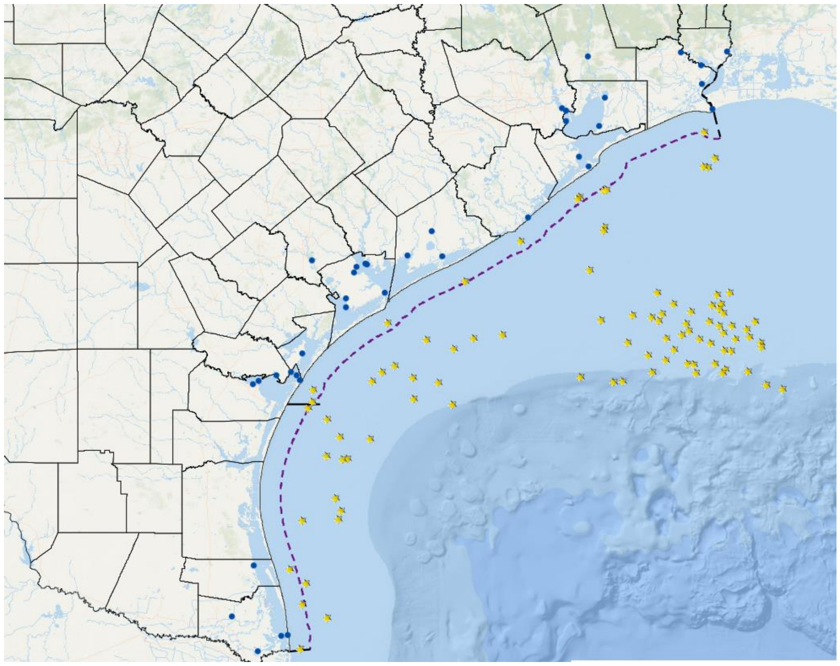


Figure 7-6. Artificial Reef Structures in Texas (TPWD, 2021)

Of the 1.8 million active saltwater fishing licenses holders, 25% of the holders reside in coastal counties, and 75% live outside of the coastal counties.

Harris County has the largest number of saltwater fishing license holders. The table below shows the representation of saltwater fishing license holders by Texas coastal county and TCRMP region.

Table 7-51. Saltwater Fishing License Holders in Texas Coastal Counties

Region/County	Percentage of Saltwater Fishing License Holders in Texas Coastal Counties
Region 1	**70.2%**
Brazoria	8.04%
Chambers	1.69%
Galveston	7.52%
Harris	45.21%
Jefferson	4.92%
Orange	2.83%
Region 2	**6.0%**
Calhoun	0.94%
Jackson	0.70%
Matagorda	1.39%
Victoria	2.97%
Region 3	**14.5%**
Aransas	1.54%
Kleberg	1.14%
Nueces	9.03%
Refugio	0.29%
San Patricio	2.48%
Region 4	**9.3%**
Cameron	8.69%
Kenedy	0.01%
Willacy	0.61%

Source: Texas Saltwater Fishing License dataset, TPWD 2021

As noted in **Table 7-51** above, 70% of the coastal fishing license holders reside in Region 1, with the lowest percentage of fishing license holders on the coast in Region 2 (6%). Harris County makes up over 45% of fishing license holders for the coastal region.

License holders outside the coastal counties were broadly dispersed, as shown in **Table 7-52** below. The counties represented were Texas counties, so it is assumed that the “Other" classification represents those that reside outside the state of Texas.

Table 7-52. Saltwater Fishing License Holders Outside of Texas Coastal Counties

County Name	Percentage of Saltwater Fishing License Holders Outside of Texas Coastal Counties
Other	11.05%
Bexar	9.13%
Tarrant	4.55%
Hidalgo	4.37%
Travis	3.91%
Montgomery	3.77%
Dallas	3.62%
Fort Bend	3.18%

Source: Texas Saltwater Fishing License dataset, TPWD 2021

The "Other" designation makes up the greatest percentage of license holders outside of Texas coastal counties (11%), followed by license holders in Bexar County (9%).

Saltwater license registration options ranged from One-Day All-Water Fishing Licenses to Lifetime Combo Licenses that included fishing and hunting passes for the lifetime of the license holder. Packages could be purchased by age (senior discounted for those over 65), as well as residential status (Texas resident or non-resident). Of the total number of active passes in 2021, there were 360,301 One-Day licenses for both residential and non-residential licenses. This was the most restrictive, by number of visits, license option in the dataset. **Table 7-53** shows the percentage of Residential and Non-Residential One-Day-All-Water Fishing Licenses.

Table 7-53. Percentage of Residential and Non-Residential One-Day-All-Water Fishing Licenses

	Non-Resident One-Day-All-Water, including Saltwater, Fishing License	Resident One-Day-All-Water, including Saltwater, Fishing License
Number of Active Licenses	100,284	260,017
% One-Day Licenses	28%	72%

Source: Texas Saltwater Fishing License dataset, TPWD 2021

As shown in the table above, Texas residents were the most common purchasers of One-Day-All-Water fishing passes, at 72% of those licenses sold. Non-Texas residents purchased 28% of One-Day-All-Water fishing passes.

County general population data was obtained to determine the percent of engagement by county. The eligible population for fishing licenses is individuals aged 17 years and above, so 2020 Census data was subdivided to represent only those in the eligible population. For the purposes of determining the saltwater fishing engagement, AECOM used the 2020 Census population subset of 18 years and above. **Table 7-54** shows the results of percentage of engagement for the Texas coastal counties. Aransas County has the largest participation percentage of fishing license holders at 36% of the eligible population while Harris County has the lowest participation percentage at 6% of the eligible population.

Table 7-54. Percent of the Eligible Population that are Fishing License Holders in Texas Coastal Counties

County	Eligible Population (Residents 18+)	Number of License Holders	Percentage of the Eligible Population
Aransas	19,612	6,997	36%
Jackson	11,181	3,206	29%
Calhoun	15,301	4,289	28%
Refugio	5,251	1,334	25%
Matagorda	26,974	6,306	23%
Chambers	33,624	7,679	23%
Kenedy	263	60	23%
Kleberg	23,621	5,164	22%
Orange	63,776	12,858	20%
Victoria	68,215	13,488	20%
Willacy	15,425	2,781	18%
Nueces	267,356	41,052	15%
Cameron	295,133	39,524	13%
Brazoria	274,931	36,562	13%
Galveston	266,168	34,205	13%
Jefferson	94,703	22,370	11%
San Patricio	50,604	11,274	22%
Harris	3,482,123	205,618	6%

Source: US Census Bureau, 2020 and Texas Saltwater Fishing License dataset, TPWD 2021

For counties outside the Texas coastal region, license holder participation is described in **Table 7-55**. While the level of participation is lower in the non-coastal region than in the coastal region, there are several counties, including Caldwell, Wharton, and Borden, that have over a quarter of their eligible population holding saltwater fishing licenses. The cost of a recreational all-water fishing license for Texas residents is $40, only $10 more than a freshwater fishing license; it may be the case that anglers purchasing for predominantly freshwater use may have purchased an all-water fishing license if they anticipated the possibility of saltwater fishing during that year.

Table 7-55. Percent of the Eligible Population that are Fishing License Holders Outside of Texas Coastal Counties

County	Eligible Population (Residents 18+)	Number of Saltwater Fishing License Holders	Percentage of the Eligible Population
Caldwell	15,301	4,235	28%
Wharton	30,845	7,654	25%
Borden	505	124	25%
Wilson	37,912	9,005	24%
Hardin	42,511	9,426	22%
Blanco	9,349	1,984	21%
Atascosa	35,622	7,228	20%
Bandera	17,411	3,490	20%
Austin	22,987	4,405	19%

Source: US Census Bureau, 2020 and Texas Saltwater Fishing License dataset, TPWD 2021

7.4 Parametric Insurance for Coastal Resiliency

Parametric insurance can be used as part of a local, state, or federal government's overall risk management strategy to manage natural catastrophe risks to its built infrastructure and natural environments. It can be a useful tool to mitigate risks created by under insurance. However, it is not a single solution and has many advantages and disadvantages to explore before determining if it is an appropriate risk management tool for a particular entity. A brief explanation of the pros and cons is given below, with a fuller characterization presented in the discussion that follows.

Among the benefits of parametric insurance is that it can be used to distribute risk and better protect investments that a government, community, or stakeholder has made to coastal resiliency (e.g., restoration projects, natural resources, coastal community infrastructure). It can be used as a system-wide or site-specific strategy to protect coastal infrastructure. For example, parametric insurance policies have been used to insure nature-based infrastructure, in the case of a coral reef site in Mexico, as well as traditional, built infrastructure, in the case of the State of Utah's academic buildings, which were insured against cataclysmic earthquake events. These policies present opportunities for governments, communities, and stakeholders to plan for more extreme and frequent coastal storms and other similar vulnerabilities.

However, there are inherent risks to purchasing a parametric insurance policy. Firstly, it can be difficult to select the most appropriate trigger that would lead to a payout. Then, the findings from the complicated economic and environmental models that are used to develop the policies, would need to be verified by experienced scientists and/or engineers. If the models are too conservative, a policyholder runs the risk of not generating a payout and could end up spending more on an insurance policy than it is worth. Additionally, as trigger events become more frequent and the probability of loss increases, the price of policies would likewise be expected to increase.

7.4.1 Background on Parametric Insurance Solutions

Parametric insurance is a relatively new insurance product that has been offered as an alternative to traditional insurance for approximately 25 years. Parametric insurance has become possible for insurance brokers to offer as a risk management product due to improvements in the technology and analysis requisite to measure climate impacts, such as storm frequencies and intensities or likelihood of a wildfire occurring, and determine probabilities of loss to infrastructure, ecological health, and human life.

Swiss Re

Swiss Re works with Risk Management Solutions (RMS) to develop payout schemes based on the needs and budget of a prospective policyholder. The main risk to the policyholder is based on whether the parametric conditions that trigger the payout are met in a given year. Parametric insurance policies can be developed at federal, state, and local levels, as well as for private industry users, academic institutions, and nongovernmental organizations.

Parametric insurance, because it is tied to a catastrophic event occurring rather than to protecting a particular piece of infrastructure or property, usually offers more flexibility in how the funds may be used after a payout occurs. Under a derivative policy, for instance, Swiss Re typically makes a straight, unrestricted payout to the policyholder within 30 days of the claim. The insurance coverage is based on specific criteria that correspond to the probability of loss, such as an event generating a certain windspeed at pre-approved data locations within a given zip code.

The claims process is expedited when using parametric insurance when compared to traditional insurance, because adjustors and inspectors do not need to be involved to verify damages, as payouts depend solely on an event occurring. Often times, existing data that is being collected under ongoing programs, such as wind and rain gauges at local airports, buoys from the NOAA, or quake intensity measurements from the USGS can be used to verify claims. Once a claim is verified, the policyholder may use the payout funds to cover anything that was damaged by the event, such as impacts to dunes and structures and many administrative costs, such as increased labor expenses and overtime pay and even retention fees or deductibles for other insurance policies the entity may hold. Funds may also be used to complement what an entity receives from federal funding opportunities.

Examples of parametric insurance policies that Swiss Re has provided to customers include:

- Windspeed Insurance for Quintana Roo Coral Reef in Mexico (*case study below*)
- Earthquake Insurance for the State of Utah Division of Risk Management (*case study below*)
- Earthquake Insurance for California university system (50+ locations)
- Windspeed Insurance for electric provider in France
- Insured Dike Restoration Project (marine and structural elements) in the Netherlands
- Insured Wetlands and Nature-based Features with the Canadian federal government (*pending*)

Aon

Aon is a global professional service firm offering solutions for systems, manmade, and natural disaster climate risk. The Public Sector Partnership (PSP), a suborganization within Aon, looks at non-property risk, such as the net impact to revenues and expenditures after a natural disaster (drop in S&P 500, oil and gas markets, etc.). As part of the PSP, Aon offers parametric insurance. While with a traditional insurance policy, such as someone might purchase for their home, car, or medical needs, a payout would occur after a certain deductible is reached, a parametric insurance policy pays out after a pre-determined event, such as a location receiving 5 in (127 mm) of rain over a 24-hour period, occurs. Parametric insurance policies may also consider correlated perils, such as the risk of mudslides, in addition to primary perils like a total amount of rainfall. There are typically fewer restrictions on how parametric payouts are used when compared to traditional insurance; funds paid out after a parametric insurance claim can be used for non-traditional purposes, such as setting up a revolving loan fund or paying match funds or separate insurance policy deductibles.

Additionally, Aon offers preventative coverage for natural systems. For these policies, the pre-determined events that trigger payout are typically related to specific climate stressors or indicators. For instance, for a wildfire pre-disaster parametric insurance policy, a payout scheme could be structured based on aquifer levels and a drought severity index (such as the Palmer or Keetch-Byram drought indices) or excess heat index. For coastal resilience-related policies, event triggers could include specific rates of erosion, invasive species prevalence, depletion of natural resources, salinity levels, and water levels, among others. When these event triggers are met outside of the conditions that would typically be deemed a natural disaster, the payout funds could then be used to produce science and engineering products (e.g., updated surveys, engineering models, and restoration projects) to create more resilient communities proactively, before a disaster occurs.

According to Aon, parametric insurance is a good product to assist State and local governments, which are the insurers of quality of life and natural resources for their communities, with managing climate and resilience risk. Alternative budget insurance opportunities, like parametric insurance, may allow governments to hold less liquidity in reserves and invest less in self-insurance, supplemental liquidity, etc. In some cases, the money that is freed from these traditional risk management strategies can instead be invested in infrastructure, deferred maintenance, resiliency projects, and capital works programs via targeted projects that can reduce premiums in “go forward” years. If this occurs, the money would likely have a better return on investment than had it been used to purchase more traditional risk management products (e.g., traditional insurance or self-insurance). In most cases, policies and premiums are re-evaluated annually. The advantages and disadvantages of these insurance solutions are shown in **Table 7-56**.

Table 7-56. Pros and Cons of Parametric Insurance Solutions

Pros	Cons
– No adjudication of a claims process – No deductible – Expedient payout after claim – Typically has fewer restrictions on how the payout can be spent than traditional insurance – Can be used in conjunction with federal funding – Can be tailored to community needs (e.g., locations at risk, events of concern) and budget and can be written to consider both primary and correlated perils	– Payout is contingent on the defined event occurring – The price of a parametric insurance policy is a function of the probability of loss—the greater the probability of loss, the higher the cost of the policy – More frequent catastrophes can increase costs of policies year-over-year – Community must have an established data source by which to measure the risk trigger – Custom-made policies may come with a higher price tag, due to the complicated modeling that goes behind determining policies – Long-term planning would be needed in addition to any risk management strategies to account for more frequent natural disasters

7.4.2 Insurance for Natural Ecosystems

TNC Quintana Roo Insured Reef

TNC began working with Swiss Re over 12 years ago to study and determine the value of nature as a risk reduction measure for protecting coastal infrastructure. If the value of nature as a risk reduction measure can be quantifiably determined, its value can be recognized by the insurance industry, and an insurance policy could be taken out for the natural system to protect the asset. Swiss Re and TNC have been working with organizations like RMS, IHCantabria, and the University of California Santa Cruz to develop environmental and insurance models that quantify the amount of risk reduction provided by particular natural systems. As a result of this work, insurance policies for natural systems have been sold to governments to help them protect their natural assets.

As a first step to develop such an insurance policy, TNC completed a study to determine the protective value of a large coral reef to the tourism and hotel industries along Quintana Roo, Mexico. According to the model results, without the reef in place, the estimated annual losses on the tourism and hotel sectors would increase by 250% in dollar value and the number of people affected by inundation would triple. Because of the immense value of this reef to preventing flood damages and loss of life, the Mexican state of Quintana Roo, through a coalition of stakeholders that included representatives from hotel and tourism industries, worked with Swiss Re to develop a parametric insurance policy for the reef that covered wind speed events. The Quintana Roo government purchased the policy from Swiss Re in 2019 to protect the reef from coastal storms; in 2020, Hurricane Delta's windspeeds of over 100 knots triggered a payout from the policy.

To cover the cost of the policy, the state of Quintana Roo requires that any private sector entity that wishes to use the beachfront for commercial purposes must pay an annual fee to the government. At present, the insurance payouts, when triggered, are distributed to municipalities for independent use to restore damages to the reef after the event. The future intent is for the fees and/or payout funds to be used to develop a trust fund for the reef that could receive approximately $2 to $3 million annually, depending on returns when the fund is invested. The board of the trust fund would then determine when and where the funds are used to restore the reef when damages occur.

TNC is working with Swiss Re and other parties to develop additional models that will determine if similar parametric insurance policies for natural ecosystems can be developed for other habitat types, such as salt marshes, other coral reefs, and mangroves.

7.4.3 Insurance for Natural Catastrophes

Utah Division of Risk Management Earthquake Parametric Insurance Case Study

The State of Utah is a self-funded entity that purchases insurance to cover damages associated with natural catastrophes, including earthquakes. In some cases, the State also purchases reinsurance to transfer risk in the event of major claims. The total insured value of the State's assets is approximately $39 billion. Prior to purchasing reinsurance, the State's traditional property insurance limit was $525 million, with an annual premium on this policy of $9 million. Comparing their insurance policy against the projections for frequency and severity of quakes put forward by environmental researchers, the State determined that they would need a $2 billion limit on their traditional insurance plan to account for a 100- to 200-year event, meaning that the State was significantly underinsured for a big earthquake. Purchasing traditional insurance for such an event would nearly double the State's annual insurance premium to $16 million annually.

As a partial solution to their underinsurance problem, the State purchased a parametric insurance policy from Swiss Re that covered $50 million per event with a $150 million aggregate and had a premium of $250,000. The parametric insurance was purchased for areas of greatest exposure and payouts were made on a pro rata basis based on the measured quake intensity along fault lines in specific zip codes with State-owned property. After purchasing the policy, an earthquake occurred that impacted the oldest school district in the state and caused $65 million in losses. The parametric insurance policy paid out $1 million for this event to the State within 30 days. Because there were few limitations on where the funds could be spent, the State was able to use the payout to absorb the cost needed for other policies (in this instance, a specific self-insurance retention required to be paid before the separate insurance policy coverage came into effect), rather than spending the funds on a particular recovery project. As a result, the State only ended up paying roughly $37,000 out of pocket for the entire event. It should be noted that, as with most insurance policies, future premiums may increase as the probability of loss increases. The State of Utah saw such an increase in the price of its policy. The advantages and disadvantages associated with this parametric insurance policy are shown in **Table 7-57**.

The State is working with individual homeowners to improve education/outreach for personal earthquake insurance, as well as with the State Forester to work to determine parametric indicators for wildfire suppression and future wildfire parametric insurance needs.

Table 7-57. Pros and Cons of Parametric Insurance Policy for Utah Division of Risk Management

Pros	Cons
– Affordable, simple policy – Relatively fast payout (within 30 days of claim) – Policy parameters were tailored to the State needs/budget – Reduced State dependence on Federal post-disaster funding	– Coverage was solely for areas of greatest exposure – Zip codes where the parametric event was not triggered did not receive a payout – Changes in the probability of loss resulted in increased price of the policy in year following the event

7.4.4 Applicability of Parametric Insurance to the Texas Coast

Parametric insurance products provide opportunities for Texas stakeholders to better distribute funding and manage risk related to coastal resilience projects, as described below.

- Alternative funding is critical to implementing coastal resilience measures and maintaining them over time. Parametric insurance could provide funds for disaster recovery when budgets are under the most stress or provide opportunities to establish revolving loan programs or trusts or free up capital for public works and resilience projects. However, these opportunities may take several years to establish and become fully functional and have been explored in a limited capacity by others.
- Parametric insurance could provide a means for maintaining a balanced budget for coastal stakeholders, as it can assist with distributing financial burdens over time.
- Parametric insurance is not a single solution but can supplement other funding sources. It could provide an opportunity to generate local match funding that can be leveraged for federal disaster recovery programs.
- The ability to receive insurance payouts quickly and with more flexibility in how the funds are used may allow these policies to boost community response and recovery early in post-disaster efforts.
- Options for pre-disaster policies could allow for funding influxes to shore up the coast before a storm event and reduce the ultimate impacts when one occurs. This could lead to reducing future premiums on a policy when implemented effectively. However, this risk should be considered carefully, as there may be a lower likelihood of payout.
- Triggers can be customized based on a range of indicators ranging from erosion to water levels, temperatures, salinity levels, etc. However, selecting a trigger is not always straightforward and may result in no payouts generated if the selected trigger is not achieved during an event. Experts familiar with the risk being selected should be consulted prior to choosing a policy.
- The State of Texas has a potential role to play in ensuring that policyholders are paying for policies based on legitimate modeling results and current science. Given the higher cost associated with customized policies, the GLO may be able to facilitate a level of transparency and standardization for new parametric insurance policies to avoid exposing communities to too much risk.

7.5 Alternative Mitigation Credit Options

AECOM has been contracted by the Texas GLO to assist with coordinating and executing ongoing implementation efforts of the 2019 TCRMP. As a part of this effort, AECOM is conducting a reconnaissance-level inquiry with external agencies and partners from other states to explore the potential use of alternative and advanced mitigation credit options as a means of creating: 1) opportunities for protecting and enhancing sensitive wetland habitat that also provided a green infrastructure tool for increasing coastal resilience and 2) a potential funding source for project implementation of actions outlined in the TCRMP. The purpose of this primer is to convey the AECOM Team’s intent to coordinate with representatives of partners outside of Texas during a scheduled call to collect relevant information on alternative mitigation credit programs.

7.5.1 A Resilient Texas Coastline

The Texas coastline represents an integrated network of built and natural environments that must be considered in partnership to achieve coastal resiliency. It is an economic powerhouse for the state and nation, hosting most of the state's refineries, ports, aerospace, and other critical industries, but is also a vulnerable region susceptible to impacts from natural disasters and long-term environmental, social, and economic pressures. The GLO TCRMP documents a statewide effort to preserve and enhance the state's coastal natural resources while promoting economic growth. The TCRMP identifies priority issues that encompass risks and threats to the vitality of coastal communities, habitats, and industries and serves as a strategic roadmap that unites stakeholders from industries, agencies, academia, governments, and other interested parties to create solutions that support a resilient coastline.

7.5.2 GLO Tier 1 Projects

The GLO's 2019 TCRMP documents a statewide effort to preserve and enhance the state's coastal natural resources while promoting economic growth. As a part of the TCRMP, 123 vetted Tier 1 projects were identified as high-priority actions with a total project cost of $5.4 billion. Tier 1 projects consist of nature-based, infrastructure-based, or a hybrid (e.g., living shorelines) of actions that mitigate, both collectively and individually, the coastal vulnerabilities identified in the TCRMP.

GLO is currently in the process of coordinating across multiple funding streams to better leverage local, state, and federal funds for implementation of Tier 1 projects. The State of Texas does not provide a dedicated funding stream for coastal resiliency planning and projects, creating the need for a versatile approach that can maximize applicable funding.

7.5.3 Background on Existing Mitigation Banking Practices

Urbanization associated with the growth and transformation of communities can affect natural landscapes, impacting biodiversity, ecosystem processes, and agricultural areas. Expanding infrastructure projects may have adverse impacts to the natural environment.

Finding a balance between new infrastructure and preservation of land for biodiversity conservation, ecosystem processes, agriculture, and open public spaces is most effectively assessed and implemented using regional planning principles. Although avoidance is preferred, project impacts to wetlands and other environmentally sensitive areas are sometimes unavoidable. Section 404 of the Clean Water Act requires that lost function of impacted wetlands be replaced through use of a USACE-regulated mitigation bank (preferred) or an in-lieu fee program.

Use of the existing mitigation banking and in lieu fee program framework has many drawbacks, including a time-consuming approval process (5+ years), restrictive site criteria that may prevent areas of GLO land designated for Tier 1 projects from being added to existing banks as a credit, and a complex and costly process due to the involvement of multiple state and federal agencies. Therefore, it may be beneficial for GLO to explore alternative mitigation planning efforts to provide the mutual benefit of providing funding for prioritized Tier 1 projects while offsetting the unavoidable ecosystem impacts for planned infrastructure projects across the state. **Appendix J** provides an overview of existing alternative mitigation planning efforts and programs reviewed by the GLO.

7.5.4 Potential Role for Alternative Mitigation Credit Options

The use of alternative mitigation credits, similar to an in-lieu fee program, may provide an additional means for consistent funding of projects identified in the TCRMP, while also providing a mutually beneficial avenue for state agencies (e.g., TxDOT) to offset unavoidable ecosystem impacts for planned infrastructure projects.

ALTERNATIVE MITIGATION CREDIT OPTIONS
TEXAS GENERAL LAND OFFICE PRIMER

OVERVIEW

AECOM has been contracted by the Texas General Land Office (GLO) to assist with coordinating and executing ongoing implementation efforts of the 2019 Texas Coastal Resiliency Master Plan (TCRMP). As a part of this effort, AECOM is conducting a reconnaissance-level inquiry with external agencies and partners from other states to explore the potential use of alternative and advanced mitigation credit options as a means of creating: 1) opportunities for protecting and enhancing sensitive wetland habitat that also provided a green infrastructure tool for increasing coastal resilience and 2) a potential funding source for project implementation of actions outlined in the TCRMP. The purpose of this primer is to convey the AECOM Team's intent to coordinate with representatives of partners outside of Texas during a scheduled call to collect relevant information on alternative mitigation credit programs.

A RESILIENT TEXAS COASTLINE

The Texas coastline represents an integrated network of built and natural environments that must be considered in partnership to achieve coastal resiliency. It is an economic powerhouse for the state and nation, hosting most of the state's refineries, ports, aerospace, and other critical industries, but is also a vulnerable region susceptible to impacts from natural disasters and long-term environmental, social, and economic pressures. The GLO TCRMP documents a statewide effort to preserve and enhance the state's coastal natural resources while promoting economic growth. The TCRMP identifies priority issues that encompass risks and threats to the vitality of coastal communities, habitats, and industries and serves as a strategic roadmap that unites stakeholders from industries, agencies, academia, governments, and other interested parties to create solutions that support a resilient coastline.

GLO TIER 1 PROJECTS

As a part of the 2019 TCRMP, 123 vetted Tier 1 projects were identified as high-priority actions with a total combined cost of $5.4 billion. Tier 1 projects consist of nature-based, infrastructure-based, or a hybrid (e.g., living shorelines) of actions that mitigate, both collectively and individually, the coastal issues of concern identified in the TCRMP. To represent the ecological diversity of the Texas Coast, planning for the Tier 1 projects is completed on a regional scale based on four coastal areas of the state with diverse characteristics.

GLO is currently in the process of coordinating across multiple funding streams to better leverage local, state, and federal funds for implementing Tier 1 projects. The State of Texas does not provide a dedicated funding stream for coastal resiliency planning and projects, creating the need for a versatile approach that can maximize applicable funding.

POTENTIAL ROLE FOR ALTERNATIVE MITIGATION CREDIT OPTIONS

The use of alternative mitigation credits, similar to an in-lieu fee program, may provide an additional means for consistent funding of projects identified in the TCRMP, while also providing a mutually beneficial avenue for state agencies (e.g., Texas Department of Transportation) to offset unavoidable ecosystem impacts for planned infrastructure projects.

QUESTIONS FOR AGENCIES

Our Team's intent is to understand how alternative mitigation credit programs are being implemented in other states. We are primarily looking for information about establishing the framework necessary for a successful program, key stakeholders to involve, and any other lessons learned in the process. The following list of questions provides an overview of information we are looking to collect, as applicable.

1. What is the structure of the program developed by your agency, and why was this the preferred format?
2. Has the program been implemented and is it being used?
3. How are mitigation credits determined/assigned/verified (e.g., functional assessment models or protocols)?
4. Who is the final arbitrator of deciding the mitigation credits applicable for permitted impacts?
5. Who is eligible for the program and what is the entry way into the program (application, permit, etc.)?
6. What is the process for implementation, adaptive management, and subsequent monitoring?
7. What key stakeholders are involved? How does the program tie into federal processes?

8 Project Evaluation, Maintenance, and Implementation

A complementary task to identifying and progressing conceptual projects toward implementation was to assist the GLO in developing an effective manner for tracking and monitoring the 2019 TCRMP implementation. As the Tier 1 project types expand beyond the purview of the GLO's Coastal Division to include infrastructure and other agency-led components, effectively recognizing and publicizing the successful implementation of Tier 1 projects is a significant effort, but one that has long-term benefits.

8.1 Database and Project Tracking Updates

A project geospatial database (database) was developed for the TCRMP and updates were made to the database, as appropriate, by AECOM throughout the 2023 TCRMP planning process. AECOM identified opportunities to provide the GLO with additional project screening and identification tools associated with the TCRMP database, along with visualization features. Additionally, upon development of the list of projects for TAC evaluation identified in Project Screening and Prioritization, AECOM developed basic project attributes to populate the TCRMP database and subsequent project datasheets. This project attribute development was initially limited to project types, location, and status. Upon development of the tiered project list, AECOM enhanced the project attributes for the Tier 1 projects to include detailed cost estimates, funding updates, and project benefit details. Project benefit details leverage data developed under Ecosystem Services and Hazard Mitigation and Coastal Modeling and Support to provide further supporting project details.

8.1.1 Project Status

The possible project statuses for individual projects did not change and are included in **Table 8-1**.

Table 8-1. Possible Project Statuses for Individual Projects

Acquisition	Restoration and Construction	Other
• Conceptual	• Conceptual	• Monitoring
• Acquisition Pending	• Engineering & Design	• Study
• Acquired	• Permitted	• Other
	• Shovel Ready	
	• Under Construction	
	• Completed	

8.1.2 Attribute Modifications

As a part of the 2023 planning process, AECOM was charged with managing the project database that was previously developed and maintained for the 2017 and 2019 TCRMP documents, as well as, updating the database where appropriate. Updates to the database, described below, were a result of new information developed since 2019. The descriptions also include background information from the 2017 and 2019 database, as applicable.

Funding

The 2019 database ensured that information about project funding was readily available. It tracked the total project cost, funding sources (e.g., CEPRA, CMP, GOMESA), and the leveraged amount. Additionally, the TCRMP database also tracked the sources for that leveraged amount. For the 2023 TCRMP database, AECOM added the current amount funded for each project to the database.

Grant Cycles

Grant cycles have not been previously tracked in either the 2017 TCRMP or 2019 TCRMP and are a new addition under the 2023 TCRMP. The database now tracks the CEPRA, GOMESA, and CMP Cycles, as well as grant types (CMP 306; 306A).

Project Contacts and Stakeholders

Previously, the TCRMP database only included the local sponsor (the implementing entity, also referred to as the Professional Services Provider) and other project partners. Since 2019, the database now includes the project's funding partners, land ownership interests, and a project point of contact. For the point of contact, the database also includes their phone number, email, and address, if available.

Parent/Child Projects

In the updated database, unique IDs were created for parent and child projects along with additional information for the child projects. A project name will distinguish the child project from the parent and other child projects, and data of the child phase type and description will define whether it is a maintenance project of a portion of a parent project, and it will describe what component of the parent project this child project encompasses.

Project Schedule

The project type, status, phase, and scheduled completion date were included previously as part of the 2019 TCRMP Database. Additional information was added to the 2023 database to develop this section further. The database now includes a project start and closeout date and provides a link to online project information developed by outside organizations to each project if one is available.

8.1.3 Project Collections

The Project Collections List was developed to understand the relationship between phased projects in the TCRMP internal project database and better track the progression of these projects. This list will be used to update the database structure to include an identifier for projects that are related via geography, project purpose, entity, etc., as well as update the public interface to display project phases under a single Project Collection. The development of this list took into consideration the name and description of the projects, the location of the projects relative to each other, and the needs at the project site. A brief description of each of the criteria used to identify the linked projects, and the Project Collections process (**Figure 8-1**) is included below.

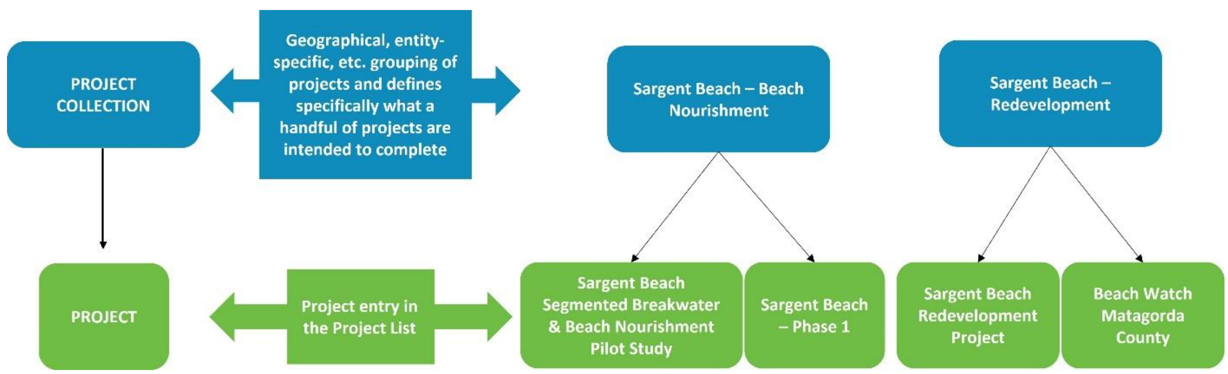


Figure 8-1. Project Collections Process

Project Name/Description

Using the Project List table in the internal TCRMP project database, projects were reviewed for related project titles and initial project groupings were formed based on this criterion. In some cases, the project name also included a phase (e.g., Shamrock Island Restoration – Phase 2). Once the groupings were established, each project description was reviewed to verify if the projects were related to the same goal, were intended to complete a portion of a larger project goal, or were replicating a previously completed project (i.e., beach nourishment project). The project description was also used to identify the project phase, if not listed in project name. If a link was provided for outside sources related to the project, these were reviewed to help determine project phase as well. Projects with related names, but no description were kept with the groupings for further verification. If a project name or description duplicated that of another project, the project was left in the grouping and was marked as a possible duplicate. Some projects included information regarding duplicates in the Project List table and were marked as duplicates in the Project Collections list. Projects that were determined not to be related were removed from the groupings.

Project Location/Site

The Project Locations shapefiles (Point, Line, Polygon) from the database were used to verify the location of the project groupings and identify other projects that may be related but were not identified through having a similar project name. Projects that were not located near the project site were inspected further to determine if the project location within the database needed to be updated or if the project was unrelated. The specific project site (e.g., Moses Lake) was used to help group projects based on the resiliency needs related to that site.

Project Collections Process

A Project Collection identifier will be attributed to each grouping and each project within that grouping will be given that identifier within the internal database. In the ArcGIS Online interface, the Project Collection identifier will identify the project site on the Interface map (either by point or polygon) and the related/phased projects that fall under that Project Collection. It will also include a brief description of the project site. This will also be incorporated into both the database and interface.

Introducing this process into the database and interface will help organize and maintain the current TCRMP projects, and, as more projects are incorporated into the database in the future, can help reduce the number of duplicate projects and help track the progression of phased projects.

8.1.4 TCRMP Interface

The TCRMP Interface is an ArcGIS online portal made to allow users to view project information housed in the TCRMP ArcGIS database. As it currently stands, the platform is only available to the GLO as a way to access that information without an ArcGIS license.

GLO TCRMP Viewer

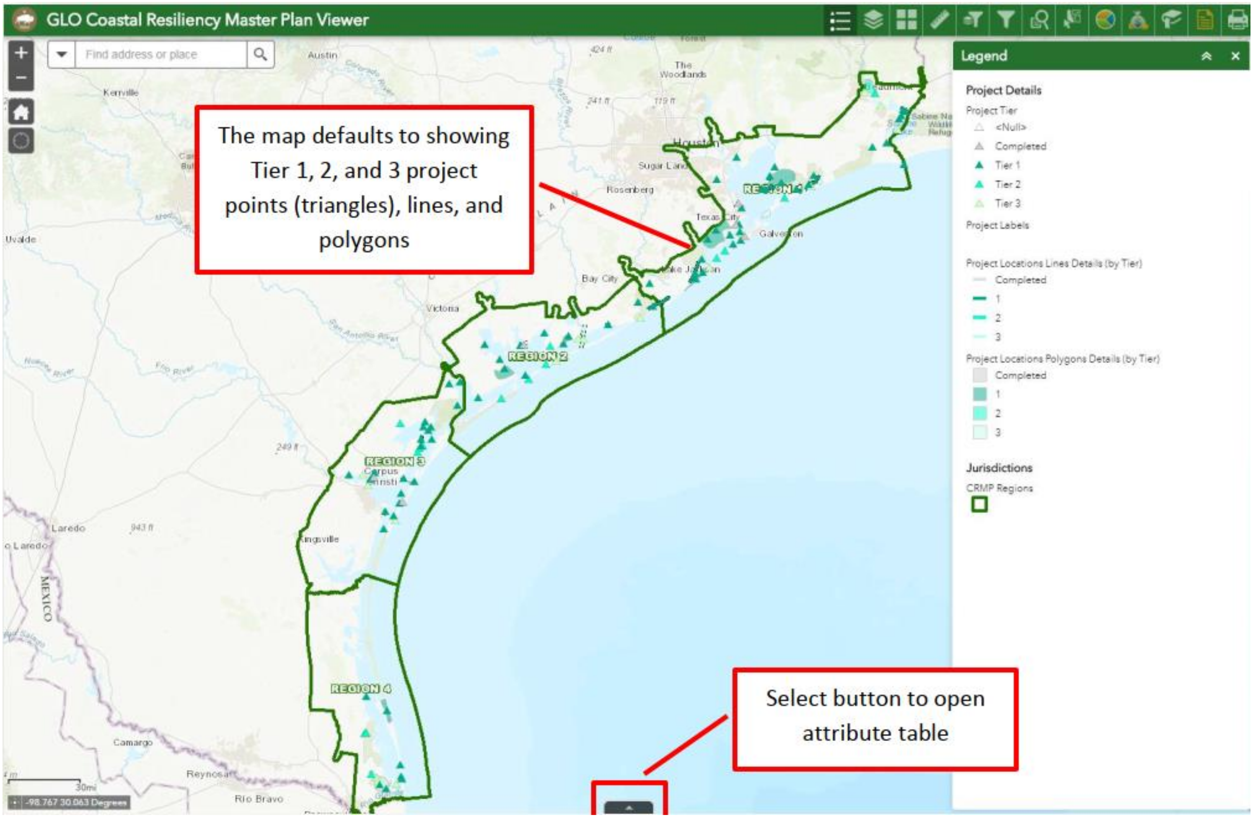


Figure 8-2. TCRMP Viewer Initial Screen

Above is the initial screen you will see upon accessing the viewer (**Figure 8-2**). Initial data shown includes Tier 1, 2, and 3 projects based on the 2019 TCRMP, along with applicable lines and polygons that further define specific projects. Also shown are the boundaries for the four planning regions identified in this plan. Beyond this initial page, the platform also includes project attributes, a search bar, and a tool bar (i.e., legend, layers, basemaps, measure, project details). As mentioned, this platform does not currently have public access but that may be something developed in the future.

8.2 Project Evaluation Datasets

8.2.1 Background

The 2023 TCRMP is the third installment of a statewide plan to protect and promote a vibrant and resilient Texas coast that sustains a strong economy and healthy environment (built and natural) for all. As with previous versions, the 2023 TCRMP identifies vulnerabilities that encompass coastal risks and threats to society, the economy, and the environment. Implementing the 2023 TCRMP requires a holistic framework of responses to these vulnerabilities; each response is considered an Action. Ten Actions have been identified through a data-driven approach to reduce or avoid long-term vulnerabilities to the identified hazards. These Actions will help to identify and categorize projects to be included in the 2023 TCRMP, as each project is intended to align with one or more of the ten Actions identified. Prioritized projects will move on to the next step of development in which information such as funding and financing opportunities will be considered. The purpose of this memorandum is to outline proposed data to assist in identifying a well-balanced portfolio of projects to be included in the 2023 TCRMP with an emphasis on the project evaluation phase, though application of the data may be relevant for the project development phase. This process is outlined in **Figure 8-3**.

This Project Evaluation Dataset Memo begins with an overview of project evaluation considerations for developing a well-balanced portfolio of projects that addresses both physical and socioeconomic resilience. This is followed by a discussion on data for consideration. **Appendix K** includes a literature review on common and/or recent guidance and methodologies used in project evaluation for resilience and a discussion on incorporating equity in resilience planning. Information presented here is subject to change based on feedback and data availability.

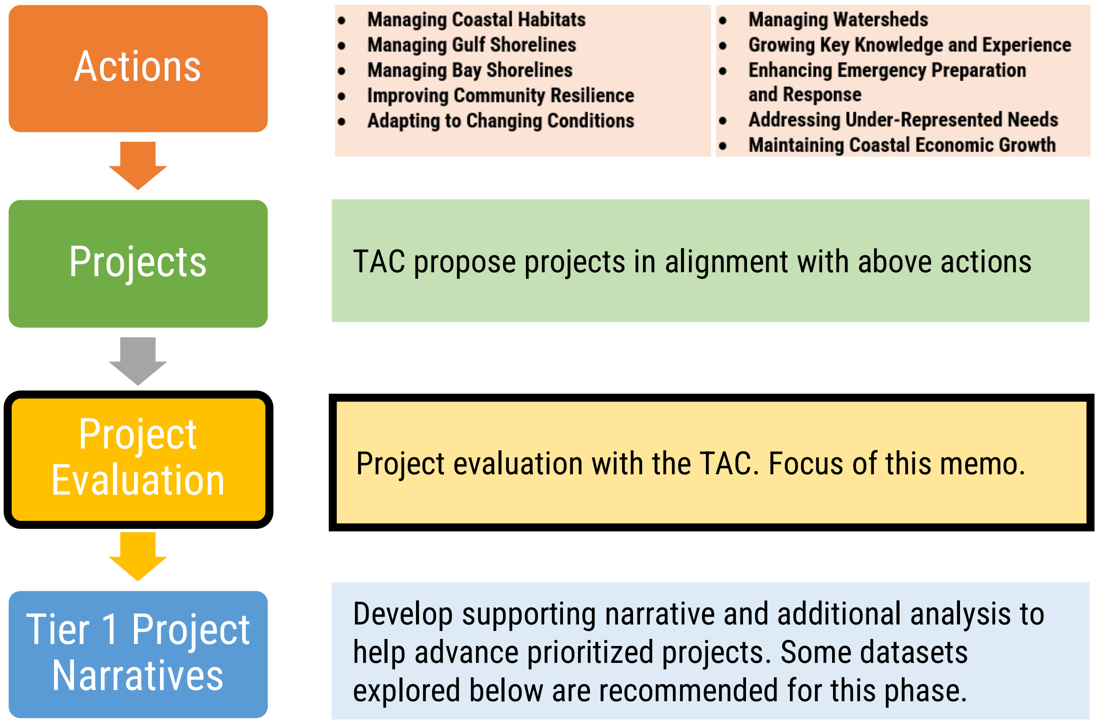


Figure 8-3. Project Evaluation Step as Part of Larger Project Development Process for the 2023 TCRMP

Project Evaluation Process & the Role of Data

Similar to the Action development, it is important for the project evaluation process to be driven both by data and stakeholder input. The data-driven approach will be well-documented and transparent, relying on public sources as available. To align with the Actions and the overall framework of the 2023 TCRMP (see **Figure 8-4**), the evaluation process should account for social, economic, and environmental considerations. This data will contextualize projects to align the prioritized project list with the objectives of the 2023 TCRMP to help coastal communities increase resiliency and mitigate the negative impacts associated with identified vulnerabilities.

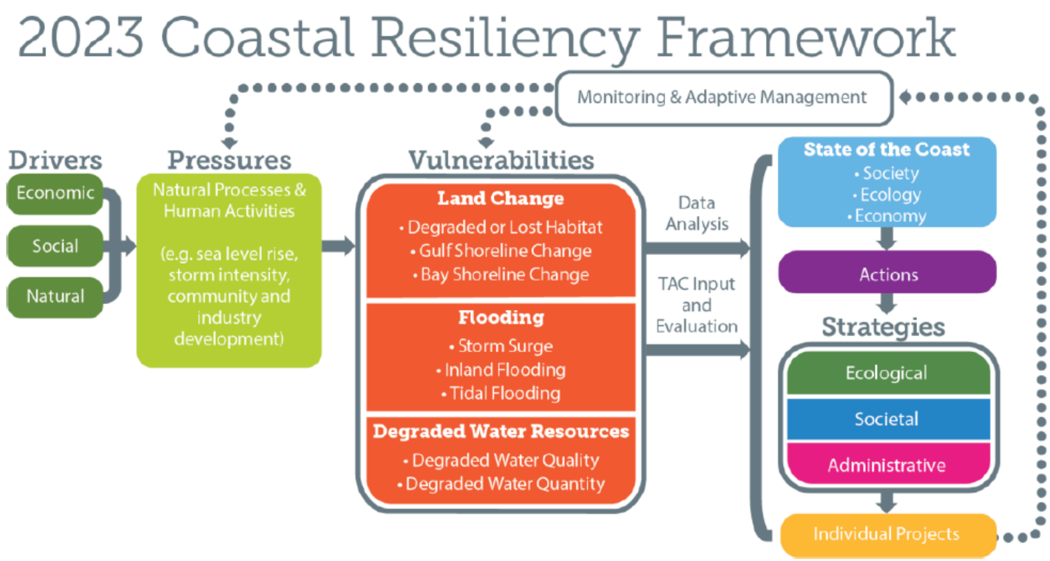


Figure 8-4. 2023 Coastal Resiliency Framework

This information is anticipated to be used in workshops with the TAC in the summer of 2022. From the full list of proposed projects, the TAC will prioritize projects, as was done for previous versions of the TCRMP. It will be important for the TAC to have access to the project information and supporting data as they review the project evaluation form. Information will be available in an overall project tracker, which is envisioned to be a multi-source data system that feeds outputs in an Excel database and a dashboard (e.g., PowerBI, ArcGIS) that can be used to visualize the information with filtering and aggregation. Given that the workshops will be held using a hybrid virtual / in-person format, there may need to be some adjustments to the format of the project evaluation workshops, which will be the subject of future discussions. After the TAC completes their evaluation, the project team may use the data to help determine if the Tier 1 project list addresses the ten Actions.

The data proposed in this memo are anticipated to help inform the TAC's evaluation process, but as proposed here, this information will not be used to rank projects or introduce descriptive ratings (e.g., good/bad or high/low). Instead, the data will allow the TAC to understand the context of proposed projects and compare them in an organized way, with the overall goal of developing a well-balanced portfolio of projects that addresses both physical and socioeconomic resilience. The data fall under three key categories: contextual social, economic, and environmental data; project-related benefits; and hazard-related data (**Figure 8-5**).

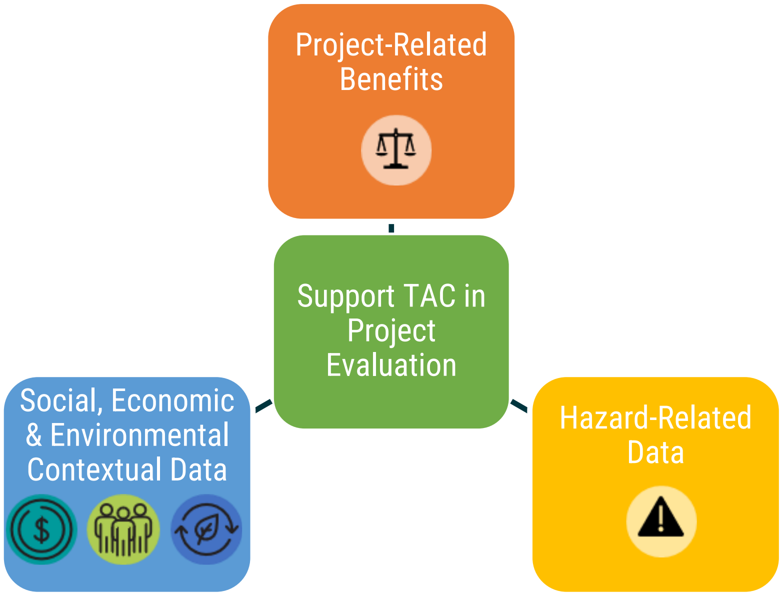


Figure 8-5. Types of Data to Be Used to Support Project Evaluation

In addition to refinement of the project meeting format and the proposed data, additional components related to the project evaluation process may also still be included, such as:

- A scoring system,
- Weighting, and/or
- Data aggregation (e.g., composite "social" percentiles).

Scoring, weighting, and aggregation introduce additional complexity to the project evaluation process but may be helpful for developing a data-driven approach to evaluation and may be subject to further discussions. These additions are not the subject of this memo, which focuses on potential data to support a project evaluation process.

Data to Support Project Evaluation

This section recommends a subset of data to be used for the TCRMP project evaluation process and other data that may be better suited for the following phase (Tier 1 project narratives). Mindful of resource constraints, and that the project evaluation process is to occur early in the planning phase, it is important to note that this list is not intended to be exhaustive. Additionally, note that there is some overlap between the datasets and that the final data selected may likely be a subset or altered collection of data pieces based on input and future discussions with the project team. Following their descriptions, all information is summarized in **Table 8-2**, which also includes details related to whether the data are recommended for use in the project evaluation phase.

Data are recommended based on several factors, including applicability, replicability, and ease of interpretation. The aim was to address the majority of project types and Actions. While specific types of projects may be well suited to be evaluated with particular datasets (e.g., transportation projects may have a unique set of helpful information to consider), that type of information would be better suited for the prioritized project development phase.

The data recommended below were developed based on a literature review, the 2023 TCRMP Actions, the 2019 TCRMP, and the project list. Project types and project subtypes range from fully nature-based solutions to fully infrastructure-based solutions. 'Study', 'Plan', 'Policy', or 'Program' designations constitute a separate, non-structural project type; however, non-structural projects are not the focus of the data proposed here.

Note that the emphasis is on information that can be presented spatially, so as to assist the TAC as it prioritizes projects. It may also be the case that some project types or database inputs may be used as a binary input that could be helpful to view as a filter or aggregator. For example, nature-based solutions may be projects tagged as NbS and then the user could see the maps with the information presented solely for NbS-tagged projects.

Social and economic contextual data is provided mostly at the census tract and/or county level and will ultimately be presented spatially based on percentiles (some of which are coastal-based and others of which are statewide, with preference for the latter when feasible). Project-related benefits are more spatially detailed, but data may be more limited. Hazard assessment data are also more spatially detailed but are not quantified for with-project scenarios, and therefore are more beneficial for helping to determine areas of concern.

Contextual: Economic Data

Economic data can provide important information relating to businesses, income, property, and real estate information. Economic data considered for this assessment include:

Employment: Employment per square mile based on ESRI Business Analyst 2020 data, captured at the census tract level. Information is available at the six-digit NAICS code level, allowing for aggregation for tourism industries or other industries of interest. Information is also available for several employees by business, allowing for an understanding of small businesses.

Wages: BLS Quarterly Census of Employment and Wages from 2020 by two-digit NAICS code. Information is provided at the county-level but may be overlaid onto ESRI business establishments to calculate information at the census tract level.

HUD LMI data: LMI regions are defined as areas that are primarily residential and where at least 51 percent of residents qualify as LMI populations (US HUD 2015)[4]. Area median income (AMI) can be captured at the census tract level, and the proportion of the population in various LMI categories may be presented based on statewide percentiles.

Commercial and residential real estate value: CoStar analytics at the census tract level for real estate value can be collected. These data may not be necessary to include given that the Hazus modeling already includes information on value of the structures.

Avoided Damages: This will be informed only under a no-action scenario at this stage from Hazus modeling (please see Hazard-Related Data for more information). Avoided damages for projects could be incorporated in the next phase (Tier 1 project narratives).

Contextual: Social Data

Social data can be used to help understand which communities may be more vulnerable to identified hazards. Effective investments in adaptation and hazard mitigation efforts can improve community resilience, or the capacity to prepare for, respond to, and recover from significant hazard events while minimizing damage to social well-being, the economy, and the environment. Furthermore, protecting community assets, such as local cultural districts, is important for supporting daily life for residents, businesses, and tourists alike. Included in the following list are also datasets related to the built environment, which are directly correlated to avoiding loss of life and core functions of society and to adaptive capacity. Social data considered for this assessment include:

Population density: Population per square mile at the census tract level from 2019 American Community Survey (ACS) 5-year estimates.

[4] Low income: up to 50 percent of the Area Median Income (AMI); Moderate income: greater than 50 percent AMI and up to 80 percent AMI; Medium income: greater than 80 percent AMI and up to 120 percent AMI.

Social Vulnerability Index: University of South Carolina's Hazards and Vulnerability Research Institute (HVRI) Social Vulnerability Index (SoVI)® , which was used in the State of Texas CDBG-MIT Action Plan and was calculated specifically for census tracts and counties in Texas.

Historical investment: Historical investment information will be considered at the census tract level, although data is specifically focused on coastal tracts, and therefore, the percentile universe is not statewide. Note the information collected relates to CMP, Coastal Impact Assistance Program (CIAP), GOMESA, and CEPRA grant investments since 2010 (plus 2007-2010 for CIAP),[5] which was provided at the project-level and includes other information such as the applicant entity and their contributions, third-party contributions, and status of project. Only active or completed projects will be included, not proposed or canceled projects. Furthermore, only the contributions from the grants will be included, rather than other funding sources (such as local match), as this information was not consistently provided for all grant types. Additional information may also be collected from GLO's dataset on CDBG Disaster Recovery Mapping Viewer, which includes information on awards and FEMA claims (Texas GLO 2021).

Critical Infrastructure: Focusing protective investments on critical facilities and emergency response can provide cascading benefits. The 2016 GLO Infrastructure Study with data prepared by CB&I will be leveraged for this layer.

Local district overlays: Special district overlays can identify any special cultural or historic zones. These could include polygon locations of the historic sites managed by the Texas Historical Commission or the National Register of Historic Places, or cultural districts such as those designated by the Texas Commission of the Arts (point data) (Texas Commission on the Arts 2021; Texas Historical Commission 2022). Information varies in terms of geographic extent and is typically polygon or point-based. If used, it may be best utilized as a binary assignment to tag to projects if they are within a certain proximity of the site or district.

Local building codes: The National Building Code Adoption Tracking Portal can identify jurisdictional building code adoption status. Information is available by hazard (flood, hurricane, seismic, and others) or for combined hazards at the level of Census Incorporated Places and Counties. This information may be best applied as a descriptor, such as the building code adopted for the area (e.g., 2012 International Building Code).

Contextual: Environmental Data

Environmental data addresses potential benefits that leverage natural processes to reduce coastal vulnerability and/or minimize contamination. Environmental data considered for this assessment include:

Ecosystem Services: FEMA provides standardized monetized values for a variety of ecosystems and the 2019 TCRMP provided ranges for certain habitats. Ecosystem service-related data may be incorporated using project-level information, if available, such as number of acres protected or introduced; this could support future quantification and/or monetization for the Tier 1 project narratives phase.

Environmental Justice (EJ) Screening Tool Environmental Indicators & Hazardous Sites: Identifying sites that house hazardous chemicals and materials in the region is critical in a coastal region particularly vulnerable to flooding. The EPA's Risk Management Plan (RMP) database can be used to identify industrial facilities that handle large quantities of hazardous substances in the region. Additionally, the EPA's environmental indicators comprise part of the EJ Screening Tool. Specific relevant environmental indicators include proximity to waste and hazardous chemical facilities or sites and proximity to toxicity-weighted wastewater discharges; these could be combined with the EJ Screening Tool's demographic index to develop an EJ Index for each of the two indicators and show population at risk (relative to the national average).

[5] Note this is based on the information provided in email correspondence. The data itself does not have a 'date' field. The CMP data do include a 'cycle' field– which sometimes appear as a year, and other times do not. The "CEPRA" shapefile also has cycle but is not date-based.

Coastal Environment Data Overlays: GLO maintains several maps and tools related to natural resources, particularly for coastal areas (Texas GLO 2022). A number of these could be used to understand the geographic context of a project, such as the Coastal Resources Mapping Viewer, Priority Protection Habitat Areas, the Oil Spill Response Mapping Tool, and the Environmental Sensitivity Index Shoreline. Some of these may be better suited for inclusion in the next phase (Tier 1 project narratives). Some, however, may be used as a binary assignment for projects based on their location (e.g., whether the project is located in a priority protection habitat area). This could also include the Bay Shoreline Change Rate dataset from UT-BEG and GLO's hardened shoreline locations.

Hazard-Related Data

Hazard-related data brings information from the vulnerabilities assessment, as well as details related to past events and risks. Hazard-related data considered for this assessment include:

Hazus Risk Estimation (No Action): Hazus provides standardized tools and data for estimating risk from a host of natural hazards, including earthquakes, floods, tsunamis, and hurricanes (FEMA 2021b). In the 2019 TCRMP, loss estimates were modeled for physical damage resulting from storm surge and SLR, in addition to business interruptions. Physical damages assessed include damages to structures (by structure type) and contents, inventory losses, relocation costs, income loss, rental income loss, and wage loss. Damages were estimated for six metro areas on the Texas coast and were modeled for current conditions and future conditions (2100) with no action. Results were aggregated at the census block level. It is recommended that Hazus risk estimations be used as a proxy for a high-level assessment of potential damages under no action.

Composite Disaster Index: This is a county-level index highlighting counties most frequently impacted by most severe natural hazards in the past two decades, as is including in the CDBG-MIT Plan.

National Risk Index: The National Risk Index (NRI) is a dataset and online tool that illustrates the communities most at-risk for select natural hazards, defining risk as a function of expected annual losses from natural hazards, social vulnerability, and community resilience (FEMA 2021a). The NRI defined social vulnerability as the susceptibility of social groups to the adverse impacts of natural hazards, including disproportionate death, injury, loss, or disruption of livelihood, defined at the county and census tract level. The NRI also leverages the HVRI SoVI®. As such, the NRI findings expand upon the HVRI SoVI® while considering other factors such as exposure and resilience.

Project-Specific Benefits

The majority of project-specific benefits may be better suited for the following phase (Tier 1 project narratives) due to difficulty in developing and/or collecting necessary data. Project-specific benefits data considered for this assessment include:

Project Information: Information such as project costs and project effectiveness (gleaned from Hazus modeling the TAC's input on how projects perform against each of the eight vulnerabilities) will be important information for the next phase ("Tier 1 project narratives"). As able, with the information gathered by the June workshops, information on the projects may be included – such as their descriptions, any available information on costs, sponsors, and other relevant information.

Average Annual Habitat Units (AAHU) by species: In ecosystem restoration planning, the USACE's objective is to contribute to national ecosystem restoration (NER). NER is measured in terms of increases in the net quantity and/or quality of desired ecosystem resources (US Army Corps of Engineers 2015). Under USACE guidance, Habitat Units are used as inputs to the Cost Effectiveness Incremental Cost Analysis to compare the alternative plans' average annual cost against the AAHU estimates. This would require additional analysis across project alternatives and would not be suitable for the project evaluation phase.

Water Quality Improvements: Water quality improvements are measured by a reduction in the number of days exceeding water quality thresholds. Because assessing water quality improvements would require additional water quality modeling and analysis, which will not be completed at the time of project evaluation, it is not recommended that water quality improvements be considered in the project evaluation phase.

Storm Surge Mitigation: Natural infrastructure, such as marshes and mangroves, and hard infrastructure, such as levees and seawalls, can mitigate damages from storm surge. Estimating damage reductions requires hydrology and hydraulic modeling, which will not be performed at the project evaluation level. While it is not recommended that storm surge mitigation benefits be quantified at the project evaluation level, it is recommended that storm surge mitigation be included as a binary variable to identify projects that are able to mitigate storm surge, a leading source of coastal vulnerability. It is recommended that storm surge mitigation benefits be quantified later in the planning process.

Recreation Benefits: Recreation benefits can be measured through the Unit Day Value method, which is estimated based on the average willingness to pay of users' recreation resources. This method, however, relies on information related to change in access to recreation, such as number of recreation days or beach width. This data has not been collected on a project evaluation level, and it is not recommended that recreation benefits be considered in the project evaluation framework.

8.2.2 Summary Table of Datasets to Support Project Evaluation Phase

Table 8-2. Summary Table of Datasets to Support Project Evaluation Phase

DATASET	SOURCE	DESCRIPTION/ PURPOSE	FOR THIS PHASE?	DATA CATEGORY(IES)
CONTEXTUAL: ECONOMIC DATA				
EMPLOYMENT	ESRI Business Analyst	Overview of employment density aggregated by two-digit NAICS code industries and number of employees by business, to understand industries, business types and number of employees at risk from hazards under no action.	Yes	
WAGES	Quarterly Census of Employment and Wages, BLS	Overview of employee wages by NAICS code to understand the potential wage losses caused by hazard events. Information from BLS is available at the county-level.	Yes	
HUD LMI DATA	LMI data, HUD	Overview of primarily residential LMI populations and AMI to understand concentrations of lower income households.	Yes	
REAL ESTATE VALUE	CoStar	CoStar analytics to understand residential and commercial real estate values at the census tract level.	Maybe	
AVOIDED DAMAGES (BENEFITS)	See below under Hazus Risk Estimation	See below.	See below	
CONTEXTUAL: SOCIAL DATA				
POPULATION DENSITY	ACS 5-year estimates, 2019	Overview of population per square mile at the census tract level, to understand the population at risk from hazards.	Yes	
SOCIAL VULNERABILITY INDEX	HVRI SoVI®	Overview of concentrations of social vulnerability to understand uneven distributions in a community's ability to prepare for, respond to, and recover from hazards and identify where resources might be used most effectively to reduce vulnerabilities.	Yes	
HISTORICAL INVESTMENT	CMP, CIAP, GOMESA, and CEPRA; past CDBG awards	Overview of past investments made on infrastructure in frontline communities to identify discrepancies in historical investments which have created high social vulnerability and exacerbated present-day vulnerability to natural hazards.	Yes	

DATASET	SOURCE	DESCRIPTION/ PURPOSE	FOR THIS PHASE?	DATA CATEGORY(IES)
CRITICAL INFRASTRUCTURE	2016 GLO Infrastructure Study	Overview of protective investments on critical facilities and emergency response procedures, to understand potential benefits of more resilient critical infrastructure.	Yes	
LOCAL OVERLAY DISTRICT	State/local government data portals	Overview of special district locations and boundaries, such as historical and cultural assets. Information is available at the point-level and polygon-level for historical sites.	Maybe	
LOCAL BUILDING CODES	National Building Code Adoption Tracking Portal	Identify jurisdictional building code adoption status, to understand adoption and implementation of building code mitigation activities. Information is available for Census-designated Places.	Maybe	
CONTEXTUAL: ENVIRONMENTAL DATA				
ECOSYSTEM SERVICES	FEMA standardized values for NbS activities / Project-specific data	Overview of nature-based solutions and their respective ecosystem services, to understand the benefits of nature-based solutions to mitigate hazard events.	Maybe	
EJ SCREENING TOOL ENVIRONMENTAL INDICATORS & HAZARDOUS SITES	EPA's Risk RMP database	Identification of sites that house hazardous chemicals and materials and are vulnerable to hazards, to understand high-risk locations which may exacerbate negative impacts to communities and the environment during and post-hazard event.	Yes	
COASTAL ENVIRONMENT DATA OVERLAYS	GLO's GIS datasets, UT-BEG	Information on natural resources and shoreline sensitivity along the Texas Coast, may be best suited as binary assignments or for next phase.	Maybe	
HAZARD-RELATED DATA				
HAZUS RISK ESTIMATION, NO ACTION	Hazus, Current and Future Conditions	Overview of natural hazard vulnerability, including earthquakes, floods, tsunamis, and hurricanes based on historical and scenario-based modeling, to understand areas of high vulnerability and potential economic losses, building damage and social impacts from natural hazards based on historical events and planned scenarios.	Yes	
COMPOSITE DISASTER INDEX	CDBG-MIT	Overview of counties most frequently impacted by the most severe natural hazards, to understand county-wide vulnerability to severe natural hazard events.	Maybe	

DATASET	SOURCE	DESCRIPTION/ PURPOSE	FOR THIS PHASE?	DATA CATEGORY(IES)
NRI	FEMA's NRI, 2021	Overview of communities that are most vulnerable to natural hazards at the census tract level, to define risk as a function of potential annual losses from natural hazards, social vulnerability, and community resilience.	Maybe	
PROJECT-SPECIFIC BENEFITS				
PROJECT INFORMATION	Dependent on project-specific data	Overview of project information to understand how effectively actions outlined in the TCRMP are addressed.	For Next Phase	
AAHU BY SPECIES	Dependent on project-specific data	Overview of potential net increases in quantity and quality of ecosystem resources, to understand the cost effectiveness of projects and compare alternative plans to support project selection.	For Next Phase	
WATER QUALITY IMPROVEMENTS	Dependent on project-specific data	Overview of water quality improvements, to understand the number of days exceeding water quality thresholds and identify opportunities to decrease this through project implementation.	For Next Phase	
STORM SURGE MITIGATION	Dependent on project-specific data	Overview of potential storm surge mitigation measures, to understand damage reductions realized by implementing potential natural infrastructure projects.	For Next Phase	
RECREATION BENEFITS	Dependent on project-specific data	Overview of public recreation benefits calculated via the Unit Day Value method, to understand potential additional recreation benefits realized by projects.	For Next Phase	

Next Steps

Outlined below are the key next steps related to project evaluation:

- Workshop planning and logistics.
- Selection of final data for use in project evaluation phase.
- Consideration for data aggregation (and other considerations as discussed in Project Evaluation Process & the Role of Data).
- Development of database and spatial visualization platform.
- Development of matrix that correlates project evaluation data with ten actions to be used to understand how TAC prioritization results align with actions.
- Tier 1 project narratives for Tier 1 projects.

8.3 Tier 1 Project Evaluation Summary

As part of the development of the 2023 TCRMP, the TAC served in a project evaluation role. Under this effort, regional TAC meetings were held to present eligible projects for consideration of their priority and level of benefit towards overall coastal resilience in Texas. This section summarizes the approach to collecting TAC evaluation information and feedback for individual projects and the methodology used to leverage TAC evaluation responses in determining Tier 1 projects for this iteration of the TCRMP.

8.3.1 Survey Forms and Data Collection

Microsoft Forms was used as the interface to collect survey responses and comments from TAC members on the 2023 evaluated projects. The Microsoft Forms are broken down by region and county, so each survey form only contained projects from that specific area. The TAC members were able to rank various metrics related to the project's benefits, issues the project addresses, project importance, and to provide additional written comments/feedback.

After completing the survey, TAC responses were saved to the cloud in the Microsoft Forms program, which can be accessed at any time from the admin links to the survey. Raw data was downloaded as an Excel spreadsheet for the purposes of analyzing the results. Each exported table from Microsoft Forms was labeled according to its respective region and county. These were saved individually to store original data outputs, as well as compiled into another spreadsheet for processing of all TAC results in one location.

8.3.2 Data Processing for Evaluation

The compiled raw data was used calculate and present all TAC results. The copied raw data for Microsoft Forms contained a string of text alongside the numeric score (i.e., "4 – Certain Feasibility"). This is not useful for formulas and calculations, so the text responses were converted to be numeric responses only (i.e., "4"). The responses that were only a string of text: "Yes, No, Unsure" were converted to single character responses for simplicity to be "Y, N, U" (excluding additional comments). None of the original responses were edited to change their value or meaning and were only condensed for more streamlined processing.

In addition, the number of participating TAC members who completed the surveys was gathered from the number of unique IDs of the respondents. The unique IDs were run through a python script that counted and returned the number of unique participants to avoid counting duplicate participants. Participation was evaluated on a regional basis to reflect the number of participants in that regional TAC meeting who completed the county surveys. For inter-regional projects, the same process was used with IDs from both regions to find the number of unique inter-regional participants.

8.3.3 Measured Metrics and Calculations

The metrics discussed below are a measured or calculated product of the processed data. These metrics serve to set up a framework for the subsequent evaluation process. All measured metrics and calculations are solely dependent on the processed data.

Vulnerability Scoring and Sum

The eight vulnerability scores for each project were averaged and displayed representing the respective vulnerability category with a possible range of [0-4]. For each project, a vulnerability scoring sum was also calculated, which is a summation of all eight averaged vulnerability scores with a possible range of [0-32]. This cumulative score gives an indication of the range of different environmental vulnerabilities the projects plans to address. The higher the score, the more the vulnerability is addressed. A normalized score [0-1] was created from the [0-32] range for simplified processing.

Feasibility

Feasibility scores, ranging [0-4], were averaged from the TAC responses for each project. These responses are an indication of whether TAC members think that a project can be reasonably accomplished. The higher the score, the more feasible the project is.

Priority

Priority scores (Y, N) were counted for each project. The percentile of the "Yes" and "No" responses were calculated based on the respective TAC member choice divided by the total number of responses. The priority score was calculated the same as the priority "Yes" percentile, but as a decimal with a possible range of [0-1]. Priority scores are an indication of what projects the TAC views are most urgent or important towards improving coastal resilience. The higher the Y:N ratio, the higher the priority of that project as assessed by TAC members.

Grouped Vulnerability Score

The grouped vulnerabilities are categorized as Land Change (1), Flooding (2), and Degraded Water Resources (3), and encompass the following individual vulnerabilities:

1. Degraded/Lost Habitat, Gulf Shoreline Change, and Bay Shoreline Change
2. Storm Surge, Inland Flooding, and Tidal Flooding
3. Degraded Water Quality and Degraded Water Quantity

From within each of these groups, the highest score among the vulnerabilities in that group was selected to represent the group for that project (i.e., if the Degraded/Lost Habitat score was greater than the Gulf Shoreline Change and Bay Shoreline Change scores in group 1, the Degraded/Lost Habitat score was used). Group vulnerability scores were then summed together to generate a score with a possible range of [0-12]. Grouped vulnerability scores combine related vulnerabilities to output a score that is a snapshot of the best addressed vulnerabilities for each project. The better a project addresses each of the different category groups, the higher the score will be. A normalized score [0-1] was created from the [0-12] range for simplified processing.

8.3.4 2023 Selected Evaluation and Ranking Method

A new type of evaluation and ranking method was selected for 2023 compared to the 2019 and 2017 TCRMPs. For this rendition of the TCRMP, a multi-step system was used to evaluate the list of projects into three categories: Tier 1, 2, and 3 (no change from previous TCRMPs). This 3-step process utilizes all the gathered metrics from TAC members (i.e., feasibility score, vulnerability score, and priority score) to ensure thorough and representative ranking determination of 2023 Plan projects (previously, only the priority score was used, with feasibility being a secondary consideration). Unlike the other methods used in previous TCRMPs, the 3-step evaluation is not a single formula ordered ranking system. This system evaluates projects on a Tier 1/Pass/Tier 3 basis with multiple factors that could potentially highlight red flags or outlying low scores for projects, as well as identify promising projects with the most valued attributes to respond to coastal vulnerabilities.

The three evaluation metrics are feasibility, priority, and vulnerability / grouped vulnerability.

1. Step 1: In the first step, feasibility scores are screened at a 2.0 cut off point. Projects that fall below 2.0 are removed from consideration and designated Tier 3, while projects above 2.0 are pushed forward as "PASS" projects to the next evaluation step.
2. Step 2: Priority score evaluation is step two, where "PASS" projects from step 1 with scores greater than or equal to 0.75 are designated at Tier 1 projects. "PASS" projects with priority scores less than 0.75 but greater than or equal to 0.5 are kept in consideration for step 3. Projects below 0.5 are designated as Tier 3 and removed from further consideration.
3. Step 3: Step 3 evaluates "PASS" projects with a priority score between or equal to 0.75 – 0.65 if they also have EITHER a grouped vulnerability score OR vulnerability score greater than or equal to 0.78 to be Tier 1 projects. The remaining ("PASS") projects for consideration now become Tier 2, and the previously Tier 3 projects remain Tier 3.

Below is a record of the cutoffs and designations for each of the three steps. After these processes, the remaining is a list of 74 individual Tier 1 projects.

Cutoffs

- Step 1: Feasibility
  - Pass: x ≥ 2.0
  - Tier 3: x < 2.0
- Step 2: Priority
  - Tier 1: x ≥ 0.75
  - Pass: 0.75 > x ≥ 0.5
  - Tier 3: x < 0.5
- Step 3: Vulnerability
  - Tier 1:
    - Priority 0.75 ≥ x ≥ 0.65
    - Vulnerability OR Grouped Vulnerability ≥ 0.78

8.4 Project Costs

Cost estimates for all candidate projects were developed to provide a sense of scale as well as a point of reference for understanding project efficiencies (the relationship between project cost and project results or benefits). The cost assessment methodology provided for comparison of similar projects and included an explicit set of assumptions associated with each project definition. The process also entailed development of standard project templates, by project type or subtype that featured quantified parameters to be developed for each project and were used to compute standardized costs for the proposed projects. Detailed, line-item costs were then produced for each project.

All cost estimates were developed at a planning level based on available information and stated assumptions. Any costs developed for a project by one of the project's stakeholders, typically based on more detailed design and refined project specific inputs, would supersede the costs developed as part of the Resiliency Plan. The estimates included the following cost and related items:

- **E&D Fee:** It was assumed that these fees would be approximately five to ten percent of the total construction cost of a given project, depending on the overall scale of the project. This percentage estimate is based on a review of past projects and current design and construction practices.
- **Construction Cost and Management:** This category includes the overall cost of construction, as well as any fees for professional services rendered during construction to monitor contractor compliance with contract requirements, schedules and costs.
- **Mobilization and Demobilization Costs:** These fees cover contractor costs associated with movement of equipment and personnel at project start-up and closure. This was assumed to be up to ten percent of the construction cost.
- **Annual O&M Costs:** These costs include fees incurred for the administration, supervision, operation, maintenance, and preservation of the projects being constructed. It was estimated based on monitoring frequency, maintenance frequency, and operation duration.
- **Project Activities and Primary Project Materials:** Templates for each project type were developed to include principal project features for the corresponding project type. Design elevations and dimensions were based on project-specific information obtained from publicly available sources or set to a standard set of parameters for the applicable project template. The estimated quantities apply to both the project activities (e.g., amount of soil material requiring excavation) as well as the project materials (e.g., amount of stone needed for construction)

- **Contingencies:** A 5 to 20 percent contingency was used to develop final estimated construction costs for projects and was based on current practice for coastal projects. “Contingency” is the allowance for costs expected to be part of a project total, taking into consideration such factors as deviations in anticipated quantities and labor requirements, among others.
  - The amount of contingency required for each project is related to the expected feasibility of completing the project (5% - High Feasibility, 10% - Medium-High Feasibility, 15% - Medium-Low Feasibility, 20% - Low feasibility), or in some cases, the amount of project data available.
  - The expected feasibility for the amount of project contingency was determined for each project based on the TAC’s assessment of the project feasibility on a scale of 0 to 4. For the projects evaluated in 2019, a project was considered highly feasibility if the project received a TAC feasibility score of 3.14 to 4; medium-high feasibility if the project received a TAC feasibility score of 2.9 to 3.14; medium-low feasibility if the project received a TAC feasibility score of 2.54 to 2.9; and low feasibility score if the project received a TAC feasibility score of 0 to 2.54.

In addition to cost items, the detailed project costs include data and details used to assess project benefits:

- **Impact Area:** Determines the approximate populated area the completed project will impact. The area options are large scale (occurs in multiple locations along the coast), metropolitan (50,000+ people), micropolitan (10,000 to 50,000 people), and rural (<10,000 people).
- **Sector:** Identifies the primary industry (as defined by USACE) related to the project. The sectors include emergency management, environmental, flood risk, hydropower, navigation, recreation, regulatory, and water storage.
- **Site Visitors:** Estimates the number of visitors to the site per day (local/non-local), boaters, and multi-day/overnight users.
- **Equipment:** Estimates the number and types of construction equipment required for completing construction. These numbers are based off of typical construction equipment noted for each project activity, based on relevant construction experience.
- **Crew Size:** Estimates the size of the crew necessary based on construction activities. In most cases, typical crew sizes were developed based on relevant construction experience and applied to project conditions. In some instances, these typical crew sizes were modified to ensure feasibility.
- **Special Considerations:** The primary special consideration is related to whether a particular project is expected to BUDM, and allows for a BUDM supplier to be identified, if possible. Other special considerations may be noted in the “Assumptions & Notes” section.

The detailed costs were computed for each proposed priority project by assuming a standard design template for the project. The standard design templates (or, typical sections) for the projects assume a consistent cross-section for a variety of project types based on typical coastal construction practices for the state of Texas. Once the project type was determined, an applicable cross-section is applied over the total length of the project. This results in an estimated quantity of construction materials needed (for instance, CY of sand). Then, a unit cost for the material specific to the region in which the project is being constructed is used to compute a total cost for the project. The standard project templates for conceptual designs are included in **Appendix L**.

The templates help create a standardized method for computing costs that allow the estimates to be directly compared to one another, serving as high-level planning assumptions to produce one standard final design template suitable for each type of project (e.g., beach nourishment, breakwater construction) at any given location along the coast. The project-specific design itself should be assessed for local RSLR trends, wave conditions, ecological factors, during each project’s E&D phase to refine these planning level design templates. The GLO recommends that a 50-year life expectancy be assumed for each project during final design.

The full results of the cost assessment are presented in **Appendix L**.

8.4.1 Detailed Project Costs Methodology

To properly represent 2023 TCRMP Tier 1 projects and their respective, estimated detailed costs, up-to-date costs for materials and equipment were sourced for use in AECOM's cost evaluation. The recommended unit costs for 2023 were compiled from references such as (a) previously used unit costs for the 2019 TCRMP, (b) recent local USACE advertisements and bids, and (c) recently GLO awarded contracts for relevant projects. The USACE and GLO bid tabulations used ranged from 2020-2022. Unit costs for construction materials, activities, labor, and equipment throughout these references were compiled and compared to evaluate the resulting recommended unit cost to be used in the 2023 detailed project costs. Other project unit costs for construction activities, like beach nourishment or dredging costs per CY, were also evaluated. The following sections discuss recommended unit costs for Construction Materials, Construction Activities, and Equipment.

Construction Materials

Stone

250-lb class stone in the 2019 TCRMP was used at a unit cost of $45/ton in the detailed project costs (this cost was for materials only with no allowance for labor or crew size to install the rock). Bulk materials, such as stone, vary in price due to many factors including, but not limited to, project location, GIWW/waterway access, project depth, and overall demand. Since the implementation of the 2019 TCRMP, stone prices have significantly increased. Riprap unit prices listed on two recently awarded GLO contracts from 2020-2022 were $130/ton and $185/ton. As another recent example from the 2020-2022 timeframe, USACE bids advertised shoreline protection riprap at $117/ton as a recommended cost, which was later bid by contractors at $125/ton and $85/ton. The GLO and USACE unit costs are assumed to have included materials and labor. Due to some or all of these unit costs including labor as a part of the line-item cost for stone, it is recommended that $85/ton be used as a unit price for 250-lb class stone (materials only).

This updated unit cost for stone in pricing breakwaters yields a project cost within ranges of GLO provided bids for breakwater costs per linear foot (i.e., between $500 – $890 per LF).

2000-lb class stone, a larger, heavier stone, is recommended to be priced higher than the 250-lb class stone due to its size, ability to be handled, and difficulty of transportation. It is recommended that the larger 2000-lb class stone be priced at $110/ton, a $25/ton increase (approximately 30%) over the 250-lb class stone, based on engineering judgment.

	2019 Cost	Recommended 2023 Cost
250-lb Class Stone	$45/ton	$85/ton
2000-lb Class Stone	$65/ton	$110/ton

Geotextile

In the 2019 TCRMP detailed project costs, geotextiles were priced at $2.90/SY. Current prices are similar with records from USACE bids and provided GLO awarded contracts having geotextiles priced at $3.00/SY. In the 2023 TCRMP, it is recommended that geotextiles be priced at a cost of $3.00/SY, a $0.10 increase from 2019.

	2019 Cost	Recommended 2023 Cost
Geotextile	$2.90/SY	$3.00/SY

Spartina (Cordgrass) Plant Plugs

AECOM coordinated with experienced contractors familiar with *Spartina alterniflora* planting projects to develop a per plant cost and a recommended density of plants per acre. It was understood from this outreach the most successful planting projects that yield the quickest establishment are typically done on 18'' centers, amounting to 19,500 plants per acre. The reported price ranges were $1.50-$3.00 per plant. AECOM recommends that pricing of Spartina be $2.25 per plant plug. This is much less than the 2019 TCRMP cost of plants in general at $25/plant. AECOM is confident this recommendation reflects the current prices of marsh grass through the feedback from experienced contractors and project managers familiar with the market.

	2019 Cost	Recommended 2023 Cost
Plants (*Spartina*/Cordgrass)	$0.64/plant*	$2.25/*spartina* plant plug

*Adjusted to assume the same number of plants per acre from 2019 to 2023

Recommended Costs for Other Materials

From 2019 to 2022, costs have risen dramatically for nearly all materials, goods, and services. For other materials, where AECOM did not have more recent bids or awarded contracts to reference for updated unit prices, a 15% markup was applied. This markup helps keep costs more up to date with typical market factors increasing cost, such as inflation and supply chain constraints.

Material	Unit	2019 Local	2019 Non-Local	2023 Local	2023 Non-Local
Bollards	each	$100.00	$150.00	$115.00	$175.00
Cable Fence	LF	$1.00	$2.00	$1.15	$2.30
Concrete	CY	$20.00	$30.00	$28.75	$34.50
Pipeline (Utility/Infrastructure)	LF	$30.00	$45.00	$34.50	$51.75
Recycled Concrete	CY	$20.00	$30.00	$28.75	$34.50
Sand Fence	LF	$41.00	$61.50	$47.15	$71.00
Sand or Soil Fill	CY	$48.00	$72.00	$55.20	$82.80
Seeding	SY	$1.35	$2.16	$1.55	$2.16
Soft Clay Fill	CY	$15.00	$25.00	$17.25	$28.75
Stiff Clay Fill	CY	$25.00	$37.50	$28.75	$43.13
Geotube Fill – Slurry*	CY	$5.00	$5.00	$6.00	$6.00
Marsh Fill	CY	$10.00	$10.00	$11.50	$11.50
Geotubes	LF	$2.00	$3.00	$2.50	$3.50
6'X6' Box Culvert	LF	$500.00	$600.00	$575.00	$690.00
Maintenance Dredged Material	CY	$2.90	$2.90	$3.34	$3.34

Construction Activities

Aerial Photography

The 2019 TCRMP used a $5,000 lump sum fee for aerial photography, but evaluation of GLO provided awarded contracts shows this cost is low. Across the awarded contracts, the fees for aerial photography ranged from approximately $6,000 - $7,000 for smaller jobs and $15,000 – $25,000 for larger projects. The recommended aerial photography lump cost based on the provided range is a unit lump sum cost of $10,000 per project that can be applied to all relevant projects.

	2019 Cost	Recommended 2023 Cost
Aerial Photography (lump sum)	$5,000	$10,000

Dredging

Unit costs of $25/CY for dredging are recommended to be used in cost estimates based off the $25/CY price for the awarded Bahia Grande Hydrologic Restoration Project contract. TCRMP projects that involve non BUDM related dredging will likely be smaller volume clamshell spread operations, assumed to be similar to the Bahia Grande project operations. Larger hydraulic dredging operations, which involve removing hundreds of thousands of CY of material, may have costs ranging from $10-$15/CY due to cost savings from economies of scale. However, dredging of this scale is not commonly seen in the TCRMP project list, except for beach nourishment projects that are part of larger, typically federal efforts.

	Recommended 2023 Cost
Dredging	$25/CY

Shoreline Nourishment

Nourishment prices across five GLO awarded contracts ranged from $18.75/CY to $67/CY, with an average of $38.4/CY. Nourishment costs vary due to different project locations, material types, and, importantly, project size. Larger projects will have lower costs per CY and vice versa. This information aids in understanding the current cost ranges of nourishment projects and allows AECOM to better estimate feasible nourishment quantities based on the stakeholders provided budget. Shoreline nourishment costs recommended per Tier 1 project for the 2023 TCRMP are evaluated on a case-by-case basis using specific project considerations.

	Recommended 2023 Cost
Shoreline Nourishment	$18.75/CY - $67/CY

Equipment

Construction Equipment

Daily rates were obtained from a recent, local construction contractor labor and equipment rate sheets. The listed values are from FY2021 and are carried through with no markup.

Equipment Item	2019 Monthly Cost	2023 Recommended Monthly Cost
Barge (Spud)	$10,000	$33,000
Bulldozer (Cat. D-6)	$15,000	$16,800
Crane**	$15,000	$45,000
Dredge – Hydraulic**	$30,000	$300,000
Dump Truck (10-14 CY)	$15,000	$10,500
Excavator (Cat 320 Marsh)	-	$84,000
Excavator (Cat 320 Track)	$15,000	$15,000
Front-End Loader	$15,000	$13,500
Tugboat (600 HP)	$30,000	$105,000

**Costs of these items were not included in the equipment rate sheets and were estimated using engineering judgment and standard rates in today's dollars according to a conservative price point.

8.5 Project Benefit Metrics

8.5.1 Introduction

This section report outlines the methodology used to identify benefits for the Tier 1 projects, as listed on the project cut sheets. The benefits, a subset of which were selected for each project, fall under three categories: economic, environmental, and social (see **Table 8-3**). The subset of benefits for each project was selected based on their applicability to the project, determined largely from the project description, project type, and project purpose. Projects were evaluated for a maximum of seven benefits. Benefits were not evaluated for coastwide projects.

It is important to note that the benefits do not necessarily reflect benefits offered by the project, but rather represent information about the conditions and assets that currently exist in the defined project areas that could be enhanced, protected, and/or supported as a result of project investment. For example, the structure damage from a 1% storm in the project area represents the structure damages that are modeled to occur in the project area under a no-action scenario, and do not represent the avoided structure damages from the investment. Furthermore, the benefits evaluated are not exhaustive or all-encompassing but were selected due to relevance, data availability, and feasibility of developing a methodology for conducting analysis. There are many benefits that Tier 1 projects may provide that were not evaluated, such as improvements to water quality, public safety enhancements, reduced travel delays, property value improvements, economic benefits of increased tourism, and restored habitats, among others. A number of these benefits lack sufficient data to make assumptions for quantification, require more granular geographic inputs and project-specific considerations, and/or did not have methodologies that would be applicable to projects coastwide. However, such benefits should be explored in future analysis. In turn, this analysis evaluates projects individually and does not capture the potential of cumulative benefits that could be realized from implementing numerous projects, nor does it evaluate the potential for regional partnerships to improve projects' efficacy or to streamline implementation.

Table 8-3. Benefits Evaluated for Tier 1 Projects

Category	Benefit	Source	Geographic Input
Economic	Building replacement value	Hazus 2018	Identified project census block(s)
Economic	Structure damage (1% storm)	Hazus 2018	Identified project census block(s)
Economic	Existing jobs	ESRI Business Analyst	Identified project census block(s)
Economic	Support funding eligibility (binary)	Project description	N/A (binary)
Economic	Avoided future flood risk (binary)	Project description	N/A (binary)
Environmental	Number of critical habitats	USFWS Information for Planning and Consultation	Defined project area
Environmental	Number of endangered species	USFWS Information for Planning and Consultation	Defined project area
Environmental	Number of migratory bird species	USFWS Information for Planning and Consultation	Defined project area
Environmental	Protected habitat in the area (binary)	Project description	Defined project area
Environmental	Number of Rookery Islands	Project description	Project description
Environmental	Oyster habitat protected / created (binary)	TPWD Oyster Database	N/A (binary)
Environmental	Nitrogen removal by oysters (lbs N, annually)	TPWD Oyster Database Role and Value of Nitrogen Regulation Provided by Oysters in the Mission-Aransas Estuary, Texas, USA (Pollack et al. 2013)	Project description or complete containment of oyster polygon within defined project area
Environmental	Seagrass protected / created (binary)	TPWD Seagrass Viewer	N/A (binary)
Environmental	Seagrass carbon sequestration (tons C)	Seagrass blue carbon dynamics in the Gulf of Mexico: Stocks, losses from anthropogenic disturbance, and gains through seagrass restoration (Thorhaug et al. 2017)	Project description
Environmental	Wetland types	NWI	NWI
Environmental	Acres of wetland protected / created	NWI	Project description or complete containment of wetland polygon within defined project area
Environmental	Existing wetland carbon sequestration (tons C)	Texas Blue Carbon Opportunities: Wetland Biogeochemistry and Carbon Offset Optimization Strategies (Feagin 2022b)	Project description
Environmental	Decreased wave energy (binary)	Project description	N/A (binary)

Category	Benefit	Source	Geographic Input
Social	Social Vulnerability	SOVI 5-classification score (county-level), Texas CDBG-MIT Action Plan	Identified project county(ies)
Social	Number of critical facilities	Hazus 2018	Defined project area or identified project census block(s)
Social	Trips on evacuation route (daily)	TxDOT	TxDOT evacuation routes near project defined areas
Social	Number of homes (occupied housing units)	2020 Decennial Census	Identified project census block(s)
Social	Public access improvements (binary)	Project description	N/A (binary)
Social	Addressing data gaps (binary)	Project description	N/A (binary)
Social	Education and outreach (binary)	Project description	N/A (binary)

8.5.2 Identifying Project Areas for Benefit Quantification

Quantification of benefits requires an understanding of the project areas for benefits that are not binary (yes/no). A database of Tier 1 projects was developed that represented projects spatially as polygons, lines, and points.

- For polygons, benefits were quantified using the delineated polygon area or using overlapping census blocks when projects had benefits relating to the built environment (see below).
- For projects represented as lines, a buffer of 200 feet was applied to determine the area or boundaries of overlapping census blocks were used when projects had built environment benefits.
- For projects represented as points that corresponded with geographic features, like watersheds, rivers, creeks, or prairies, benefits were quantified for the entire geographic area under consideration.

See **Appendix M** for the list of census blocks assigned to projects with built environment benefits and for the geographic regions associated with point projects.

Benefits relating to the built environment include building replacement value, structure damage from the 1% storm, number of jobs, number of critical facilities, and number of occupied homes. These benefits were considered when:

- Projects are in proximity or adjacent to an urbanized area with over 1,000 households or significant built infrastructure (e.g., critical facilities).
- Projects create structural improvements (e.g., breakwaters and seawalls) or support/enhance natural systems (e.g., erosion control, wetland creation) that prevent long-term flooding and storm damage.

This logic was taken into consideration along with the project's purpose to determine if these benefits should be quantified.

The following examples illustrate five projects and the project areas used to determine their benefits, organized by project spatial category (polygon, line, point).

Polygon Projects

Management of Christmas Bay System (Project #11)

Management of Christmas Bay System (Project #11) is located in Brazoria County and calls for wetland restoration and breakwaters to limit exposure from vessel wakes on the GIWW. This project is not located within close proximity of an urbanized area or structures and was not evaluated for built environment benefits. The project polygon depicted in **Figure 8-6** was used to quantify benefits, including but not limited to the number of wetland types addressed, number of endangered species in the project area, oyster habitat creation/protection, and social vulnerability (which is assigned based on the County that the project sits in).

Figure 8-6. Management of Christmas Bay System: Project Area for Quantification within Brazoria County

O'Quinn I-45 Estuary Shoreline Protection and Marsh Restoration (Project #346)

O'Quinn I-45 Estuary Shoreline Protection and Marsh Restoration (Project #346) is located in Galveston County and calls for the restoration of habitat function to a portion of a preserve and stabilization of the entire shoreline to prevent future loss along Jones Bay. Built environment benefits were calculated for this project due to its proximity to an urbanized area to the northwest (Bayou Vista) and capacity for shoreline stabilization. These built environment benefits were calculated for the census blocks depicted in **Figure 8-7**.

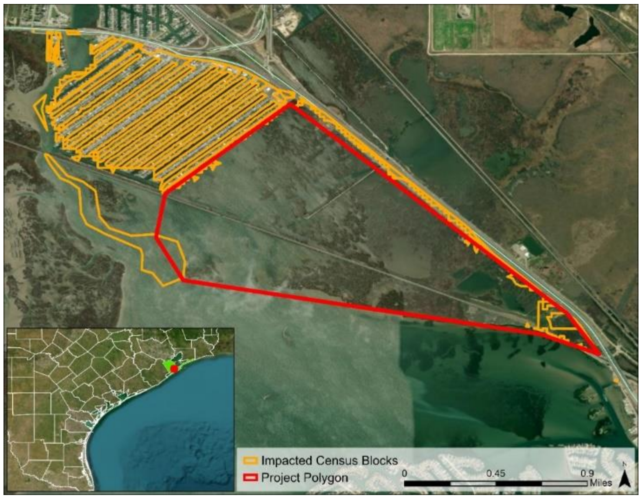


Figure 8-7. O'Quinn I-45 Estuary Shoreline Protection and Marsh Restoration within Galveston County

Line Projects

Dagger Point Stabilization (Project #9268)

Dagger Point Stabilization (Project #9268) is located in Aransas and Calhoun Counties and addresses bay shoreline erosion concerns in the ANWR. This project is not located within close proximity of an urbanized area or structures. The project line and the 200-foot buffer around it, depicted in **Figure 8-8**, were used to quantify benefits. Some benefits quantified include number of wetland types addressed, number of endangered species in the project area, and wildlife management area addressed.

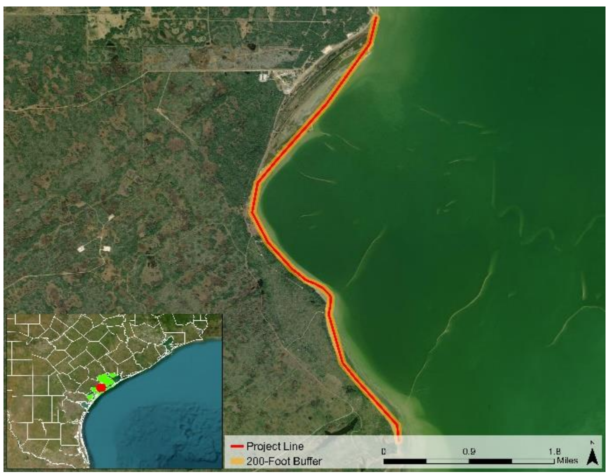


Figure 8-8. Dagger Point Stabilization within Aransas and Calhoun Counties

Rincon Reef Breakwater (Project #9287)

Rincon Reef Breakwater (Project #9287) is located in Nueces County and calls for the construction of a new submerged breakwater with integrated oyster reef parallel to the shoreline to reduce wave energies while creating oyster habitat. Built environment benefits were calculated for this project due to its proximity to an urbanized area (Corpus Christi) and capacity for shoreline stabilization. Census blocks with built structures closest to the shoreline (east of US Route 181) were chosen for this analysis (**Figure 8-9**).

Figure 8-9. Rincon Reef Breakwater within Nueces County

Point Projects

Projects identified as points typically cover larger geographic or ecological areas, like watersheds, as described in Table 2 of **Appendix M**. The Petronila Creek and Oso Creek Watershed Improvements project was initially identified as two points, one per creek. These points are associated with entire watershed regions, which are delineated in **Figure 8-10**. While there is an urbanized area (City of Corpus Christi) located within the project area and the project is anticipated to alleviate flooding, given the large expanse of the watershed, structural damages and building exposure value were not included as benefits for this project. Types of benefits included for this project include social vulnerability, critical facilities in the project area, and oyster habitat and seagrass area creation/protection.

Figure 8-10. Petronila Creek and Oso Creek Watershed Improvements in Nueces County

8.5.3 Economic Benefits

Building Replacement Value and Structure Damage

To identify the value of structures located in the project area, 2018 FEMA Hazus GBS data was utilized. Within the GBS data set, "Total Exposure" was summed to calculate the value (in 2018 dollars) of the structures within the selected census blocks for the project areas. When applicable, structure damage from the FEMA Hazus Coastwide 1% present-day scenario storm under no action model run was calculated. The "Building Loss" (in 2018 dollars) data output from the model runs was summed for the identified census blocks in the project area. Structure damages were only calculated for projects related to shoreline protection and beach nourishment when deemed applicable based on the project's proximity to urbanized areas or structures.

Existing Jobs

To estimate the number of jobs that presently exist in the project area, ESRI Business Analyst was used. Number of employees was summed for the businesses located in the FEMA Hazus Coastwide 1% present-day scenario storm under no action. The "All Businesses" feature was accessed in the ArcGIS Pro Business Analyst tool to sum "Employee Count" for the census blocks intersecting the 1% present-day scenario storm, with the sum of the number of employees serving as a proxy for the total number of jobs. The ESRI Business Analyst dataset is built from a list of licensed and geocoded businesses.[6] Therefore, it may not capture commercial fishing jobs or other jobs that are not in a geocoded business in the project area.

Support Funding Eligibility

Projects identified as "Studies, Plans, and Programs" may be assigned a binary benefit that they are a funding pre-requisite if the project is intended to help develop a strategy in a way that might help future applications for funding.

Avoided Future Flood Risk

This is a binary variable applied to projects when they avoid future development from occurring in areas with flood risk and, as such, avoid future damages in hazardous areas. Specifically, land acquisition or habitat restoration projects of larger scale, like the Neches River Forested Floodplain, can limit projects in high-risk areas and avoid future economic losses such as those associated with structure damage.

8.5.4 Environmental Benefits

Endangered Species, Migratory Bird Species, and Critical Habitat

The USFWS Information for Planning and Consultation (IPaC) tool was used to identify the number of critical habitats, endangered species, and migratory bird species in the project area (US Fish & Wildlife Service 2022a). The IPaC tool uses USFWS data to estimate the number of species and critical habitats within each project area uploaded to the tool, which is updated on an ongoing basis. This can be done by employing the following process: (1) uploading a specific shape file, (2) selecting by state or county, and (3) defining or sketching an area (i.e., polygon). Feature outputs include endangered species and migratory bird species, in addition to critical habitats, which are counted for the number of species within the project area. To calculate the number of migratory bird species in the specified area, IPaC draws from the USFWS Birds of Conservation Concern database which is derived from the Avian Knowledge Network. Species data are maintained by the USFWS field offices and are updated on an ongoing basis.

The IPaC tool only provides information on species and critical habitats that are solely or jointly managed by the USFWS's Ecological Services Program. Therefore, endangered species under the sole jurisdiction of entities such as NOAA Fisheries may not be represented in the benefit metrics. Additionally, the tool can be considered generous in terms of the output (i.e., the number of endangered species) identified for a given polygon since the data used to generate the output is based on the known or expected range of each species. Additionally, areas of influence are also considered and may not necessarily align with site-specific or project-specific information since species are mobile in nature or barriers may be in place which restricts species' connectivity and does not guarantee inhabitance in the project area.

Protected Habitat in the Area

To identify whether the project area overlaps with or addresses a WMA or NWR, the project description was used in conjunction with the output from IPaC tool. Projects that overlap with a WMA may provide multi-benefits to both regional wildlife habitat and connectivity.

[6] More information on what is included in ESRI Business Analyst can be found in their documentation here: https://storymaps.arcgis.com/stories/d13b635ab9ac44759e99eb52646877f8

Rookery Islands

For projects specifically protecting rookery islands for nesting birds, the number of rookery islands protected is included as a project benefit when discussed in the project description. Rookery islands data published by the National Audubon Society were reviewed but ultimately not utilized given the vintage of the data.

Oysters

Projects that intersect oyster reefs were identified when referenced in project descriptions and based on mapped areas of the Eastern oyster (*Crassostrea virginica*) in the Gulf of Mexico Data Atlas from the NOAA NCEI (NOAA 2018). The benefit was assigned when deemed applicable based on the project description. Nitrogen removal and regulation through oyster reef restoration was estimated at 204 pounds of nitrogen per acre per year based on Pollack et al. (2013), who report that 6.7 pounds of nitrogen is removed per acre of reef through denitrification and burial of biodeposits into sediment, while oyster harvesting physically transports nitrogen from the estuary at 193 pounds per acre. The study area was Texas's Mission-Aransas Estuary, offering a localized nitrogen removal figure. The nitrogen removal benefit metric has its strength in its localized data source and its holistic evaluation methods which include oysters in addition to their biodeposits. However, the metric has limitations since nitrogen removal rates can vary depending on oyster density, total nitrogen input into the system, and water temperature.

Seagrass

Projects that lie within 250 feet of seagrass areas were identified using TPWD seagrass data and assigned a binary benefit category when deemed applicable based on the project description (Texas Parks & Wildlife Department 2022). For certain projects, seagrass carbon stocks were estimated assuming 6.2 tons of carbon sequestered per acre of seagrass bed. This metric is based on a 20-centimeter soil core from four natural seagrass sites along the Texas Gulf coast (Thorhaug et al. 2017). One caveat with this estimate is that it could be a lower-bound estimation of the true carbon sequestration capacity for projects that create or restore seagrass habitats. According to Thorhaug et al. (2017), restored seagrass beds may have diverse carbon sequestration rates when compared to existing seagrass beds. The average carbon sequestration rate for natural seagrass beds is used herein over reported metrics for restored sites due to the former value's derivation from sites within Texas and the broad extent of seagrass bed habitat quality along the Texas coast.

Coastal Wetlands

Wetland areas and types were identified using NWI data from USFWS (US Fish & Wildlife Service 2022b). Two types of wetlands from the inventory were included: freshwater and estuarine. If the project area completely contains a wetland (or multiple), the acreage of the contained wetlands was calculated in GIS using the NWI data. Otherwise, the project description was used. The total acreage of wetland benefit metrics includes both freshwater and coastal wetlands within a project area.

For projects involving restoration and protection of existing coastal wetlands, carbon sequestration from coastal wetlands was calculated. The rate of carbon sequestration for restoration and/or protection of coastal wetlands was estimated to be 42.5 tons per acre, extrapolated from Soil Survey Geographic database soil coring data across numerous locations in Texas (Feagin 2022b). This sequestration value is based on soil cores taken at a depth of 1 meter, which is the depth at which carbon is typically considered stable, and therefore sequestered (Feagin 2022a). Further, this value accounts for sequestered soil organic carbon, which comprises approximately 98% of the total carbon stored across the average of all Texas coastal wetlands (Feagin 2022a).

Wave Energy

Where the project description mentioned the protection of shorelines (i.e., shoreline stabilization), breakwater construction, or coastal habitat restoration, the binary benefit of decreased wave energy was assigned.

8.5.5 Social Benefits

Social Vulnerability

The SoVI® uses the index employed by the Texas CDBG-MIT Action Plan, which was developed by the University of South Carolina's HVRI. The SoVI® is categorized into a five-score classification of vulnerability at the county level: low, medium low, medium, medium high, and high. Projects were assigned one of these five scores based on the project area's county; project areas that spanned more than one county were assigned the higher vulnerability (e.g., if located in two counties with medium high and high scores, respectively, the high score was assigned). This benefit was applied in instances where projects were determined to provide benefits to communities with a countywide SoVI® score other than "low," based on the description and projects' primary and secondary actions.

Critical Facilities

Critical facilities in the project area were identified using Hazus version 5.1 The critical facilities database used only included point features and did not include linear features such as highway or railway segments, or natural gas pipelines. The facilities included are outlined in **Table 8-4**. More information on the source of these facilities can be found in the Hazus Inventory Technical Manual (Hazus 5.1) (FEMA 2021).

Table 8-4. Critical Facilities by Type

Facility Type	Facility
Transportation Systems	Airport Facility
	Bus Facility
	Ferry Facility
	Highway Bridge
	Port Facility
	Railway Bridge
	Railway Facility
	Railway Segment
Utility Systems	Communication Broadcast Facility
	Electric Power Facility
	Natural Gas Facility
	Oil Refineries
	Portable Water Facility
	Wastewater Facility
Essential Facility	Emergency Center
	Fire Station
	Medical Care Facility
	Police Station
	School

Trips on Evacuation Route (Daily)

If the project area included an evacuation route and/or it was determined that the project may offer protection to an evacuation route, the number of trips on the evacuation route was included as a benefit. To calculate the number of trips taken on evacuation routes, an evacuation route line shapefile from TxDOT was downloaded. TxDOT Traffic County Database System was accessed to calculate the number of trips protected on these routes. In order to do so, polygons were drawn around the evacuation routes that intersected the project areas or identified census blocks (for projects with built environment benefits) to calculate the annual average daily traffic total along them (TxDOT 2021).

Number of Occupied Homes

To calculate the number of impacted housing units, occupied housing units from Table H1 (Occupancy Status) from the 2020 Decennial Census were summed for the applicable project area census blocks (US Census Bureau 2020).

Public Access Improvements

Projects that explicitly mention heightened recreational considerations or public access improvements are assigned this binary variable.

Education & Outreach and Addressing Data Gaps

The education benefit refers to projects that intend to educate residents about the planning and implementation process or of initiatives that preserve natural resources. Project descriptions were used to determine if this binary benefit was applicable.

The addressing data gaps benefit refers to projects that provide accurate and timely data to inform policy decisions. Project descriptions were used to determine if this binary benefit was applicable.

8.5.6 Additional Income Metrics

While not incorporated into the project benefit evaluation, two additional metrics were evaluated for all projects to better understand their proximity to disadvantaged communities and low- and moderate- income households. For line projects, census block groups or census tracts that intersected the lines were selected for the analysis. For points and polygons, the census block groups or census tracts that intersected with the polygons were selected for the analysis. For projects with medium, medium high, or high social vulnerability, the total number of disadvantaged communities census tracts or low- and moderate-income communities addressed in defined project areas was quantified, unless there was explicit statement that the project conferred no benefit to local populations. These outlier projects included those solely related to water quality and treatment, which confer benefits on endangered species and habitat but minimal human-related impacts.

Disadvantaged Communities Census Tracts

The Climate and Economic Justice Screening Tool (CEJST) uses publicly-available, nationally-consistent datasets to identify disadvantaged communities across the United States at the census tract level based on environmental, climate, and socioeconomic indicators (White House 2022). In CEJST Version 1.0, each census tract (2010 boundaries) is analyzed based on a series of indicators of burdens, which are organized into the following categories: climate change, energy, health, housing, legacy pollution, transportation, water and wastewater, and workforce development. Communities are considered disadvantaged if (1) they are in census tracts that meet the thresholds for at least one of the tool's categories of burden, (2) they are on land within the boundaries of Federally Recognized Tribes, or (3) are completely surrounded by disadvantaged communities and are at or above the 50th percentile for low income. Classification of a project as containing disadvantaged areas is based on the project's intersection with census tracts.

Low- and Moderate-Income Households

The U.S. Department of Housing and Urban Development (HUD) administers the Community Development Block Ground (CDBG) Entitlement Program, which funds development by expanding economic opportunities, principally for low- and moderate-income (LMI) communities. The HUD CDBG program requires that "each CDBG funded activity must either principally benefit [LMI] persons, aid in the prevention or elimination of slums or blight, or meet a community development need having a particular urgency because existing conditions pose a serious and immediate threat to the health or welfare of the community for which other funding is not available" (HUD 2022). LMI is defined as those whose income is 80 percent of area median income (AMI).[7] The number of LMI households per project area was calculated based on the census block groups in the project areas (2010 boundaries) based on HUD's FY2021 LMI data as of November 2022 with state median income (SMI) waiver applied. The proportion of LMI households was calculated based on the intersection of the project area with census block groups.

The results of the CEJST and LMI analysis are summarized in **Table 8-5**. The list of respective census tracts and census block groups are listed alongside the data outputs if there are 5 or fewer census tracts or block groups in each project area.

[7] It is important to note that the US Department of Housing and Urban Development (HUD) defines the "LMI Universe" as the total number of households, not including group quarters. The "LMI Universe" was used to calculate the proportion of total LMI households in each area.

Table 8-5. Disadvantaged Communities and HUD LMI Communities Results by Project, for Applicable Projects

Project	Year	County	Number of Census Tracts Identified as Disadvantaged (CEJST)	Associated Disadvantaged Census Tracts (CEJST)	Proportion of LMI Households in Project Area (HUD) [8]	Associated Census Block Groups [9]	5-Rank SoVI® Classification
Adolph Thomae, Jr. Park Living Shoreline Restoration - Phase 5	2023	Cameron County	1	48061010100	67%	480610101004	High
Austwell Water Quality and Erosion Mitigation	2023	Refugio County	1	48391950400	60%	483919504002	Medium High
Bahia Grande Living Shoreline	2023	Cameron County	1	48061014200	79%	480610142001	High
Bayside Water Quality, Access, and Habitat Creation	2023	Refugio County	1	48391950400	47%	483919504001	Medium High
Beach and Dune System Monitoring Program for Cameron and Willacy Counties	2023	Cameron County, Willacy County	2	48489950700, 48061012700	57%	480610123051, 480610127002, 484899507001	High
Big Boggy Marsh Protection Project	2023	Brazoria County	1	48039664200	50%	480396642003	Medium
Bird Island Restoration and Creation of Gulf Cut Island Complex	2023	Matagorda County	1	48321730501	50%	483217305011	Medium
Boggy Cut GIWW Stabilization	2023	Matagorda County	1	48321730501	50%	483217305011	Medium
Boggy Nature Park Shoreline Stabilization	2023	Calhoun County	1	48057000500	44%	480570005001	Medium
Cameron County Gulf Beach Nourishment	2023	Cameron County	1	48061012700	53%	480610123051, 480610127002	High
Carancahua Bay Community Reefing Project	2023	Calhoun County	0	None	50%	480570003001	Medium
Carancahua Bay Habitat Preservation and Enhancement	2019	Calhoun County	0	None	50%	480570003001	Medium
City of South Padre Island Living Shoreline	2019	Cameron County	0	None	50%	480610123051	High

[8] Based on the number of households per census block group. The proportion of LMI households was calculated for the census block groups that intersect with the project area.
[9] The more granular geographic input metric is listed (census block groups) to account for the calculation of LMI households. Percentages rounded to the nearest whole number.

Project	Year	County	Number of Census Tracts Identified as Disadvantaged (CEJST)	Associated Disadvantaged Census Tracts (CEJST)	Proportion of LMI Households in Project Area (HUD) [8]	Associated Census Block Groups [9]	5-Rank SoVI® Classification
Columbia Bottomlands Ecosystem and Preservation	2023	Brazoria County, Fort Bend County, Galveston County, Harris County, Matagorda County, Wharton County	30	30 Census Tracts in Project Area	37%	318 Census Block Groups in Project Area	Medium
Corpus Christi Bay Wastewater, Stormwater Quality, and Pollution Management Improvements	2019	San Patricio County, Nueces County	5	48409010302, 48355001400, 48355006300, 48355006400, 48355001200	34%	28 Census Block Groups in Project Area	Medium High
Dagger Island Buckeye Beneficial Use	2023	San Patricio County	1	48409010302	28%	483550062001, 484090103021	Medium High
Dagger Point Stabilization	2023	Aransas County, Calhoun County	2	48057000500, 48007950100	61%	480079501001, 480570005002	Medium
Dollar Bay Wetland Protection, Restoration, and Acquisition	2019	Galveston County	1	48167723900	32%	481677220011, 481677220012, 481677239004	Medium
East Living Shoreline and Living Wetland Enhancement	2023	Aransas County, Calhoun County	2	48057000500, 48007950100	61%	480079501001, 480570005002	Medium
Feeder Berm North of Fish Pass Beneficial Use	2023	Nueces County	0	None	29%	483550062001	Medium High
Follet's Island Nourishment and Erosion Control	2019	Brazoria County	1	48039664200	47%	480396642003	Medium
Fulton Beach Road Protection	2019	Aransas County	1	48007950100	54%	480079501003, 480079501005	Medium
Galveston Island West of Seawall to 8 Mile Road Beach Nourishment – Phase 1	2019	Galveston County	0	None	49%	481677259002, 481677260001	Medium
Goose Island State Park Habitat Restoration and Protection	2019	Aransas County	1	48007950100	63%	480079501001	Medium
Harbor of Refuge Old Landfill Shoreline Erosion Response and Protection	2023	Calhoun County	1	48057000400	30%	480570004001	Medium

Project	Year	County	Number of Census Tracts Identified as Disadvantaged (CEJST)	Associated Disadvantaged Census Tracts (CEJST)	Proportion of LMI Households in Project Area (HUD) [8]	Associated Census Block Groups [9]	5-Rank SoVI® Classification
Houston Parks and Recreation Department's Riparian Restoration Initiative	2023	Harris County	26	26 Census Tracts in Project Area	57%	41 Census Block Groups in Project Area	Medium
Hydrologic Restoration of Welder Flats	2023	Calhoun County	1	48057000500	55%	480570005002	Medium
Lake Austin Coastal Prairie Conservation	2023	Matagorda County	1	48321730501	46%	483217305011, 483217305013	Medium
Little Bay Restoration Initiative	2023	Aransas County	1	48007950300	41%	480079502001, 480079502002, 480079503002	Medium
Long Reef and Deadman Island Shoreline Stabilization and Habitat Protection	2019	Aransas County	1	48007950100	63%	480079501001	Medium High
Lower Clear Creek and Dickinson Bayou Watershed Flood Risk Reduction Program	2023	Brazoria County, Chambers County, Fort Bend County, Galveston County, Harris County	29	29 Census Tracts in Project Area	35%	241 Census Block Groups in Project Area	Medium
Mad Island Marsh Preserve Shoreline Stabilization and Habitat Protection	2019	Matagorda County	1	48321730600	50%	483217306001	Medium
Moody National Wildlife Refuge Conservation and Restoration	2019	Chambers County	1	48071710500	79%	480717105002	Medium
Neches River Forested Floodplain	2023	Hardin County	8	8 Census Tracts in Project Area	48%	79 Census Block Groups in Project Area	High
Newcomb's Point Shoreline Stabilization	2019	Aransas County	1	48007950100	63%	480079501001	Medium

Project	Year	County	Number of Census Tracts Identified as Disadvantaged (CEJST)	Associated Disadvantaged Census Tracts (CEJST)	Proportion of LMI Households in Project Area (HUD) [8]	Associated Census Block Groups [9]	5-Rank SoVI® Classification
Nueces County Gulf Beach Shoreline Renourishment/BUDM	2023	Kleberg County, Nueces County	1	48273020100	36%	482730201001, 483550062001	Medium High
Nueces County Hydrologic Restoration Study	2019	Kleberg County, Nueces County	2	48355006300, 48409010900	36%	483550063001, 484090107002, 484090109003	High
Oliver Point Shoreline Protection and Reef Restoration	2019	Matagorda County	1	48321730600	51%	483217306001	Medium
Oyster Reef Restoration in Mesquite-Carlos-Ayres Complex	2023	Aransas County, Calhoun County	2	48057000500, 48007950100	61%	480079501001, 480570005002	Medium
Petronila Creek and Oso Creek Watershed Improvements	2023	Jim Wells County, Kleberg County, Nueces County	42	42 Census Tracts in Project Area	49%	220 Census Block Groups in Project Area	Medium High
Port Alto County Park Shoreline Protection and Restoration	2023	Calhoun County	0	None	50%	480570003001	Medium
Port Aransas Nature Preserve Stabilization and Restoration – Phase 2	2019	Nueces County	0	None	39%	483550051021, 483550051022, 483550062001	Medium
Protection and Restoration of Benny's Shack Islands	2023	Willacy County	1	48489950700	70%	484899507001	High
Protection and Restoration of Rabbit Island	2023	Kenedy County	1	48261950100	39%	482619501001	High
Resaca System Restoration Project - Phase 1	2023	Cameron County, Hidalgo County, Willacy County	42	42 Census Tracts in Project Area	65%	122 Census Block Groups in Project Area	High
Restoration of Sea Turtle Nesting Beach at Padre Island National Seashore	2023	Willacy County	1	48489950700	70%	484899507001	High
Restore Barrier Island Bayside Wetlands on South Padre Island	2023	Cameron County	0	None	50%	480610123051	High

Project	Year	County	Number of Census Tracts Identified as Disadvantaged (CEJST)	Associated Disadvantaged Census Tracts (CEJST)	Proportion of LMI Households in Project Area (HUD) [8]	Associated Census Block Groups [9]	5-Rank SoVI® Classification
Restore Laguna Madre Rookery Islands	2019	Cameron County	1	48061010100	54%	480610101004, 480610123051	Medium High
Rincon Reef Breakwater	2023	Nueces County	1	48355006300	46%	483550063001	Medium High
San Bernard NWR Sargent Unit Beneficial Use	2023	Matagorda County	1	48321730501	71%	483217305012	Medium
Sargent Beach & Dune Restoration	2019	Matagorda County	1	48321730501	60%	483217305012, 483217305013	Medium
Shell Point Ranch Wetlands Protection	2019	Aransas County	1	48007950100	63%	480079501001	Medium High
Shoreline Protection and Restoration at Olivia Haterius County Park	2023	Calhoun County	0	None	50%	480570003001	Medium
South Padre Island Beach and Dune Management and Restoration	2019	Cameron County	0	None	50%	480610123051	High
South Padre Island Coastal Beach Protection	2019	Cameron County, Willacy County	1	48489950700	56%	480610123051, 484899507001	Medium
Southeast Texas Flood Coordination Study – Regional Flood Sensor System	2023	Jefferson County, Hardin County	8	8 Census Tracts in Project Area	65%	24 Census Block Groups in Project Area	High
Texas Coastal Prairie Initiative	2023	Brazoria County, Fort Bend County, Galveston County, Harris County, Jackson County, Matagorda County, Waller County	6	6 Census Tracts in Project Area	26%	13 Census Block Groups in Project Area	Medium
Texas Point Beach Nourishment Project	2019	Jefferson County	0	None	31%	482450116001	High

9 Project Summary Table

The Project Summary Table for the 2023 TCRMP incorporates all Tier 1 projects, all TAC evaluated projects, and all projects added to the TCRMP planning process since the 2019 Plan, including those not evaluated by the TAC. The projects are organized by newly evaluated projects by the TAC first, then carryover Tier 1 projects from the 2019 TCRMP, and thirdly, projects not evaluated by the TAC. Projects are listed in alphabetical order by project name.

2023 TCRMP Projects

Project Information			Evaluation	TAC Vulnerability Scoring										TAC Overall Results				2023 Project Tier	
Project ID	Region	Project Name	Evaluation Status	DLH	GSC	BSC	INFL	STMSRG	TDFL	DWQL	DWQN	Vulnerability Score (Normalized)	Grouped Vulnerability Score (Normalized)	Feasibility	Y Count	N Count	Priority	Tier	Notes/Exceptions
9243	0	1,000 Mile Living Shoreline Project - Phase 2	Newly Evaluated	2.988	1.512	2.667	1.366	2.084	1.951	2.309	1.141	0.873	0.850	2.24	55	32	0.632	T2	
9266	3	Aransas NWR Ditch and Road Hydrologic Restorations, Wetland Development, and Shoreline Protection	Newly Evaluated	2.523	0.167	2.045	1.651	1.476	1.548	1.837	1.415	0.675	0.678	2.35	25	17	0.595	T2	
9217	0	Adaptive Management Capacity and Support for Oyster Reef Restoration	Newly Evaluated	2.824	0.683	1.444	0.506	1.134	0.904	2.289	0.617	0.542	0.707	2.49	51	36	0.586	T2	
9229	4	Adolph Thomae, Jr. Park Living Shoreline Restoration - Phase 5	Newly Evaluated	2.586	0.071	2.433	1.607	2.172	2.138	1.793	0.966	0.740	0.746	3.26	24	4	0.857	T1	
9259	3	Air Force and Wynn Channel Dredging	Newly Evaluated	1.810	0.390	1.452	0.683	0.927	0.878	0.725	0.600	0.369	0.356	2.12	16	27	0.372	T2	
1390	1	Anahuac National Wildlife Refuge East Unit Beneficial Use	Newly Evaluated	3.186	0.545	1.895	1.281	1.804	1.842	2.211	1.175	0.750	0.833	2.90	51	6	0.895	T1	
9202	1	Anahuac National Wildlife Refuge Pumping Stations	Newly Evaluated	2.679	0.429	0.907	1.818	1.684	1.589	2.138	1.679	0.691	0.756	2.78	36	19	0.655	T2	
9214	1	Anahuac National Wildlife Refuge Wildlife Refuge Oyster Bayou Boat Ramp	Newly Evaluated	0.491	0.179	0.309	0.236	0.327	0.309	0.218	0.111	0.058	0.050	2.89	9	48	0.158	T2	
1372	3	Aransas National Wildlife Refuge Long Lake Marsh and Channel	Newly Evaluated	2.674	0.116	2.130	1.422	1.600	1.644	1.733	1.273	0.671	0.683	2.57	30	16	0.652	T2	
1370	2	Aransas National Wildlife Refuge Matagorda Island West Marsh Beneficial Use	Newly Evaluated	2.868	0.676	1.947	0.750	1.417	1.162	1.514	0.529	0.569	0.651	2.44	25	13	0.658	T2	
9272	3	Austwell Pier Erosion Mitigation	Newly Evaluated	1.545	0.093	1.705	0.714	1.302	1.143	0.636	0.349	0.371	0.379	2.62	17	27	0.386	T2	
9271	3	Austwell Water Quality and Erosion Mitigation	Newly Evaluated	2.295	0.119	2.467	1.372	1.750	1.500	1.844	0.844	0.648	0.684	2.56	33	11	0.750	T1	
9042	4	Bahia Grande Living Shoreline	Re-evaluated for 2023	3.129	0.379	2.700	1.433	1.700	1.700	2.300	0.700	0.756	0.819	2.84	26	2	0.929	T1	2019 Tier 1 Project
1262	1	Bastrop Bayou Marsh Acquisition	Newly Evaluated	3.024	0.675	1.538	1.950	1.825	1.850	2.150	1.211	0.767	0.818	2.68	35	5	0.875	T1	
9230	1	Bay Harbor Island Stabilization	Newly Evaluated	2.878	0.450	1.951	0.439	1.100	1.171	1.634	0.475	0.524	0.636	2.81	30	10	0.750	T1	
9270	3	Bayside Water Quality, Access, and Habitat Creation	Newly Evaluated	2.638	0.200	2.702	1.222	2.467	1.739	1.630	0.778	0.717	0.777	2.85	38	8	0.826	T1	
9199	3	Bayside Wetland Resilience Study on Mustang Island	Newly Evaluated	2.957	1.333	2.600	0.955	2.152	2.244	1.867	0.818	0.809	0.811	2.61	35	12	0.745	T1	
1327	4	Bayview Land Acquistion	Newly Evaluated	2.552	0.034	0.429	1.828	0.759	0.552	2.032	1.567	0.504	0.728	2.13	13	15	0.464	T2	
9231	4	Beach Access Enhancements in Cameron County	Newly Evaluated	1.621	1.742	1.500	1.172	1.933	1.600	0.933	0.433	0.574	0.501	2.97	18	10	0.643	T2	
9298	4	Beach and Dune System Monitoring Program for Willacy and Cameron Counties	Newly Evaluated	2.690	2.767	1.138	1.483	2.567	2.000	1.138	0.862	0.792	0.736	2.83	22	3	0.880	T1	
1392	0	Beneficial Use Master Plan Continuation	Newly Evaluated	2.898	1.741	2.372	1.518	1.976	1.976	1.639	1.012	0.821	0.741	2.78	70	18	0.795	T1	
1265	2	Big Boggy Marsh Protection Project	Newly Evaluated	3.000	0.725	2.512	1.526	2.000	2.073	2.341	1.590	0.858	0.855	2.85	35	6	0.854	T1	
1268	2	Bird Island Restoration and Creation of Gulf Cut Island Complex	Newly Evaluated	2.976	0.513	1.700	0.615	1.051	0.950	0.974	0.568	0.480	0.550	2.59	32	9	0.780	T1	
1269	2	Bird Rookery Island Creation in Espiritu Santo Bay	Newly Evaluated	2.872	0.216	1.263	0.324	0.838	0.757	0.800	0.286	0.363	0.488	2.42	26	13	0.667	T2	
51	2	Boggy Cut GIWW Stabilization	Re-evaluated for 2023	2.732	0.675	2.878	1.237	1.975	1.800	1.744	0.946	0.753	0.751	2.58	37	4	0.902	T1	2019 Tier 1 Project
9237	2	Boggy Nature Park Shoreline Stabilization	Newly Evaluated	2.816	0.289	2.538	0.892	1.632	1.605	1.564	0.676	0.637	0.678	2.89	33	6	0.846	T1	
1270	1	Brazos River County Park Addition	Newly Evaluated	2.122	0.128	0.289	1.225	0.487	0.333	1.475	0.667	0.326	0.528	2.64	15	24	0.385	T2	
9246	1	Brown Ranch Shoreline Stabilization and Marsh Protection	Newly Evaluated	2.667	0.482	2.466	0.982	1.690	1.741	1.474	0.696	0.648	0.661	2.44	38	18	0.679	T2	
9232	4	Cameron County Beach Nourishment	Newly Evaluated	2.724	3.258	1.200	1.483	2.900	2.367	0.967	0.633	0.844	0.818	2.80	25	3	0.893	T1	
1272	1	Camp Mohawk County Park Expansion Along Chocolate Bayou	Newly Evaluated	1.769	0.053	0.474	2.051	1.051	0.897	1.474	0.703	0.429	0.587	2.54	18	18	0.500	T2	
9187	2	Carancahua Bay Community Reefing Project	Newly Evaluated	2.675	0.237	1.436	0.500	1.079	0.973	2.125	0.667	0.500	0.661	2.89	31	9	0.775	T1	
1361	4	Children's Beach Shoreline Restoration - Phase 2	Newly Evaluated	2.233	1.367	2.233	1.103	2.133	2.000	1.000	0.448	0.667	0.596	2.80	17	11	0.607	T2	
1240	2	Chinquapin Oyster Reef Restoration	Re-evaluated for 2023	2.821	0.400	1.750	0.641	1.150	1.025	2.275	0.590	0.557	0.707	2.46	26	13	0.667	T2	2019 Tier 1 Project
9276	1	Chocolate Bay Preserve Shoreline Protection and Marsh Restoration	Newly Evaluated	3.234	0.364	2.935	1.370	2.021	2.064	2.298	0.778	0.817	0.878	2.83	41	5	0.891	T1	
9275	1	City of Seabrook Crothers Gardens Park, Waterfront Loop, and Wetlands Trail	Newly Evaluated	1.756	0.116	1.267	0.978	0.957	0.933	1.261	0.478	0.386	0.423	2.72	18	28	0.391	T2	
9274	1	City of Seabrook Public Pier	Newly Evaluated	0.298	0.021	0.234	0.149	0.255	0.149	0.087	0.000	0.000	0.000	2.89	6	40	0.130	T2	
1278	2,3	Coastal Bend Oyster Restoration and Enhancement	Newly Evaluated	2.873	0.404	1.426	0.604	1.132	1.020	2.370	0.714	0.550	0.724	2.54	36	20	0.643	T2	
1279	0	Coastal Grassland and Wetland Conservation	Newly Evaluated	2.802	0.828	1.360	1.690	1.310	1.264	2.247	1.459	0.693	0.769	2.48	52	34	0.605	T2	
9273	3	Coastal Strategic Plan for Mission River	Newly Evaluated	2.111	0.091	0.826	1.778	0.933	0.955	2.222	1.295	0.531	0.690	2.52	26	21	0.553	T2	
9200	0	Colony Island Network Development and Implementation Tool (CINDI)	Newly Evaluated	2.868	0.719	1.330	0.430	0.814	0.721	0.667	0.353	0.395	0.468	2.47	49	41	0.544	T2	
9223	2	Colorado River Delta Land Assemblage	Newly Evaluated	2.659	0.900	1.675	1.436	1.756	1.610	1.875	1.184	0.701	0.713	2.49	28	13	0.683	T2	
1284	1	Columbia Bottomlands Ecosystem	Newly Evaluated	3.073	0.128	0.436	2.050	0.949	0.692	2.244	1.425	0.577	0.849	2.49	29	10	0.744	T1	Combined to project 1284, scores averaged
9102	1	Columbia Bottomlands Preservation	Re-evaluated for 2023	2.878	0.050	0.300	1.902	0.775	0.650	2.049	1.075	0.500	0.781	2.53	30	9	0.769	T1	Combined to project 1284, scores averaged
1286	1	Construction and Enhancement of Artifical Reefs in the Northern Gulf of Mexico	Newly Evaluated	2.633	0.567	0.345	0.250	0.393	0.345	0.679	0.357	0.258	0.387	2.59	14	16	0.467	T2	
9126	2	Coon Island Restoration	Re-evaluated for 2023	2.700	0.436	2.098	0.718	1.359	1.275	1.436	0.711	0.562	0.612	2.49	29	12	0.707	T2	2019 Tier 1 Project
9198	3	Copano Bay Shoreline Protection and Restoration	Newly Evaluated	2.761	0.140	2.630	1.295	2.152	1.870	1.804	0.913	0.728	0.767	2.33	29	17	0.630	T2	
9225	3	Creating a Conservation Corridor in the Mission River Delta	Newly Evaluated	2.739	0.488	1.511	1.674	1.356	1.341	2.174	1.568	0.686	0.750	2.54	31	15	0.674	T2	
1375	3	Dagger Island Buckeye Beneficial Use	Newly Evaluated	2.634	0.256	2.317	1.179	1.756	1.488	1.650	0.725	0.637	0.681	2.46	30	10	0.750	T1	
9268	3	Dagger Point Stabilization	Newly Evaluated	2.783	0.455	3.156	1.091	1.911	1.622	1.457	0.867	0.715	0.742	2.76	40	6	0.870	T1	
9211	0	Data Repository for Resiliency Planning	Newly Evaluated	2.894	0.506	1.833	0.819	1.627	1.264	0.667	0.807	0.543	0.591	2.49	59	29	0.670	T2	
9247	4	Developing a Comprehensive Conservation and Resiliency Management Plan for the Lower Laguna Madre	Newly Evaluated	2.897	1.500	2.483	2.000	2.222	2.214	2.586	2.276	1.000	0.891	2.90	23	4	0.852	T1	
9234	2	Developing New Water Supply for Estuarine Marsh Management	Newly Evaluated	2.278	0.342	0.895	0.816	0.568	0.684	2.000	2.371	0.516	0.609	2.39	21	20	0.512	T2	
1386	4	DMPA 214 Bird Island Beneficial Use	Newly Evaluated	3.033	0.286	1.786	0.552	1.379	1.000	0.857	0.179	0.464	0.584	2.59	20	7	0.741	T2	
9083	1	Double Bayou Habitat Preservation	Re-evaluated for 2023	2.638	0.175	2.172	1.070	1.193	1.211	2.088	0.810	0.598	0.668	2.52	38	18	0.679	T2	2019 Tier 1 Project
9265	3	East Living Shoreline and Living Wetland Enhancement	Newly Evaluated	2.818	0.333	2.432	1.465	1.977	1.762	2.023	1.073	0.747	0.780	2.44	30	11	0.732	T1	
1289	2	East Matagorda Bay Emergent and Intertidal Reef Enhancement Project	Newly Evaluated	2.780	0.282	1.700	0.615	1.026	0.950	1.564	0.514	0.485	0.597	2.49	28	12	0.700	T2	
9309	2	East Matagorda Shoals New Island Creation	Newly Evaluated	2.732	0.375	1.225	0.410	1.026	0.825	0.974	0.395	0.398	0.516	2.35	28	13	0.683	T2	
1316	2	Eidelbach Flats New Island Creation	Newly Evaluated	2.805	0.538	1.350	0.487	1.179	0.950	0.919	0.395	0.437	0.538	2.32	27	13	0.675	T2	
1290	1	Enhancement of Moist Soil Units at Justin Hurst Wildlife Management Area	Newly Evaluated	2.692	0.194	0.692	1.368	1.027	1.184	2.000	1.514	0.558	0.684	2.73	26	13	0.667	T2	
9239	2	Espiritu Santo Bay Oyster Reef Restoration	Newly Evaluated	2.865	0.250	1.324	0.528	1.111	0.886	2.184	0.429	0.494	0.696	2.58	24	14	0.632	T2	
9241	2	Espiritu Santo Bay Shoreline Conservation	Newly Evaluated	2.541	0.189	1.405	1.184	1.378	1.297	1.658	0.974	0.555	0.623	2.11	21	18	0.538	T2	
9209	3	Farming Out Pollutants in Petronila Creek	Newly Evaluated	2.359	0.079	0.919	1.474	0.800	1.000	3.077	1.882	0.612	0.791	2.18	30	10	0.750	T1	
1385	3	Feeder Berm North of Fish Pass Beneficial Use	Newly Evaluated	2.622	2.568	0.935	0.889	2.067	1.905	0.867	0.568	0.661	0.620	2.53	35	10	0.778	T1	
9262	2	Foester and Powderhorn Lakes Inflow Management, Enhancement, and Wetland Restoration	Newly Evaluated	2.784	0.222	1.568	1.361	1.324	1.405	2.474	2.297	0.721	0.760	2.43	25	13	0.658	T2	
9261	3	Freshwater/Sediment Inflow Management/Water Impoundment Restoration at Burgentine Lake	Newly Evaluated	2.413	0.182	1.523	1.727	1.432	1.318	2.065	1.733	0.659	0.702	2.38	23	22	0.511	T2	
9190	1	Galveston Bay Park Plan	Newly Evaluated	1.325	0.250	1.800	1.579	2.625	1.875	0.816	0.421	0.559	0.580	1.50	24	17	0.585	T2	
21	1	Galveston Bay Rookery Island Restoration	Re-evaluated for 2023	3.383	0.364	1.872	0.630	1.370	1.283	1.244	0.422	0.552	0.676	2.57	39	6	0.867	T1	2019 Tier 1 Project
9201	1	Galveston Island Nourishment and Stabilization	Newly Evaluated	2.364	3.023	0.933	1.045	2.500	2.178	1.205	0.432	0.735	0.768	2.67	34	9	0.791	T1	
9267	3	GIWW Traditional Spoil Placement Island Restoration	Newly Evaluated	2.545	0.262	2.250	1.186	1.581	1.452	1.326	0.833	0.603	0.607	2.45	29	13	0.690	T2	
9253	3	Going to Scale: Expanding Oyster Restoration in Aransas Bay	Newly Evaluated	3.200	0.424	1.706	0.912	1.559	1.500	2.882	0.971	0.704	0.883	2.56	33	3	0.917	T1	
9254	1	Going to Scale: Expanding Oyster Restoration in Galveston Bay	Newly Evaluated	3.404	0.489	1.409	0.391	0.936	0.783	2.872	0.556	0.568	0.829	2.76	40	6	0.870	T1	
9255	2	Going to Scale: Expanding Oyster Restoration in Matagorda Bay	Newly Evaluated	3.000	0.188	1.364	0.563	1.094	0.879	2.559	0.517	0.528	0.759	2.32	21	13	0.618	T2	
9220	2,3	Guadalupe Delta Land Protection	Newly Evaluated	2.585	0.180	1.698	1.558	1.596	1.471	1.692	1.176	0.634	0.660	2.45	39	17	0.696	T2	
9269	2,3	Gulf Shoreline Erosion and Pass Cavallo Exchange Maintenance	Newly Evaluated	2.451	2.255	1.686	0.878	1.960	1.720	1.208	0.804	0.693	0.628	2.22	35	19	0.648	T2	
9249	2	Harbor of Refuge Old Landfill SHoreline Erosion Response and Protection	Newly Evaluated	2.075	0.158	2.300	0.711	1.590	1.308	2.725	0.632	0.607	0.754	2.66	31	8	0.795	T1	Combined to project 9250, scores averaged
9250	2	Harbor of Refuge Peninsula Shoreline Protection, Flood Mitigation, and Marsh Creation	Newly Evaluated	2.275	0.128	2.525	1.108	1.897	1.718	1.462	0.649	0.622	0.662	2.54	30	10	0.750	T1	Combined to project 9250, scores averaged
9251	2	Harbor of Refuge South Shoreline Protection and Marsh Restoration	Newly Evaluated	2.550	0.158	2.475	0.868	1.925	1.513	1.564	0.541	0.612	0.681	2.36	31	9	0.775	T1	Combined to project 9250, scores averaged
9210	3	Hazel Bazemore Park Restoration	Newly Evaluated	2.156	0.024	0.395	1.222	0.545	0.535	1.386	1.091	0.363	0.520	2.38	17	31	0.354	T2	
9304	1	Hickory Cove Marsh Restoration	Newly Evaluated	3.000	1.034	3.067	1.581	2.452	2.219	1.933	1.097	0.894	0.859	2.88	29	3	0.906	T1	
9248	1	Highland Bayou Shoreline and Marsh Restoration Project	Newly Evaluated	2.739	0.205	1.659	1.600	1.667	1.841	2.413	1.023	0.704	0.801	2.73	32	12	0.727	T1	
9252	1	Houston Parks and Recreation Department's Riparian Restoration Initiative	Newly Evaluated	3.091	0.071	0.829	2.465	1.585	1.488	2.595	1.659	0.741	0.948	2.98	34	8	0.810	T1	
1305	2	Hughson Lakes Conservation and Restoration	Newly Evaluated	2.200	0.189	1.081	1.051	1.053	1.105	1.514	0.821	0.460	0.527	2.33	18	22	0.450	T2	
9219	3	Hybrid Living Shoreline Stabilization Along Corpus Christi Bay	Newly Evaluated	2.064	0.444	2.638	0.957	2.085	1.617	1.283	0.523	0.613	0.677	2.41	31	17	0.646	T2	
1342	2	Hydrologic Restoration of Welder Flats	Newly Evaluated	3.000	0.216	2.154	1.158	1.447	1.432	2.054	1.361	0.685	0.739	2.50	34	5	0.872	T1	
9207	3	Implement and Expand the Use of Nature-Based Stormwater Infrastructure in the Baffin Bay Watershed	Newly Evaluated	2.161	0.133	1.000	1.767	1.033	1.167	2.645	1.900	0.625	0.748	2.37	22	11	0.667	T2	
9205	0	Implementation of a Coastal Harmful Algal Bloom Monitoring Network in Texas	Newly Evaluated	1.976	0.274	0.429	0.289	0.253	0.226	2.812	1.179	0.368	0.560	2.59	52	34	0.605	T2	
1307	1	J.D. Murphree Wildlife Management Area Shoreline Protection	Newly Evaluated	3.000	1.000	2.483	1.172	1.933	1.900	1.867	0.852	0.766	0.777	3.00	26	4	0.867	T1	
9228	1	Jones Bay Oystercatcher Habitat Restoration	Newly Evaluated	3.489	0.400	1.745	0.478	1.152	1.326	2.000	0.556	0.586	0.779	3.15	42	3	0.933	T1	
9218	1	Keith Lake Fish Pass and Baffle Repairs and Upgrades	Newly Evaluated	2.833	0.828	1.733	1.069	1.483	1.607	2.167	1.107	0.685	0.753	2.73	22	7	0.759	T1	
1383	3	Key Allegro Island Beneficial Use	Newly Evaluated	1.980	0.188	1.510	1.021	1.458	1.149	1.000	0.660	0.458	0.479	1.88	14	35	0.286	T2	
9224	2	Lake Austin Coastal Prairie Conservation	Newly Evaluated	2.846	1.184	1.605	1.865	1.947	1.923	1.842	1.378	0.789	0.756	2.49	29	11	0.725	T1	
9289	2	Lavaca and Navidad Rivers Sediment Management Study	Newly Evaluated	1.735	0.333	1.438	1.303	1.030	1.156	1.618	1.406	0.520	0.507	2.54	17	17	0.500	T2	
9059	3	Little Bay Restoration Initiative	Re-evaluated for 2023	2.809	0.391	2.283	1.723	1.702	1.745	2.809	1.674	0.821	0.848	2.70	38	10	0.792	T1	2019 Tier 1 Project
1371	2	Little Bird Island Beneficial Use	Newly Evaluated	2.944	0.171	1.444	0.400	0.778	0.750	0.943	0.294	0.385	0.508	2.41	26	12	0.684	T2	
9192	1	Lower Clear Creek and Dickinson Bayou Watershed Flood Risk Reduction Program	Newly Evaluated	1.091	0.091	0.721	2.891	1.622	1.689	1.326	0.905	0.538	0.589	2.47	33	11	0.750	T1	
1313	2,3	Lower Guadalupe River and Delta Colonial Waterbird Rookery Enhancements	Newly Evaluated	2.208	0.157	1.019	0.725	0.846	0.627	0.918	0.673	0.352	0.420	1.94	17	38	0.309	T2	
1387	1	Lower Neches WMA Lake Street Drive Beneficial Use	Newly Evaluated	3.000	0.621	2.467	1.688	2.129	2.063	1.900	1.357	0.826	0.806	2.94	30	2	0.938	T1	
11	1	Management of the Christmas Bay System	Re-evaluated for 2023	3.095	0.750	2.810	1.325	2.098	2.098	2.268	1.026	0.840	0.861	2.58	33	6	0.846	T1	2019 Tier 1 Project
9299	3	Mangrove Establishment Demonstration Project	Newly Evaluated	2.000	0.676	1.611	0.838	1.605	1.474	1.568	0.571	0.539	0.572	2.14	19	21	0.475	T2	
9281	3	Marina Breakwater Reconstruction	Newly Evaluated	0.956	0.455	1.391	0.841	2.109	1.644	0.609	0.386	0.424	0.438	2.70	20	28	0.417	T2	
9213	2	Matagorda Bay Habitat Enhancement: Firm Water for Focused Environmental Flows	Newly Evaluated	2.487	0.289	0.641	0.641	0.538	0.641	2.051	2.128	0.484	0.582	2.26	25	14	0.641	T2	
9204	1	McFaddin NWR Gulf Shoreline Stabilization	Re-evaluated for 2023	2.967	3.133	0.733	0.800	2.200	2.000	1.333	0.700	0.746	0.760	2.33	23	6	0.793	T1	2019 Tier 1 Project
1389	1	McFaddin NWR Willow Lake Marsh Beneficial Use	Newly Evaluated	3.333	1.067	1.967	1.467	2.167	2.000	2.100	1.071	0.823	0.878	2.93	27	3	0.900	T1	

Project ID	Region	Project Name	Evaluation Status	DLH	GSC	BSC	INFL	STMSRG	TDFL	DWQL	DWQN	Vulnerability Score (Normalized)	Grouped Vulnerability Score (Normalized)	Feasibility	Y Count	N Count	Priority	Tier	Notes/Exceptions
1325	3	Mustang Island State Park - Dune Habitat Conservation and Restoration	Newly Evaluated	2.894	2.213	0.696	0.717	1.894	1.568	0.787	0.457	0.591	0.623	3.21	32	15	0.681	T2	
9279	1	Neches River Forested Floodplain	Newly Evaluated	2.806	0.267	0.516	2.710	1.452	0.935	2.194	1.655	0.668	0.892	2.61	23	8	0.742	T1	
9186	3	Nueces Bay Shoreline Repairs	Newly Evaluated	2.163	0.220	2.605	0.976	2.024	1.707	1.279	0.674	0.616	0.665	2.54	26	17	0.605	T2	
9278	3	Nueces County Gulf Beach Shoreline Renourishment/BUDM	Newly Evaluated	2.565	2.889	0.783	1.000	2.587	2.222	0.977	0.465	0.724	0.733	2.39	35	11	0.761	T1	
9288	3	Nueces County North Beach Wetlands Restoration and Enhancement	Newly Evaluated	2.432	0.571	1.795	1.073	1.455	1.372	1.909	0.884	0.606	0.650	2.51	26	19	0.578	T2	
9195	3	Nueces County Regional Waste Water Plant	Newly Evaluated	1.800	0.045	0.372	0.750	0.341	0.364	3.304	2.136	0.466	0.658	2.64	31	15	0.674	T2	
320	1	Old River Cove Restoration	Re-evaluated for 2023	2.903	0.964	2.966	1.367	2.333	1.967	1.793	0.931	0.826	0.814	2.81	27	4	0.871	T1	2019 Tier 1 Project
346	1	O'Quinn I-45 Estuary Shoreline Protection & Marsh Restoration	Re-evaluated for 2023	3.170	0.227	2.681	1.660	1.936	2.222	2.478	1.091	0.840	0.912	2.70	41	4	0.911	T1	2019 Tier 1 Project
9188	2,3	Oyster Reef Living Shorelines	Newly Evaluated	2.604	0.314	2.096	0.736	1.442	1.294	2.212	0.694	0.600	0.709	2.48	40	16	0.714	T2	
9226	3	Oyster reef restoration in Mesquite-Carlos-Ayres complex	Newly Evaluated	3.114	0.500	1.788	0.939	1.667	1.485	2.771	0.912	0.706	0.872	2.50	29	7	0.806	T1	
1331	3	Oyster Shell Recycling Program for Reef Restoration	Newly Evaluated	2.943	0.559	1.588	0.606	1.324	1.235	2.457	0.750	0.605	0.767	3.00	25	11	0.694	T2	
1380	3	PA9-S Beneficial Use	Newly Evaluated	2.237	0.378	1.632	0.444	1.324	1.189	1.222	0.543	0.458	0.523	2.03	16	21	0.432	T2	
9280	3	Packery Channel Repairs	Newly Evaluated	1.622	1.511	1.178	0.578	1.711	1.467	1.000	0.682	0.504	0.466	2.89	25	21	0.543	T2	
9286	3	Packery Channel Seagrass	Newly Evaluated	2.822	0.889	1.356	0.500	1.205	1.256	2.068	0.667	0.563	0.695	2.33	22	24	0.478	T2	
1332	2	Paired Subtidal and Intertidal Oyster Reef Restoration in Texas Bays	Newly Evaluated	2.971	0.212	1.500	0.606	1.194	0.909	2.353	0.500	0.533	0.741	2.59	27	8	0.771	T1	
1382	3	Pelican Island (M3) Beneficial Use	Newly Evaluated	2.605	0.432	1.842	0.459	1.526	1.297	1.474	0.541	0.529	0.626	2.18	22	15	0.595	T2	
9296	3	Petronila Creek and Oso Creek Watershed Improvements	Newly Evaluated	2.375	0.097	1.129	2.156	1.161	1.452	3.091	2.033	0.724	0.881	2.25	24	11	0.686	T1	
9277	1	Pierce Marsh Wetland Restoration and Shoreline Protection	Newly Evaluated	3.277	0.523	2.638	1.766	2.021	2.234	2.468	0.911	0.862	0.926	2.96	41	4	0.911	T1	
9244	2	Port Alto County Park Shoreline Protection and Restoration - Phase 2	Newly Evaluated	2.300	0.211	2.400	1.026	1.605	1.579	1.579	0.649	0.598	0.624	2.68	31	9	0.775	T1	
9240	3	Port Bay Wetlands Protection	Newly Evaluated	2.477	0.093	1.545	1.356	1.614	1.386	1.767	1.146	0.600	0.658	2.36	28	17	0.622	T2	
5192	4	Port Isabel Breakwater	Newly Evaluated	1.645	0.207	2.267	1.400	2.100	1.800	1.700	0.552	0.617	0.685	2.67	13	15	0.464	T2	
9212	2	Port Lavaca Lighthouse Beach Park Restoration and Resiliency	Newly Evaluated	2.150	0.162	2.150	0.846	1.615	1.462	1.500	0.447	0.538	0.584	2.36	27	13	0.675	T2	
9256	0	Portable Levee Tester	Newly Evaluated	1.219	0.958	1.178	2.293	2.447	2.243	0.873	0.817	0.638	0.492	2.16	31	55	0.360	T2	
9001	3	Portland Living Shoreline	Re-evaluated for 2023	2.268	0.103	2.415	0.900	1.500	1.400	1.250	0.921	0.563	0.571	2.35	28	13	0.683	T2	2019 Tier 1 Project
9221	2	Powderhorn Lake Conservation Program	Newly Evaluated	2.744	0.222	1.526	1.500	1.436	1.447	1.816	1.237	0.632	0.684	2.43	26	13	0.667	T2	
1393	4	Protection and Restoration of Benny's Shack Islands	Newly Evaluated	3.267	0.143	2.393	0.483	1.321	1.107	1.000	0.444	0.528	0.624	2.90	22	5	0.815	T1	
1394	4	Protection and Restoration of Rabbit Island	Newly Evaluated	3.167	0.214	1.750	0.552	1.286	0.929	0.931	0.241	0.464	0.598	2.69	21	6	0.778	T1	
9196	3	Protection of the GIWW Shoreline at the Aransas National Wildlife Refuge	Newly Evaluated	2.783	0.364	2.957	1.000	1.957	1.761	1.326	0.667	0.684	0.706	2.89	39	7	0.848	T1	
1339	0	Quantifying Water Availability and Quality from Submarine Discharge Points into Gulf Estuaries	Newly Evaluated	1.714	0.506	0.724	0.649	0.480	0.527	2.313	2.342	0.475	0.513	2.49	37	43	0.463	T2	
1369	4	Railroad Spur Drainage Detention Area	Newly Evaluated	2.444	0.200	0.292	2.040	0.440	0.520	2.077	1.654	0.499	0.747	2.89	13	11	0.542	T2	
1378	3	Ransom Point Beneficial Use	Newly Evaluated	2.610	0.250	2.300	0.976	1.625	1.410	1.744	0.641	0.610	0.673	2.38	25	15	0.625	T2	
9235	4	Resaca System Restoration Project - Phase 1	Newly Evaluated	3.100	0.107	0.714	2.533	0.893	1.179	2.933	2.897	0.775	1.000	2.53	21	5	0.808	T1	
9236	3	Restoration of Freshwater Inflow to Townsend Bayou	Newly Evaluated	2.723	0.130	1.894	1.333	1.067	1.286	2.574	2.391	0.719	0.756	2.64	37	9	0.804	T1	
1341	4	Restoration of Sea Turtle Nesting Beach at Padre Island National Seashore	Newly Evaluated	3.133	3.103	0.571	0.857	2.571	2.000	0.750	0.407	0.718	0.734	2.79	24	3	0.889	T1	
9063	4	Restore Barrier Island Bayside Wetlands on South Padre Island	Re-evaluated for 2023	2.806	0.500	2.567	1.000	1.867	2.100	2.100	0.533	0.723	0.803	2.43	20	8	0.714	T1	2019 Tier 1 Project
9263	3	Restore Tatton Prairie Overland Sheetflow and Erosion and Shoreline Protection	Newly Evaluated	2.413	0.186	2.022	1.761	1.600	1.400	2.000	1.778	0.705	0.698	2.53	24	22	0.522	T2	
9287	3	Rincon Reef Breakwater	Newly Evaluated	2.766	0.364	2.326	0.978	1.894	1.630	2.200	0.795	0.692	0.785	2.30	33	14	0.702	T1	
9295	1	Sabine-Neches Sediment Management Study	Newly Evaluated	2.290	1.452	1.968	1.469	1.129	1.032	1.742	1.419	0.666	0.613	2.59	18	14	0.563	T2	
1391	2	San Bernard NWR Sargent Unit Beneficial Use	Newly Evaluated	3.049	1.179	2.125	1.297	1.897	2.000	1.744	0.921	0.767	0.776	2.71	33	8	0.805	T1	
1346	1	San Luis Pass Park Shoreline and Facility Repair and Improvements	Newly Evaluated	1.262	0.925	1.462	0.439	1.171	1.167	0.500	0.200	0.349	0.314	2.68	18	22	0.450	T2	
9245	2	Sand Point Peninsula Living Shoreline	Newly Evaluated	2.744	0.263	2.923	0.868	2.026	1.889	1.711	0.658	0.700	0.759	2.43	30	8	0.789	T1	
9215	2	Shoreline Protection and Restoration at Olivia Haterius County Park	Newly Evaluated	2.053	0.263	2.350	0.974	1.816	1.763	1.000	0.351	0.552	0.571	2.87	32	8	0.800	T1	
9184	4	South Padre Island Resilient Public Access	Newly Evaluated	2.367	2.467	0.400	0.793	2.567	2.000	0.552	0.241	0.600	0.624	1.90	19	9	0.679	T2	
9257	1	Southeast Texas Flood Coordination Study - Regional Flood Sensor System	Newly Evaluated	1.192	0.667	0.760	3.107	2.593	2.667	1.038	1.429	0.722	0.642	3.07	25	3	0.893	T1	
9238	3	St Charles Bay Watershed and Drainage Restoration	Newly Evaluated	2.349	0.190	1.773	2.114	1.477	1.357	2.205	1.977	0.721	0.760	2.57	30	13	0.698	T2	
9294	1	Sydnes Island Restoration	Newly Evaluated	2.844	0.793	2.667	1.000	1.767	1.387	1.207	0.500	0.646	0.653	2.59	25	7	0.781	T1	
9293	1	Taylor Landing Water Main Project	Newly Evaluated	0.448	0.036	0.000	0.741	0.321	0.259	2.393	2.357	0.316	0.371	2.59	9	19	0.321	T2	
1356	1	Texas Bayou Water Control Structure	Newly Evaluated	3.000	1.467	1.433	0.867	1.767	1.900	2.467	1.533	0.780	0.849	2.39	21	9	0.700	T1	
9173	1	Texas City Levee Erosion Control and Marsh Restoration	Re-evaluated for 2023	3.170	0.400	2.936	1.723	2.522	2.174	1.915	0.800	0.851	0.879	2.80	39	5	0.886	T1	2019 Tier 1 Project
9216	1	Texas Coastal Prairie Initiative - Region 1	Newly Evaluated	3.000	0.814	1.208	1.806	1.254	1.186	2.055	1.529	0.686	0.785	2.57	50	21	0.704	T1	
1357	1	Texas Point Land Aquisition	Newly Evaluated	2.867	1.310	1.733	1.069	1.724	1.862	1.571	0.852	0.694	0.714	2.46	22	8	0.733	T2	
1388	1	Texas Point National Wildlife Refuge Beneficial Use	Newly Evaluated	3.200	1.867	1.933	1.167	2.233	2.267	2.000	1.133	0.860	0.861	2.80	28	2	0.933	T1	
1359	1	Texas Point NWR Shoreline Protection Sabine Neches Waterway and Oyster Habitat Creation	Newly Evaluated	3.067	2.100	2.233	0.867	2.033	1.867	1.862	0.828	0.804	0.798	2.80	28	2	0.933	T1	
9164	0	Texas Seagrass Restoration	Re-evaluated for 2023	3.059	1.106	2.143	0.819	1.417	1.434	2.353	0.845	0.705	0.783	2.25	56	32	0.636	T2	2019 Tier 1 Project
1360	0	Texas Shroebird and Seabird Stewardship Program	Newly Evaluated	2.837	0.622	0.841	0.296	0.506	0.457	0.628	0.430	0.319	0.420	2.65	57	29	0.663	T2	
9208	3	The Aguanita Project: Improving Water Quality in Petronila Creek and Baffin Bay	Newly Evaluated	2.543	0.111	0.622	1.523	0.644	0.717	2.979	2.047	0.588	0.808	2.51	31	17	0.646	T2	
1363	2	The Importance of Pass Cavallo to the Health of Matagorda, Espiritu Santo, and Lavaca Bays	Newly Evaluated	2.242	2.061	1.970	0.839	1.344	1.516	1.781	1.094	0.686	0.618	2.75	22	13	0.629	T2	
9107	1	The Marshland Restoration Project at Anahuac National Wildlife Refuge	Re-evaluated for 2023	2.737	0.456	0.965	0.982	0.947	1.105	2.351	2.000	0.609	0.701	2.17	33	25	0.569	T2	2019 Tier 1 Project
1364	1	Varner Creek Park	Newly Evaluated	1.375	0.026	0.103	0.725	0.205	0.256	0.775	0.359	0.155	0.282	2.41	12	26	0.316	T2	
9242	1	Walter Umphrey Park Bulkhead Repair and Resiliency Uprade	Newly Evaluated	1.034	0.690	2.167	0.767	1.867	1.333	0.724	0.367	0.457	0.519	2.86	16	13	0.552	T2	
9227	1	West Bay Living Shorelines at Sweetwater Preserve and Maggie's Cove	Newly Evaluated	3.191	0.500	2.739	1.109	1.872	2.021	2.149	0.674	0.769	0.848	2.89	41	4	0.911	T1	
9290	1	West Jefferson County Regional Water Supply Improvements	Newly Evaluated	0.448	0.143	0.143	0.815	0.643	0.333	2.037	2.333	0.336	0.373	2.81	11	16	0.407	T2	
9258	3	West Marsh Hurricane Repair & Bayside Resilience	Newly Evaluated	2.581	0.643	2.116	1.049	1.585	1.439	1.439	0.925	0.623	0.626	2.48	28	15	0.651	T2	
9222	2	West Matagorda Peninsula Acquisition Program	Newly Evaluated	2.366	1.675	1.500	0.850	1.675	1.268	0.897	0.667	0.571	0.542	2.11	25	16	0.610	T2	
9193	1	West Orange County Flood Control Project	Newly Evaluated	1.800	0.067	0.483	2.968	1.567	1.067	1.586	1.536	0.582	0.721	2.23	19	13	0.594	T2	

2019 Plan Carryover Projects

Project ID	Region	Project Name	Evaluation Status	ALDH	GBEDD	BSE	EFCSSD	CFD	IWQQ	ICR	ADVSD	IOC SUM	Feasibility	Y Count	N Count	Priority	Tier	Notes/Exceptions
1237	0	Abandoned and Derelict Structure Removal Program	2019 Carryover	2.140	1.100	0.740	1.000	0.590	1.830	2.110	3.710	13.22	Null	Null	Null	1.000	T1	Existing GLO Priority
2	0	Abandoned Vessel Removal Program	2019 Carryover	2.140	1.100	0.740	1.000	0.590	1.830	2.110	3.710	13.22	Null	Null	Null	1.000	T1	Existing GLO Priority
2311	0	Beach Monitoring and Maintenance Program	2019 Carryover	2.360	2.860	2.350	2.740	1.580	1.410	1.820	0.220	15.34	Null	Null	Null	1.000	T1	Existing GLO Priority
252	1	Bolivar Peninsula Beach and Dune Restoration	2019 Carryover	2.560	3.220	0.000	2.890	2.410	1.500	2.440	0.000	15.02	Null	Null	Null	0.884	T1	Evaluated by TAC in 2019
9101	1	Brazos River and San Bernard River Restoration Strategy and Management Plan	2019 Carryover	2.440	2.330	1.760	1.790	2.070	2.240	2.350	0.140	15.12	2.85	17	2	0.895	T1	Evaluated by TAC in 2019
10000	1	Chambers County Wetland Restoration	2019 Carryover	3.409	1.632	2.500	2.619	2.773	2.909	3.136	0.667	19.64	3.11	15	4	0.789	T1	Evaluated by TAC in 2019
9123	4	City of South Padre Island Living Shoreline	2019 Carryover	3.390	1.620	3.430	2.710	2.520	2.640	3.040	0.610	19.96	3.03	25	2	0.926	T1	Evaluated by TAC in 2019
9183	0	Clean Coast Texas Program	2019 Carryover	Null	Null	Null	Null	Null	Null	Null	Null	Null	2.982	73	17	0.811	T1	Existing GLO priority
240	1	Coastal Heritage Preserve	2019 Carryover	3.370	Null	2.420	2.320	2.280	1.950	3.110	0.000	15.45	Null	36	0	1.000	T1	Evaluated by TAC in 2019
9136	3	Corpus Christi Bay Wastewater, Stormwater Quality and Pollution Management Improvements	2019 Carryover	2.040	0.300	0.520	1.430	1.220	3.670	2.250	0.950	12.38	2.7	26	4	0.867	T1	Evaluated by TAC in 2019
10013	0	Data Collection to Support Continual Updates to the National Wetlands Inventory Dataset	2019 Carryover	2.246	2.026	1.704	2.560	2.482	1.882	2.366	0.556	15.82	3.034	74	21	0.779	T1	Evaluated by TAC in 2019
9180	0	Development of Optimal Coastwide Bathymetric and Topographic Models	2019 Carryover	2.090	2.220	2.530	2.590	2.520	1.290	1.840	0.870	15.95	2.55	21	7	0.750	T1	Evaluated by TAC in 2019
797	1	Dickinson Bay Rookery Island Restoration	2019 Carryover	2.830	Null	1.140	1.000	0.730	1.610	3.220	0.000	10.53	Null	32	4	0.889	T1	Evaluated by TAC in 2019
9066	1	Dollar Bay Wetland Creation, Restoration, and Acquisition	2019 Carryover	3.170	0.280	2.740	1.840	1.550	2.210	3.060	0.000	14.85	3.34	35	1	0.972	T1	Evaluated by TAC in 2019
9108	1	East and West Galveston Bay Watershed, Wetland and Habitat Conservation	2019 Carryover	3.260	0.230	1.970	2.590	2.440	3.000	3.310	0.240	17.04	3.53	33	1	0.971	T1	Evaluated by TAC in 2019
9161	1	East Bay Living Shorelines and Wetland Restoration	2019 Carryover	3.000	0.590	2.830	2.000	1.520	1.890	2.900	0.080	14.81	2.9	26	7	0.788	T1	Evaluated by TAC in 2019
9046	1	Follet's Island Conservation Initiative	2019 Carryover	2.820	Null	1.909	2.200	2.000	2.090	2.700	0.000	13.72	Null	34	1	0.971	T1	Evaluated by TAC in 2019
315	1	Follet's Island Nourishment and Erosion Control	2019 Carryover	2.300	2.900	0.000	2.450	2.060	1.000	2.050	0.000	12.76	Null	22	11	0.667	T1	Evaluated by TAC in 2019
437	3	Fulton Beach Road Protection	2019 Carryover	2.610	Null	3.250	3.110	1.700	1.670	2.060	0.000	14.40	Null	31	1	0.969	T1	Evaluated by TAC in 2019
9026	1	Galveston Island West of Seawall to 8 Mile Road Beach Nourishment - Phase 1	2019 Carryover	1.850	3.000	0.000	2.860	1.930	0.730	1.920	0.000	12.29	Null	27	7	0.794	T1	Evaluated by TAC in 2019
70	3	Goose Island State Park Habitat Restoration and Protection	2019 Carryover	3.080	Null	2.780	2.220	1.130	1.130	2.490	0.000	12.83	Null	30	2	0.938	T1	Evaluated by TAC in 2019
600	2	Half Moon Oyster Reef Restoration - Phase 3	2019 Carryover	2.930	Null	1.560	1.500	0.500	2.380	3.000	0.000	11.87	Null	29	0	1.000	T1	Evaluated by TAC in 2019
9158	3	Indian Point Marsh Area Living Shoreline	2019 Carryover	3.140	0.550	3.370	2.600	2.100	1.830	2.790	0.210	16.59	3.16	29	2	0.935	T1	Evaluated by TAC in 2019
72	3	Long Reef and Deadman Island Shoreline Stabilization and Habitat Protection	2019 Carryover	2.690	Null	2.110	1.830	0.500	0.630	2.940	0.000	10.70	Null	32	1	0.970	T1	Evaluated by TAC in 2019
9097	0	Longshore Transport Modeling	2019 Carryover	2.150	3.060	1.740	2.360	1.860	0.950	2.210	0.360	14.69	2.89	68	26	0.723	T1	Evaluated by TAC in 2019
9118	0	Long-Term Hydrologic Monitoring Program	2019 Carryover	2.274	2.028	1.888	2.340	1.812	1.400	2.370	0.270	14.38	3.234	76	17	0.817	T1	Evaluated by TAC in 2019
644	2	Mad Island Marsh Preserve Shoreline Protection and Coastal Ecosystem Restoration - Phase 1	2019 Carryover	3.130	0.720	3.250	2.630	2.000	2.180	2.840	0.000	16.75	3.58	27	3	0.900	T1	Evaluated by TAC in 2019
9070	2	Matagorda Bay Regional Inflow Study	2019 Carryover	1.890	0.530	1.290	1.750	2.180	3.050	2.630	0.000	13.32	2.96	19	4	0.826	T1	Evaluated by TAC in 2019
9150	1	Middle Armand Bayou Protection Project	2019 Carryover	3.170	Null	1.390	2.520	2.660	3.050	3.110	0.060	15.96	3.31	37	1	0.974	T1	Evaluated by TAC in 2019
9082	1	Moody National Wildlife Refuge Conservation and Restoration	2019 Carryover	3.478	1.850	2.870	2.545	2.773	2.571	2.957	0.526	19.57	3.1	16	3	0.842	T1	Evaluated by TAC in 2019
9139	3	Newcomb's Point Shoreline Stabilization	2019 Carryover	3.000	0.520	3.270	2.120	1.450	1.060	3.060	0.190	14.67	3.06	30	3	0.909	T1	Evaluated by TAC in 2019
457	1	North Pleasure Island Shoreline Protection & Restoration	2019 Carryover	2.790	Null	2.070	1.790	1.850	1.620	2.360	0.000	12.48	Null	20	0	1.000	T1	Evaluated by TAC in 2019
443	3	Nueces County Hydrologic Restoration Study	2019 Carryover	3.040	Null	2.120	1.690	1.620	3.290	2.960	0.000	14.72	Null	30	1	0.968	T1	Evaluated by TAC in 2019
922	2	Oliver Point Shoreline Protection and Reef Restoration	2019 Carryover	2.560	Null	2.170	1.610	0.670	2.280	2.890	0.000	12.18	Null	27	1	0.964	T1	Evaluated by TAC in 2019
9045	3	Packery Channel Nature Park Habitat Restoration - Phase 2	2019 Carryover	3.460	1.000	3.090	2.690	2.100	1.390	2.970	0.220	16.92	3.53	28	5	0.848	T1	Evaluated by TAC in 2019
9134	3	Port Aransas Nature Preserve Stabilization and Restoration - Phase 2	2019 Carryover	3.690	0.660	3.500	3.430	2.810	1.790	3.480	0.430	19.79	3.51	35	0	1.000	T1	Evaluated by TAC in 2019
430	2	Carancahua Bay Habitat Preservation and Enhancement	2019 Carryover	2.670	Null	2.470	2.000	0.800	1.530	2.330	0.000	11.80	Null	26	3	0.897	T1	Evaluated by TAC in 2019
9062	4	Restore Laguna Madre Rookery Islands	2019 Carryover	3.220	1.060	2.400	2.130	1.680	1.330	3.290	0.210	15.32	3.1	24	2	0.923	T1	Evaluated by TAC in 2019

Project ID	Region	Project Name	Evaluation Status	ALDH	GBEDD	BSE	EFCSSD	CFD	IWQQ	ICR	ADVSD	IOC SUM		Feasibility	Y Count	N Count	Priority	Tier	Notes/Exceptions
4	2	San Bernard National Wildlife Refuge Shoreline Protection	2019 Carryover	2.880	Null	2.380	1.500	1.000	1.440	2.310	0.000	11.51		Null	28	0	1.000	T1	Evaluated by TAC in 2019
418	2	Sargent Beach & Dune Restoration	2019 Carryover	2.060	3.290	0.000	2.880	1.290	0.650	2.120	0.000	12.29		Null	24	4	0.857	T1	Evaluated by TAC in 2019
696	3	Shamrock Island Restoration - Phase 2	2019 Carryover	3.140	Null	2.760	2.210	1.030	1.520	3.350	0.000	14.01		Null	32	1	0.970	T1	Evaluated by TAC in 2019
9003	3	Shell Point Ranch Wetlands Protection	2019 Carryover	3.000	Null	1.154	1.071	1.143	1.643	3.083	0.000	11.09		Null	26	1	0.963	T1	Evaluated by TAC in 2019
10005	3	Shoreline and Wetland Protection on Mustang Island - Phase 1: Cohn Preserve	2019 Carryover	3.260	0.810	3.110	2.380	1.920	1.960	2.770	0.380	16.59		2.54	20	9	0.690	T1	Evaluated by TAC in 2019
145	4	South Padre Island Beach and Dune Management and Restoration	2019 Carryover	1.910	3.380	0.000	2.660	1.560	0.470	1.750	0.000	11.73		Null	28	0	1.000	T1	Evaluated by TAC in 2019
9051	4	South Padre Island Coastal Beach Protection	2019 Carryover	2.630	2.680	2.230	2.390	1.810	1.520	2.840	0.200	16.30		2.85	26	2	0.929	T1	Evaluated by TAC in 2019
1202	3	Tern Island and Triangle Tree Island Rookery Habitat Protection	2019 Carryover	3.270	0.530	2.790	1.480	1.360	0.710	3.360	0.110	13.61		3.14	27	4	0.871	T1	Evaluated by TAC in 2019
1	0	Texas Coastal Resiliency Master Plan	2019 Carryover	Null	Null	Null	Null	Null	Null	Null	Null	Null		Null	Null	Null	1.000	T1	Existing GLO priority
9081	1	Texas Point Beach Nourishment Project	2019 Carryover	3.450	3.650	2.167	3.000	2.579	2.000	3.150	0.833	20.83		3.85	17	2	0.895	T1	Evaluated by TAC in 2019
Project ID	Region	Project Name	Evaluation Status																
5151	0	2019 Update to BEG Shoreline Change	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5214	0	A Comprehensive Assessment of Texas Coastal Ecosystems & Economies to Inform Ecological Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1256	2	A comprehensive strategy to protect and restore the Guadalupe River Delta	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5215	4	A Geological Framework Study of South Padre Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5421	3	A study of the Laguna Salada ecosystem to support Baffin Bay restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5216	0	Acquisition and Production of Orthoimagery for Coastal Texas	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5217	4	Adolph Thomae Jr. Park Educational Pavilion	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5152	4	Adolph Thomae Shoreline Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1257	4	Adolph Thomae, Jr. Park Living Shoreline Restoration Phase 5	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	-	Alligator Point	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1258	1	American Oystercatcher Habitat Restoration for Long-Term Resiliency in Jones Bay, Texas	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5434	3	An integrated assessmnet of nutrient loadings to Baffin Bay, Texas	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5153	1	Anahuac National Wildlife Refuge Living Shoreline	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9214	1	Anahuac National Wildlife Refuge South Unit Beach Nourishment	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Anahuac NWR	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Anahuac NWR 124 Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Anahuac NWR Cade Ranch	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Anahuac NWR Lone Tree Bayou Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5218	0	Analysis of Erosion and Subsidence in Texas Coastal Wetlands	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5219	3	Analysis of Sediment Transport and Its Impacts on Coastal Habitats in the Corpus Christi-Nueces Bays	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9260	3	ANWR GIWW Stabilization Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5220	3	Application of Remote Sensing and Ground Penetrating Radar to Study Coastal Dunes	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5154	2,3	Aransas National Wildlife Refuge Dagger Point Shoreline Preservation Phase 1	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5221	1	Armand Bayou Watershed Partnership - Strategic Plan Implementation - Phase I	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5222	-	Assess nonpoint source Nitrogen contribution to the Texas Coastal Zone from septic systems	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5223	3,4	Assessing Carbonate Chemistry Condition As a Function of Freshwater Inflow in South Texas Estuaries	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5224	0	Assessing Coastal Change in Support of the 2023 Texas Coastal Resiliency Master Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5429	1	Assessing Flow and Sediment Dynamics of Lower Brazos and San Bernard Basins	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5225	3	Assessing hydrology, ecology, and multiple land use interactions in San Antonio Bay watersheds	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5226	3	Assessing impacts of inflow on oyster health in restored reefs with microbiomes and isotopes	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5227	3,4	Assessment and economic valuation of nitrogen mitigation in Texas Coastal Bend restored marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5228	3,4	Assessment and Monitoring of Artificial Reefs in the Western Gulf of Mexico	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5229	1	Assessment of Optimal Sea Turtle Nesting Sites along the Texas Coast	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5432	3	Assessment of Seagrass Habitat and Stability in Texas Coastal Waters	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5230	1	Assessment of stormwater infrastructure for mitigating flooding and non-point source pollution	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1259	0	Audubon Coastal Bird Stewardship	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5155	1	Babe's Beach Benficial Use of Dredged Material Re-Nourishment Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5156	1	Back-Passing Nourishment Pratices - Beneficially Utilizing Existing Coastal Processes	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1260	4	Baffin Bay Petronilla Creek Watershed Water Quality Initiative	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5231	3	Baffin Bay Tributaries Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5232	3	Baffin Bay water quality study:Data collection & outreach to address water quality concerns - Phase 2	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1261	4	Bahia Grande Channel F Hydrologic Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	2	Bay City Regional Drainage Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5157	3	Bay Shore Beach Beneficial Use Project Phase 1	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5233	0	Bay Shoreline Protection - Living Shorelines (Outreach)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5234	1	Bayou Riparian Corridor Restoration: Clear Creek	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5235	1	Beach Access Ramps	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5236	1	Beach-nesting Bird Conservation through Monitoring, Stewardship, and Education	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5237	1	Beach-nesting Bird Conservation, Monitoring, Stewardship and Education	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5238	1	Beach-nesting Bird Demography & Public Engagement on the Texas Gulf Coast	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Bear Lake Grennel Slough in San Jacinto River	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1263	4	Bejarano-McFarland Living Shoreline	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1264	2	Beneficial Dredge Use to Restore Texas Coastal Marshes	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5239	3,4	Beneficial Use Master Plan -- Texas GLO Regions 3 (Coastal Bend) and 4 (Lower Coast)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5158	1	Beneficial Use of Dredged Materials on Bolivar Peninsula	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9203	1	Beneficially Used Dredged Material for Anahuac National Wildlife Refuge Roberts Mueller Tract	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	2	Big Boggy NWR	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1266	2	Big Boggy NWR Land Acquisition	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1267	1	Bird Island Cove Habitat Restoration Project Phase II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5159	1	Bird Island Cove Shoreline Protection Phase I	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5240	2	Bird Island Creation in Carancahua Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1275	2	Bird Island Habitat Creation in Matagorda Bay and Carancahua Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-03)	3	Bludworth Island Pond	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5241	4	Boat Ramp Park Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5242	1	Boater Waste Education Campaign: Evaluation and Reflection for Improved Program Effectiveness	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5243	1	Boater Waste Education Campaign: Expanding Engagement Efforts and Changing Boater Behavior	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5244	1	Boater Waste Education Campaign: Growing local capacity to reduce vessel discharge in Galveston Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5245	2	Boggy Bayou Nature Park Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5160	2	Boggy Nature Park Shoreline Stabilization	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5161	1	Bolivar Peninsula Beach & Dune Restoration Design and Engineering Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Bosquez Rd. / Avenue J Drainage Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5162	4	Brazos Santiago Pass Beneficial Use of Dredge Material	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1271	1	Brown Ranch Shoreline Protection / Wetlands Restoration Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Brownwood	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5246	1	Bryan Beach Dune and Wetland Habitat Protection Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5247	1	Buffalo Bend-Hidalgo Greenway Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5248	0	Building Resiliency on Private Lands: Connecting Landowners to Conservation Assistance Programs	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5163	2	Calhoun County Magnolia Beach Erosion Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5415	4	Cameron County Beach Access #3 Accessibility Infrastructure	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5249	4	Cameron County Beach Access #4 Enhancements - Phase II (Utilities & Rinse Stations)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Cameron County Drainage District No. 3 Flood Protection Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Cameron County Drainage District No. 5 Flood Control	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Cameron County Drainage District No. 5 Flood Control	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Cameron County Drainage District No. 5 Flood Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Cameron County Paso Real Drainage	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1273	2	Caney Creek Marsh Protection and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1274	2	Canoe Bayou Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5250	4	Capacity Building in Cameron County for Coastal Wetland Delineation and WetlandMitigation Bank Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5164	2	Carancahua Bay Shoreline Protection - AA	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Casa Blanca Drainage Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1276	3	Causeway Rookery Island Protection and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5165	3	Causeway Rookery Island Protection and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Chambers County Flood Protection Planning	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5166	4	Children's Beach Shoreline Restoration Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1277	1	Chocolate Bay - Oyster Lake Shoreline Stabilization	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Project ID	Region	Project Name	Evaluation Status																
5251	2	Chval Park	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5252	2	Chval Park	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	City of Harlingen Flood Protection Planning Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5253	1	Clear Creek Connections Paddle Trail - Kayak Launches	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5254	1	Clear Creek Nature Park Shoreline Management	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5255	3,4	Climate Impacts on Freshwater Storage near the South Texas Gulf Coast: Implications on Coastal SGD	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5435	3	Closing the loop: Recycling shells and restoring reefs for resilience and recovery	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5256	3,4	Coastal Bend Regional Resiliency - Texas Coastal Resiliency Master Plan Local Integration for Action	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5257	4	Coastal groundwater flow and its potential influence on seagrass distribution in Lower Laguna Madre	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1280	1	Coastal Habitat and Bird Conservation through Land Acquisition on Galveston Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5258	1	Coastal Prairie Restoration at Anahuac National Wildlife Refuge's Pintail Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5259	0	Coastwide Trends in Seagrass Cover and Condition in Texas Waters	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-56)	3	Cohn Preserve Breaches	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1281	2	Colorado River Delta	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1282	2	Colorado River Delta Conservation - Matagorda Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1283	2	Colorado River Selkirk Tract	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5426	1	Community Outreach through Oyster Shell Recycling and Citizen Science	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5260	1	Consequences of land use land change on water quality in Galveston Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1285	1	Conservation of Wading Bird Rookery Sites in the Northern Gulf	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5261	1,2	Construction and Enhancement of Artificial Reefs in the Northeastern Gulf of Mexico	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5263	1,2	Construction and Enhancement of Artificial Reefs in the Northern Gulf of Mexico	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5262	1,2	Construction and Enhancement of Artificial Reefs in the Northern Gulf of Mexico	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5264	2	Coordinating Implementation of the Tres Palacios Watershed Protection Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5167	3	Corpus Christi North Beach Harvey Repair	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-09)	3	Dagger Island BU Site (M4)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5265	3	Dagger Island Restoration Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5266	3	Data Collection for Oyster Mariculture Interactions with Seagrass	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5267	0	Data Development and Management for Coastal Protection and Resiliency Planning	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5212	1	Dellanera Park Beach Nourishment	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9233	4	Developing a Comprehensive Conservation and Resiliency Management Plan for the Lower Laguna Madre	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9206	2	Developing a New Water Supply for Estuarine Marsh Management	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5268	1	Development of a Galveston Bay 3D Hydrodynamic and Sediment Transport Models to Support Oyster Reef	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5269	1	Development of a Geohazards Map for Bolivar Peninsula	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5270	1	Development of a Geohazards Map for Bolivar Peninsula to Increase Community Resiliency	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1287	1	Dickinson Bay Oyster Reef Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1288	1	Dickinson Bayou Prairie and Wetland Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9264	3	Ditch & Road Hydrologic Restoration and Wetland Development Area	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Ditch “A” and Bluebonnet Drainage Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-06)	3	DMPA #187 PINS Bird Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-08)	3	DMPA #192 PINS Bird Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5271	2	Dog Island Acquisition	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5272	1	Dollar Bay Land Acquisition	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5273	1	Dollar Bay Wetland Creation, Restoration and Acquisition (R1-16)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1291	4	Dolphin Cove Shoreline Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5274	4	Dune walkover renovation at Cameron County Beach Access #3	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5275	3,4	Earth Day Bay Day Celebration 2019: a fun, family-friendly, educational event	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5276	1	East End Lagoon Public Access / Safety and Planning Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5277	1	East End Lagoon Public Accessibility Parking Enhancement Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5168	0	Economic-Natural Resource Benefit-Cost Study of CEPRA Cycle 7-9 Projects	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5213	0	Economic-Natural Resource Benefit-Cost Study of CEPRA Projects	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5278	2	Effect of oyster cage culture on sedimentation and water quality in a tidally influenced creek	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5279	0	Enhancing Critical Rookery Islands for the Protection and Preservation of Colonial Waterbirds	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5280	1,2	Evaluating the trophic value of beneficial uses restoration sites for coastal birds	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5281	4	Evaluation of Groundwater Inputs from the South Texas Sand Sheet into the Lower Laguna Madre in Kenedy County	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5282	0	Expanded Assessment of Erosion and Subsidence	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5283	4	Expansion of Fresh Water Inflows into the Lower Laguna Madre Monitoring Network	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5284	2	Expansion of King Fisher Beach Park	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1292	3	Expansion of Oyster Shell Reclamation and Restoration Program	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5285	1	Exploration Green Public Access Development and Ecosystem Restoration, Phase 3	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5419	1	Exploration Green Stormwater Wetland Water Quality Baseline Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5416	4	Fantasy Circle Beach Access Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-45)	3	Feeder Berms N of Port A	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-51)	3	Feeder Berms S of Port A	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-12)	3	Feeder Berms South of Packery Channel	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1293	1	Follets Island CMA Additions	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1294	3	Follett's Island Beach Nourishment Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5418	1	Fort Travis Public Restroom Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5286	4	FRED STONE PARK PIER UPGRADE	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5423	2	Freshwater Inflow Standards for East Matagorda Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5287	0	Freshwater Inflows to Texas Bays and Estuaries: A State-Wide Review, Synthesis, and Recommendations	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5288	1	From microbes to macrophytes: a novel ecosystem approach to assess coastal wetland restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5289	3	Fulton Beach Road Living Shoreline	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5290	1	Galveston Bay Coalition of Watersheds - A collaborative approach to watershed plan implementation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5291	1,2	Galveston Bay Estuary Resilience Assessment	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5292	1	Galveston Bay Foundation Oyster Shell Recycling Program	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5293	1	Galveston Bay Foundation Oyster Shell Recycling Program	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5294	1	Galveston Bay Foundation Oyster Shell Recycling Program	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5295	1	Galveston Bay Foundation Oyster Shell Recycling Program - Citizen science, engagement, and education	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1295	1	Galveston Bay Foundation's Oyster Shell Recycling Program	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1296	1	Galveston Bay Foundation's Oyster Shell Recycling Program	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5296	1	Galveston Bay Foundation's Oyster Shell Recycling Program Phase 4 - Sun Curing Research	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1297	1	Galveston Bay Oyster Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1298	1	Galveston Bay Oyster Restoration and Enhancement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5297	1,2	Galveston Bay Watershed Marine Debris Action Plan Supporting plan initiatives and regional database	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5169	1	Galveston Beneficial Dredge- Babe's Beach Re-Nourishment Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5170	1	Galveston Island State Park Marsh Restoration & Protection Phase III	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5298	1	Geophysical and Geologic Survey of Bolivar Roads: Understanding Sediment Distribution and Evolution	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5171	1	Gilchrist West Rollover Beach Nourishment with BUDM - Rollover Bay Reach GIWW	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-13)	3	GIWW at Corpus Christi Bay near Coyote Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9284	1	GIWW Breach at Nicks Lake	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	2	GIWW shoreline at Pelton Lake	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1299	3	Going to Scale: Expanding oyster restoration in Aransas Bay to recover oyster resources at landscape scale for ecosystem	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1300	1	Going to Scale: Expanding oyster restoration in Galveston Bay to recover oyster resources at landscape scale for ecosyste	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1301	2	Going to Scale: Expanding oyster restoration in Matagorda Bay to recover oyster resources at landscape scale for ecosyst	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5299	3	Goose Island Marsh Restoration in Aransas Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5300	3	Goose Island Marsh Walkway	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5301	3	Goose Island Shoreline Stabilization and Marsh Restoration, Phase II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5302	3	Goose Island Shoreline Stabilization and Restoration of Adjacent Habitats	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1302	3	Goose Island State Park - Newcomb Marsh Conservation and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5172	1	Gordy Marsh Restoration and Shoreline Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5303	1	Green Infrastructure For Texas: Educating Coastal Stakeholders on the Role of Green Infrastructure	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Green Lake Outfall System and Gregory Diversion Ditch	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1303	1, 3	Gulf Oyster Recycling Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Halls Bayou Drainage Project Bond C-28 & C-29	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5304	1	Hanson Riverside County Park - Columbia Bottom Land Educational Access Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Harlingen 9th & 13th Street Drainage Improvements Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Project ID	Region	Project Name	Evaluation Status																
5305	3,4	Have Changes in Laguna Madre Algal Flats Resulted in Reduced Quality of Shorebird Foraging Habit?	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9185	2	Hawkins Ranch Coastal Prairie Conservation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1304	1	Hickory Cove Breakwater and Beneficial Dredge Use for Marsh Restoration and Enhancement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5306	1,2	High Frequency Radar for Texas Bays and Ports	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5307	3	High Water Mark Project: Supporting Local Communities to Become More Resilient and Flood Prepared	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9297	1	Highland Bayou Park Shoreline Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5173	1	Historic Seawall Harvey FEMA Repairs	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	HMGP Match Funds	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5308	1	Houston Botanic Garden Stormwater Wetlands	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Houston Storm Water Master Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5430	2	Hydrologic restoration of the Welder Flats Marsh for Whooping Cranes	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1306	3	Hydrological Modeling and 5 Years of Post-contruction Ecological Monitoring	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5309	3	Identification of microbiological and water quality drivers of brown tide in Baffin Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5420	1	Identify potential BMP tools to reduce bacteria loading in Neches River	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5310	1	Identifying Pathways, Quantities and Composition of Marine Debris in Galveston Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5311	1	Identifying the Future Costs of Floods in the Houston-Galveston Area	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5312	1	Impact of river inflows on sediment dynamics in Galveston Bay under urbanization and extreme events	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Impala Drain and Upstream Ditches Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5313	0	Implementation of Coastal Nonpoint Source Management	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5174	1	Improving Resilience Through A Corps of Engineers Permit in Jamaica Beach	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5314	3	Improving Stormwater Management in Port Aransas	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5315	1	Improving the resilience of the Texas coast with high resolution terrain analysis	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5175	3	Indian Point East Shoreline Protection Phase 2	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9285	3	Indian Point Pier Road	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5176	3	Indian Point West Shoreline Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5316	3,4	Influence of Coastal Hydrology on Seagrass	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5317	0	Infrastructure Resiliency Information Exchange - Stakeholder Engagement for the Texas Coast	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5318	1	Initiating water quality sampling of stormwater treatment wetlands in Galveston Bay watersheds	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5319	3	Investigating reactive nitrogen sources and processing in Baffin Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Iowa Colony Master Drainage Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5177	4	Isla Blanca Park Beach Nourishment with Beneficial Use of Dredge Material	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	J.D. Murphree WMA Johnson Keith Lakes	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	J.D. Murphree WMA Leveed Compartments	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	J.D. Murphree WMA Lost Lake NE	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	J.D. Murphree WMA Nearby Private Landowner	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	J.D. Murphree WMA North of Keith Lake	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Jefferson County Regional Watershed Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1308	4	Johnson Tracts Conservation, Laguna Atascosa National Wildlife Refuge	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Joint Flood Control Project with WCDD #1	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5178	1	Jones Bay Oystercatcher Habitat Restoration and Enhancement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1309	1	Justin Hurst Wildlife Management Area Shoreline Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9299	1	Keith Lake Fish Pass Baffle - repairs	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1310	2	Keller Bay Habitat Preservation and Enhancement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1311	3	Key Allegro Beneficial Islands	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Kingsville Drainage Master Plan - Location 1	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Kingsville Drainage Master Plan - Location 3	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Kingsville Drainage Master Plan - Location 4	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Kingsville Drainage Master Plan - Location 7 Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	La Sara Gates	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9292	1	LaBelle Road Loop	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5320	4	Laguna Madre Living Shoreline Cultivation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5179	4	Laguna Vista Spoil Island Shoreline Protection Phase I	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9191	2	Lake Austin Coastal Prairie Conservation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5321	3	Lamar Peninsula Whooping Crane Habitat Enhancement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Linear Detention and Pipe	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5322	3	Linking Coastal Urbanization to Water Quality and Habitat Changes of the Upper Laguna Madre	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1312	2	Live Oak Bayou Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5180	0	Longshore Transport Modeling	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5323	3	Long-term monitoring of nektonic fish and crustaceans in seagrass nurseries near Cedar Bayou	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Lower Cedar Bayou	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9194	1	Lower Clear Creek and Dickinson Bayou Flood Risk Management Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5324	4	Lower Laguna Madre Estuary Program (LLMEP) - Implementation of the LLMEP Strategic Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5431	4	Lower Laguna Madre Hydrodynamic Characterization	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5325	4	Lower Laguna Madre OSSF and NPS Pollution Prevention and Awareness, and GIS Database Program	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (DUTX-009)	1	Lower Neches Wildlife Management Area	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (DUTX-003)	1	Lower Neches WMA Lake Drive West (ref. DUTX-003)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Lower Rio Grande Valley Regional Flood Protection Planning	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Lyford Trunkline	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-54)	3	M10 (Habitat Creation)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-41)	3	M4 (Habitat Creation)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5181	2	Mad Island Marsh Preserve Shoreline Protection and Coastal Ecosystem Restoration Phase 1	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1314	2	Mad Island Shoreline Protection and Ecosystem Restoration Phase II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1315	2	Mad Island Wildlife Management Area Shoreline Protection (Phase III - Freshwater Lake)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5326	2	Magnolia Beach / Indianola Beach Pavilions	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5327	3	Mangrove Expansion Alters Sediment and Water Quality and Affects Biodiversity in Texas Wetlands	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5328	2	Mapping Optimal Locations for Oyster Aquaculture A Substrate, Geochemical and Solute Flux Analyses	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5329	2	Mapping Optimal Locations for Oyster Aquaculture: I. Remote Sensing and Field Observations	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5330	1	Master Planning Public Access Along Galveston's Seawall for Long Term Success	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1317	2	Matagorda Bay Oyster Restoration and Enhancement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5422	2	Matagorda Bay shoreline resilience: Restoring seagrass pilots plus a demo	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5331	2	Matagorda County Sargent Beach Park Restroom	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	2	Matagorda Island NWR West Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1319	2	Matagorda Peninsula Coastal Management Area Expansion	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1320	2	Matagorda Peninsula Coastal Management Area Expansion II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1318	2	Matagorda Peninsula Land Acquisition	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1321	1	McFaddin NWR - Oil Cut Ditch	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5182	1	McFaddin NWR Beach Ridge Restoration Project Phase 2	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR Broken Marsh (ref. DUTX-123)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR BW2	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR East 350 ac (ref. DUTX-120 Broken Marsh)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR Mud Bayou	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR Nearby Private Landowner	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR West 139 ac	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR West 214 ac (ref. DUTX-121/027)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	McFaddin NWR West 466 ac (ref. DUTX-122/027)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5332	3	Measurement/Modeling of Aeolian Sand Transport on North Padre and Mustang Islands at Packery Channel	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-44)	3	MI (Beach Nourishment)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5333	0	Microplastic pollution and its occurrence in the diet of juvenile fish and shrimp in Texas bays	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1322	1	Middle Armand Bayou Protection Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9282	1	Middle Armand Bayou Protection Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5334	3	Mining the oyster gut microbiome to assess the impact of flooding on coastal ecosystems	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5183	2	Miramar Pointe Keller Bay Shoreline Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5335	3	Mission and Aransas Rivers TMDL I-Plan Implementation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	2	Mission River Delta	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5336	1,2	Modeled Sand Budget for the San Luis Pass Region based on Sediment Cores and Geophysical Profiles	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Project ID	Region	Project Name	Evaluation Status																
5337	3	Modeling Freshwater inflows, Nutrient Dynamics and their Relationships to Algal Blooms in Nueces Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5338	0	Modernizing Texas Beach Watch Technology System	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1323	1	Moody National Wildlife Refuge Addition	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1324	1	Morgan's Point Community Oyster Reef Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	-	Mud Lake Aquisition	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Mulberry Detention Pond	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5339	1	Multifaceted Approach to Addressing Nonpoint Source Pollution in Galveston County	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5340	1	MUMPS modeling for the Galveston Bay and Corpus Christi Bay systems	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	3	Mustang Island SP	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5424	3	Mustang Island SP Geoenvironmental Atlas	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1326	3	Mustang Island State Park Dune Habitat Protection and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5341	4	Nonpoint Source Nutrient Pollution Study in Baffin Bay Texas, Phase I	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5184	4	North Cameron County Beach Nourishment Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-19)	3	North of Packery Channel	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5185	3	North Padre Island Beach Nourishment	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	-	North shoreline of Salt Lake Brazoria NWR	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5186	3	Nueces Bay Rookery Island Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1368	3	Nueces County Flood Early Warning System	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1328	3	Nueces Delta Shoreline Erosion Protection and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1329	1	Old River Cove Shoreline Protection and Marsh Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5187	2	Oliver Point Shoreline Protection and Reef Restoration Phase 1	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5342	3	Oso Creek Bacteria in Tributaries Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5188	1	Oyster Lake Habitat Protection and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1330	0	Oyster Restoration in the Gulf of Mexico	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5433	3	Packery Channel Nature Park Shoreline Enhancement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5343	3	Packery Channel Nature Preserve Improvements Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-24)	3	Packery Flats	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Palm Valley Storm Water System Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5344	4	Parking Improvements and Educational Pavilion	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-38)	3	PCCA Habitat Creation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1333	2	Peach Creek Swamp on the San Bernard River	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1334	3	Petronila Creek Watershed Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1335	1	Phase II of the Baytown Nature Center Oyster Reef Restoration and Shoreline Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Pierce Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5345	1	Pirates' Beach Area Drainage Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-26)	3	Pita Chain	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5346	1	Pleasure Island Beach Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5347	1	Pocket Park #3 and #4 Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5348	1	Pollutants of Emerging Concern in Galveston Bay, Texas	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5189	3	Port Aransas Marina Shoreline Restoration Project Phase 3	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1336	3	Port Aransas Nature Preserve Environmental Assessment and Restoration Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5190	3	Port Aransas Nature Preserve Shoreline Protection Hurricane Harvey Repair	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1337	3	Port Aransas Nature Preserve Shoreline Stabilization and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5191	3	Port Aransas Nature Preserve Stabalization and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Port Arthur Master Drainage Plan and Policy Guide Development	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Port Isabel HUC-10 Watershed Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9302	2	Port Lavaca Lighthouse Beach Park Restoration and Resiliency	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-20)	3	Portland Nueces Bay Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	2	Powderhorn Lake degrading marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1338	2	Powderhorn Wildlife Management Area Shoreline Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5349	1	Pre- and Post-Harvey Sonar Survey of Bolivar Roads: Understanding Sediment Erosion and Deposition	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5350	1,2	Prediction of Texas wetland erosion through remote sensing, field surveys, and numerical modeling	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Primera Drainage Master Plan	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5193	2	Protection and Restoration of Matagorda Island West Marsh	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5425	3	Public Access Enhancements for the Encinal Peninsula (Flour Bluff)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5352	0	Quantifying atmospheric nitrogen deposition to the Texas Coastal Bend watershed	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5351	3	Quantifying atmospheric nitrogen deposition to the Texas Coastal Bend watershed	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5353	1	Quantifying erosion and pollution from rainfall runoff on urbanized beaches - Galveston Island study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5354	4	Quantifying groundwater discharge into the Lower Laguna Madre along the Kenedy County shoreline	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5355	0	Quantifying Microplastic (Particles and Fibers) Loading to the Texas's Coastal Bays and Estuaries	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5356	4	Queen Isabella Causeway - Material Testing	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5357	4	Queen Isabella Causeway Decommissioning and Artificial Reef Placement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5358	1	Raising public awareness of harmful algal blooms in coastal Texas: training, monitoring, reporting.	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Raymondville Ditch	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5359	0	Recent Bayhead Delta Shoreline and Wetland Loss: Potential Factors and Future Projections	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5360	0	Recent Bayhead Delta Shoreline and Wetland Loss: Potential Factors and Future Projections	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5361	1	Recovering Access and Restoring Resilience at Stewart Beach Park on Galveston Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	2	Redfish Lake Carancahua Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5436	3	Redhead Pond - Adjacent Tract(s)Acquisition	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5362	3	Redhead Pond Invasive Species Management	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5363	3	Redhead Pond Revitalization and Ecotourism-Phase 1: Water Inflow Source and Quality Assessment	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5194	1,2	Region 1 Sand Source Investigation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9291	1	Regional Ground Storage Tank	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5364	4	Removal of derelict Queen Isabella Causeway - Creation of an Artificial Reef in SW Gulf of Mexico	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5365	4	Resilient Coastal Dune Ecosystems for Erosion and Habitat Protection at South Padre Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1340	3	Restoration of Freshwater Inflow to Townsend Bayou	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5366	1	Restoration of Lower White Oak Bayou and Buffalo Bayou in Downtown Houston	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5367	1	Restoration of Nelda Stark Unit, Lower Neches Wildlife Management Area	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5368	2	Restoration of small shell island on Bill Dayâ€™s Reef to enhance nesting for American Oystercatchers	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5369	1	Restoration of the Slop Bowl Marsh, Brazoria National Wildlife Refuge: Phase I Planning	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5370	3	Restore Cole Park and Dimit Fishing Piers	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1343	2, 3, 4	Restoring Colonial Waterbird Populations in the Gulf of Mexico: Management and Stewardship of Nesting Habitat on the	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1344	2, 3, 4	Restoring Colonial Waterbird Populations in the Gulf of Mexico: Protection, Restoration, and Creation of Nesting Habitat	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5371	3,4	Restoring Colonial Waterbird Populations on the Texas Coast	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5417	4	Rio Hondo Coastal Zone Habitat Creation, Restoration & NPS Education	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5372	3,4	Riparian Evaluation of Baffin Bay Tributaries	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-64)	3	Rockport Beach	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Rose City Swamp	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Sabine Lake Pleasure Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Sabine River Basin Gages	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Sabine River Relief Ditch Extension & Expansion	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5373	1	Salt Bayou Watershed Restoration Efficacy Research - Phase I	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1345	2	San Antonio Bay Bird Island Phase II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5374	2	San Antonio Bay Living Shoreline	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5375	4	San Benito Wetlands Project - Phase 4	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9301	2	Sand Point Peninsula Living Shoreline	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1347	2	Sargent Marsh Shoreline Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1348	1, 2	Sargent Unit - Cedar Lakes Shoreline Stabilization	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	SCADA Control Systems	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	-	Schicke Point	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5195	2	Schicke Point Wetland Protection and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5376	0	Science and Resilience on the Texas Coast	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5377	4	Sea Island Circle Beach Access Amenity Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5378	1	Sea Rim State Park Shore Line Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Sebastian Drainage Improvements	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR2-06)	2	Second Chain of Islands	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Project ID	Region	Project Name	Evaluation Status																
9196	1	Sediment Bedload Collector Full Scale Demo	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5197	2	SH 316 Shoreline Protection (Ocean Drive Living Shoreline)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5198	3	Shamrock Island Protection & Habitat Enhancement Phase 3	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5379	3	Shell Bank: coastal resiliency through shell recycling, community engagement and habitat restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5380	3	Shell Bank: Enhancing coastal resiliency through shell recycling, habitat restoration and service	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5381	3	Shell Bank: Oyster shell recycling, citizen engagement, hands-on learning, & reef characterization	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5382	3	Shell Bank: Oyster shell recycling, restoration resources, and reef resilience	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1349	3	Shoreline Protection and Wetland Enhancement at the Cohn Preserve (Mustang Island)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1350	1, 2	Shoreline Protection for Priority Sites along the Texas GIWW	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1351	3	Shoreline Stabilization of Newcomb Point-Aransas County, Tx-Lamar Peninsula, Copano Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Simo Lift Station	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-39)	3	SJI (Beach/Dune Restoration)	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5383	4	South Padre Island Beach Access Improvement Program: Sea Island Design & Permitting	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5384	4	South Padre Island Beach Access Improvement Program: White Sands Design & Construction	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5199	4	South Padre Island Beach Nourishment with Beneficial Use of Dredge Material	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1352	4	South Padre Island Johnson Tracts	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1353	3	St. Charles Bay Oyster Reef Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
.	4	Storm Surge Flood Maps Development for the Lower Laguna Madre Coastal Emergency Management	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5200	1	Structure Relocation Expense Reimbursement - 214 Jettyview Rd Surfside Beach	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5386	3	Subsurface Geologic Controls on the Dune Morphology in Barrier Islands	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-32)	3	Sunset Lake	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5201	1	Sustainable Funding Strategies for Long-Term Coastal Restoration in Galveston	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1354	1	Sweetwater Preserve Shoreline Protection and Oyster Reef Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1355	1	Sydnes Island Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5387	1	Sylvian Rodriguez Park Habitat Restoration Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5388	1	Sylvian Rodriguez Park Habitat Restoration Project - Phase II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5389	3,4	Talkin' Trash	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Taylor Gully Flood Damage Reduction	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5390	3	Temporal and Spatial Variation of SGD on Nutrient Fluxes to Texas Coastal Embayments, Phase II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5391	3	Tern Rookery Island Protection and Restoration, Phase I: Feasibility Study & Alternatives Analysis	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9189	1	Texas Chenier Plain Land Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5392	0	Texas Citizen Planner, Local Coastal Planning in the wake of Hurricane Harvey	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5393	0	Texas Citizen Planner: Local Community Planning for Resiliency and Mitigation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5394	2	Texas Coastal Nutrient Input Repository - Phase I Lavaca Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5395	0	Texas Coastal Ocean Beach Water Quality Program	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5202	0	Texas Coast-wide Erosion Response Plan Update 2018	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5396	3	Texas Gulf Region Cooperative Weed Management Area: Dune Management & Restoration on Mustang Island	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5397	3	Texas Gulf Region Cooperative Weed Management Area: Controlling the Brazilian Peppertree, Phase II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5398	3	Texas Gulf Region CWMA: Dune Management & Restoration on Mustang Island, Phase II	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5203	1	Texas Point Beach Nourishment	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1358	1	Texas Point National Wildlife Refuge Beach Nourishment Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Texas Point NWR - East side 1400 ac	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Texas Point NWR 123 acres	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Texas Point NWR small site 63 acres	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5399	0	Texas Regional Stormwater Wetland Manual: Empowering communities to develop wetlands for resiliency	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5400	0	Texas Wetlands Status and Trends Online GIS Viewer	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5427	0	The Clean Coast Texas Collaborative Years 3 and 4	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5401	1,2	The effects of Rollover Pass closure on tidal wetland plant assemblages and associated fauna	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5402	3,4	The effects of upland land cover and downstream connectivity on TX coastal plain stream ecosystems	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5403	1,2	The Efficacy of Living Shorelines for Restoring Shoreline Habitat and Stability	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1362	2	The Hawkins Ranch	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5437	0	The Texas Coastal Collaborative - A dynamic approach to hazard mitigation, resiliency and NPS control	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5404	0	The Texas Gulf Shoreline on Vintage Aerial Photographs: Verifying Positions and Minimizing Errors	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5405	0	Threat of Rising Sea Level & Water Tables to Texas Coastal Septic Systems: An Integrated Study	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5204	1	Treasure Island MUD Beach Nourishment with BUDM	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5205	3	Triangle Tree Rookery Island Habitat Protection	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5206	3	Triangle Tree Rookery Island Protection and Restoration	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5207	1	Trinity River Valley Paleochannel Investigation	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5406	1	UHCL Habitat Restoration and Nature Trail	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5407	1	Understanding ecosystem responses to the closure of Rollover Pass on Bolivar Peninsula	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5408	3	Understanding the Cause of a Long-term Increase in Red Tide Frequency in Nueces-Corpus Christi Bay	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5428	0	Updating the National Wetland Inventory in Coastal Texas	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	-	Upstream in San Jacinto River	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5208	1	Village of Surfside Beach Beach Nourishment	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1365	1	Volunteer Oyster Gardening and Oyster Reef Enhancement	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9300	1	Walter Umprey Park Bulkhead Repair and Resiliency Upgrade	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	West Galv Bay GIWW Sidecast Islands	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1366	1	West Galveston Bay Living Shorelines - Sweetwater Preserve & Maggie's Cove	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5209	1	West Galveston Seawall to 8-mile Road Engineering and Design	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5409	1	Wetland Restoration Team 2.0	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5210	1	WGIPOA Beneficial Use Dredging and Marsh Restoration Project	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5410	4	White Sands Street Drive-Over and Storm Surge Barrier Design and Construction	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5411	4	Whitecap Circle Beach Access Development	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Whitecap Circle Beach Access Development	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5412	4	White-Sands Street Drive Over and Storm Surge Barrier Design and Construction	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1367	3	Whooping Crane Wintering Habitat Conservation and Protection in the Mission River Delta	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5413	4	Willacy County Coastal Youth Adventures	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	4	Willacy County Drainage District No. 2 Regional Detention Facilities	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5414	4	Willacy County Youth Coastal Adventures	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5211	1	Willow Lake Stabilization and Star Lake Water Control Structue at McFadd	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned	1	Wynnewood Acres	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
No Unique ID Assigned (BR3-37)	3	Zig Zag Chain	Not Evaluated by TAC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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