Galveston Bay Estuary Resilience Action Plan

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Abbreviations

ACS	Access to Galveston Bay Ecosystem Information
CCMP	Comprehensive Conservation and Management Plan for the Galveston Bay
EC	Galveston Bay Plan Priority “Engage Communities”
ECG	Galveston Bay Plan Goal Identifier for Galveston Bay Plan Priority “Engage Communities”
EE	Stressor identifier “Increase in Extreme Events”
EIH-UHCL Lake	Environmental Institute of Houston at the University of Houston Clear
EPA	Environmental Protection Agency
FWI	Freshwater Inflows
GBC	Galveston Bay Council
GBEP	Galveston Bay Estuary Program
GBF	Galveston Bay Foundation
GBP	The Galveston Bay Plan, 2nd Edition
GLO	Texas General Land Office
H-GAC	Houston-Galveston Area Council
HARC	Houston Advanced Research Center
HC	Habitat Conservation
ID	Stressor identifier “Increasing Drought”
IF	Stressor identifier “Increasing Inland Flooding (largely rain based)”
IS	Galveston Bay Plan Priority “Inform Science-Based Decision Making”
ISG	Galveston Bay Plan Goal Identifier for Galveston Bay Plan Goal “Inform Science-Based Decision Making”
LU	Stressor identifier “Changes to land use and the built environment (infrastructure)”
MS4	Municipal Separate Storm Sewer Systems
NEP	National Estuary Programs
NF	Stressor identifier “Nuisance Flooding”
NPS	Nonpoint Source
OA	Ocean Acidification
PEA	Public Education and Awareness
PHA	Public Health and Awareness
PI	Population Increase
PS	Point Source
PSGCRE	Galveston Bay Plan Goal Identifier for Galveston Bay Plan Priority “Protect and Sustain Living Resources: Conserve, restore, and enhance vital habitats in the lower portion of the Galveston Bay watershed”
PSGFI	Galveston Bay Plan Goal Identifier for Galveston Bay Plan Priority “Protect and Sustain Living Resources: Ensure adequate quantities of freshwater reach Galveston Bay”
PSGNS	Galveston Bay Plan Goal Identifier for Galveston Bay Plan Priority “Protect and Sustain Living Resources: Sustain and restore native species populations”
RES	Research and Monitoring
SA	Galveston Bay Plan Priority “Ensure Safe Human and Aquatic Life Use”
SAGWBP	Galveston Bay Plan Goal Identifier for Galveston Bay Plan Priority “Ensure Safe Human and Aquatic Life Use: Increase public awareness of current public health risks/Reduce risk through WBPs”

SAGWNPS	Galveston Bay Plan Goal Identifier for Galveston Bay Plan Priority "Ensure Safe Human and Aquatic Life Use: Reduce NPS and PS (including WWTF and sanitary sewer system) pollution"
SC	Species Conservation
SL	Stressor identifier "Sea Level Rise and subsidence"
SPO	Stakeholder and Partner Outreach
TAMU	Texas A & M University
TAMUG	Texas A & M University at Galveston
TCEQ	Texas Commission on Environmental Quality
TNC	The Nature Conservancy
TPWD	Texas Parks and Wildlife Department
TWDB	Texas Water Development Board
UH	University of Houston
UHCL	University of Houston Clear Lake
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WBPs	Watershed-based Plans
WH	Stressor identifier "Warmer Waters"
WS	Stressor identifier "Warmer Summers"
WW	Stressor identifier "Warmer Winters"
WWTF	Wastewater Treatment Facility

Galveston Bay

Galveston Bay is a 600 square mile, shallow, estuary on the upper Texas Gulf Coast. Galveston Bay is fed by the Trinity and San Jacinto Rivers, as well as coastal streams and bayous. The Bay and its surrounding watershed are a complex, interconnected system composed of biological, hydrological, and geological components, including runoff from the myriad activities in the watershed. Galveston Bay provides resources and ecosystem services for the nearly six million people in the immediate surrounding region, including those of the dynamic Houston-Galveston metropolitan area. The Galveston Bay Estuary Program (GBEP) was created in 1989 and is managed by the Texas Commission on Environmental Quality (TCEQ). GBEP is one of 28 National Estuary Programs (NEP) administered by the United States Environmental Protection Agency (EPA) and one of two estuary programs in Texas. In conjunction with all 28 NEPs, the non-profit Association of National Estuary Programs helps to educate lawmakers and local communities on the importance of estuaries. Estuaries are important for their role in the ecosystem as a "nursery" where many animal species reproduce and spend the early part of their lives. GBEP works to preserve Galveston Bay for generations to come.

Table 1: GBP Goals

Engage Communities
Ensure Safe Human and Aquatic Life Use: Increase public awareness of current public health risks/Reduce risk through watershed-based plans (WBPs)
Ensure Safe Human and Aquatic Life Use: Reduce nonpoint source (NPS) and point source (PS) (including wastewater treatment facility (WWTF) and sanitary sewer system) pollution
Inform Science-Based Decision Making
Protect and Sustain Living Resources: Conserve, restore, and enhance vital habitats in the lower portion of the Galveston Bay watershed
Protect and Sustain Living Resources: Ensure adequate quantities of freshwater reach Galveston Bay
Protect and Sustain Living Resources: Sustain and restore native species populations

Comprehensive Conservation and Management Plan (*Galveston Bay Plan, Second Edition*)

GBEP's strength comes from the collaborative partnerships that result from the implementation of the Galveston Bay Comprehensive Conservation and Management Plan [CCMP; also known as *The Galveston Bay Plan, Second Edition* (GBP)] (GBEP, 2018). The GBP provides a framework to address priority problems in the Galveston Bay Estuary.

The core of the GBP lies in the four plan priorities (see Table 1) developed by the Galveston Bay Council (GBC) and its five subcommittees through a series of stakeholder workshops. Plan priorities and actions provide a roadmap for GBEP and its stakeholders, who coordinate to fund and implement activities to achieve identified goals.

Coastal Resilience

Coastal resilience is the ability of our coastal economic, social, and ecological systems to withstand change and quickly recover from disaster[1]. Resilient systems are managed in ways that anticipate and plan for future disruptions, allowing the system to adapt and thrive.

Estuaries are dynamic environments with constantly changing tides, salinity regimes, fluctuating fish and wildlife populations, and habitats that migrate across landscapes. Resilient coastal communities manage their natural habitats in a manner that enables estuarine ecosystems and the adjacent built environment to better tolerate disturbances and promote estuarine resilience.

The Galveston Bay Estuary Resilience Action Plan is a stakeholder-driven project with the purpose of assessing a series of coastal resilience criteria against the goals, objectives, and actions in the GBP. This is meant to compliment the GBP and provide resilience adaptation/ mitigation recommendations for implementers of the GBP. This report was developed in coordination with subject matter experts and members of the GBC and its subcommittees through a series of workshops with questions and discussion topics. For guidance, see the EPA's "Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans[2]."

Stakeholder Expert Workgroup and Assessment

The Galveston Bay Estuary Resilience Action Plan development included advisement by a workgroup of expert stakeholders established by HARC. The group consisted of

[1] https://oceanservice.noaa.gov/ecosystems/resilience/
[2] https://www.epa.gov/cre/being-prepared-climate-change-workbook-developing-risk-based-adaptation-plans

relevant representatives and subject matter experts from the GBC, subcommittees, and other parties with state and regional interests, who provided input and guidance throughout the project to ensure it aligned with the goals and objectives of the GBP. The stakeholder expert workgroup had representation from the United States Geological Survey (USGS), Texas Parks and Wildlife Department (TPWD), Galveston Bay Foundation (GBF), the Houston-Galveston Area Council (H-GAC), the Environmental Institute of Houston at the University of Houston Clear Lake (EIH-UHCL), Texas A&M University (TAMU), the United States Fish and Wildlife Service (USFWS), Texas General Land Office (GLO), Texas Water Development Board (TWDB), and The Nature Conservancy (TNC). Expertise representation was wide and varied and included water resources, habitat restoration, wetlands, social systems, and relative sea level rise. A complete list is included in Table 2.

Table 2: Galveston Bay Estuary Resilience Assessment Stakeholder Expert Workgroup

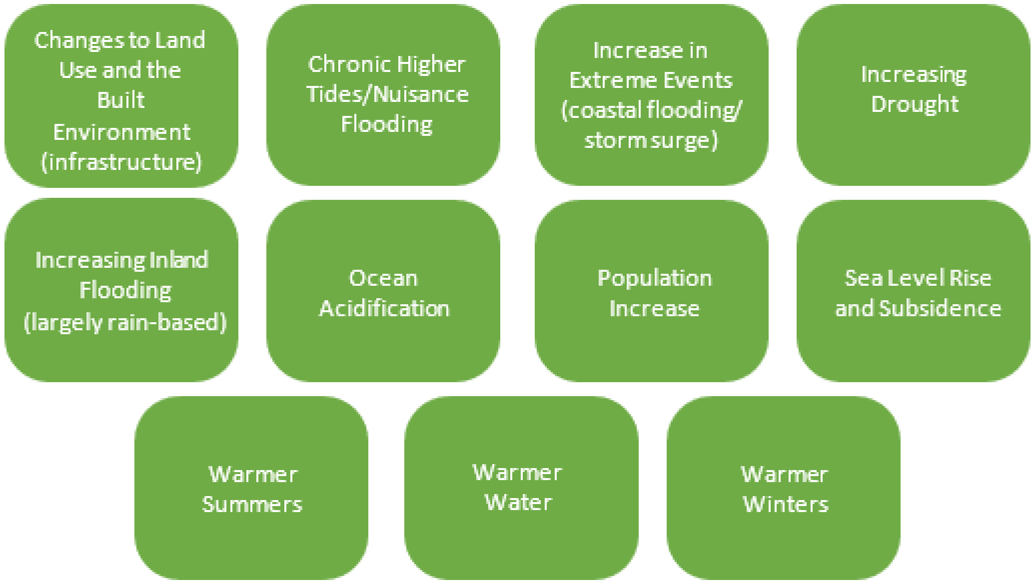
Organization	Expertise
USGS	Water Resources
EIH-UHCL	Water Resources/Ecology
TPWD	Habitat Restoration
GBF	Restoration
TAMU AgriLife Extension Service	Habitat Ecology
H-GAC	Water Quality
TPWD	Estuarine Ecology
TPWD	Kills and Spills
USFWS	Estuarine Ecology/Restoration/Conservation
Texas A&M University at Galveston (TAMUG)	Relative Sea Level Rise
TAMU	Relative Sea Level Rise and Wetlands
TAMUG	Phytoplankton/Freshwater Inflows
TAMUG	Phytoplankton Communities
GBF	Social/Community
Upper Coast Field - GLO	Coastal Biologist
TCEQ	Coastal Programs Specialist
Texas GLO	Coastal Resources
TWDB	Inflows
TNC	Sea Level Affecting Marshes Model, Marine Spatial Planning

An initial invitational facilitated workgroup meeting was held to provide an overview and purpose of the project and ask for stakeholder input from participants. This initial brainstorming session focused on input and information on the Galveston Bay Estuary Resilience Action Plan, providing participants an opportunity to identify, list, and provide feedback on the GBP goals, risk identification, and potential stressors. The purpose of the initial meeting was to gain local perspectives and information and identify concerns or interests to the workgroup regarding Galveston Bay for inclusion in the vulnerability assessment focused on coastal resilience. The initial meeting focused on establishing the context for the Galveston Bay Estuary Resilience Action Plan, which involved identifying GBEP organizational goals susceptible to estuary stressors. The workgroup identified all the GBP goals as susceptible to estuary stressors (Table 1) (see Appendix A for the complete details on GBP Priorities).

Galveston Bay Estuary Stressors

The stakeholder expert workgroup then moved on to risk identification, which involved discussing how estuary stressors will interact with the GBP priorities/ goals and how the impacts of the risks may make it difficult for GBEP to meet the GBP goals. The workgroup identified and defined 11 estuary stressors through this brainstorming session (Figure 1) that the workgroup thought were impactful when discussing coastal resilience. The following stressors are the ones that the group determined Galveston Bay is facing now or will face in the future. ***Changes to Land Use and the Built Environment (infrastructure)*** is linked to population increase, but distinct from it to focus on specific infrastructure changes. This includes everything from increased impervious pavement to increased shipping traffic (both size and quantity of ships). ***Chronic Higher Tides/Nuisance Flooding*** refers to high water that is marine or estuarine water and is not related to storm surge. ***Increase in Extreme Events (coastal flooding/storm surge)*** refers to flooding events that are marine/ estuarine water related to a storm event. Increasing drought relates to both chronic dry weather and episodic drought "events." ***Increasing Inland Flooding (largely rain-based)*** refers to freshwater flooding and distinguishes these events from the marine/estuarine nuisance flooding and from storm surge. ***Ocean Acidification*** in the context of Galveston Bay has not been well studied. Here, we refer to the extent to which acidification of Gulf and ocean water and the processes that lead to it could influence acidification of Galveston Bay water. The impacts discussed here are those for Galveston Bay waters. ***Population Increase*** refers to the number of permanent residents and tourists in the Galveston Bay region. ***Sea Level Rise and Subsidence*** refers to chronic, long-term rising marine/estuarine water that is caused by a combination of eustasy (the volume of the ocean based on water quantity and temperature) and subsidence (also referred to as Relative Sea Level Rise) in the Galveston Bay region. ***Warmer Summers*** refers to an increase in both high daily air temperatures and average temperatures during the warmest part of the year. ***Warmer Waters*** refers to the temperature of the water itself overall (i.e., not seasonally but rather daily), either due to increases in air temperature, reduction of cooler water inflows, etc. that would impact organisms in the water. ***Warmer Winters*** refers to an increase in both high daily air temperatures and average temperatures during the coolest part of the year.

Figure 1: The stakeholder expert workgroup identified 11 estuary stressors facing Galveston Bay now and in the future



For each of the stressors, risks from the stressor on meeting the GBP priority were identified. So, for example, the workgroup was asked to consider: For the GBP goal of Ensure Safe Human and Aquatic Life Use: Reduce NPS and PS (including WWTFs and sanitary sewer system) Pollution, how would the stressor of Warmer Summers pose risks that might impact GBEP in being able to meet that goal?

The workgroup determined that for this stressor and goal, the defined risks were a) using more water for irrigation leading to increased runoff, b) warmer summer water, increased likelihood of fecal indicator bacteria, and increased frequency of water quality exceedances of screening levels and c) increased evapotranspiration – compromised integrity of water bodies.

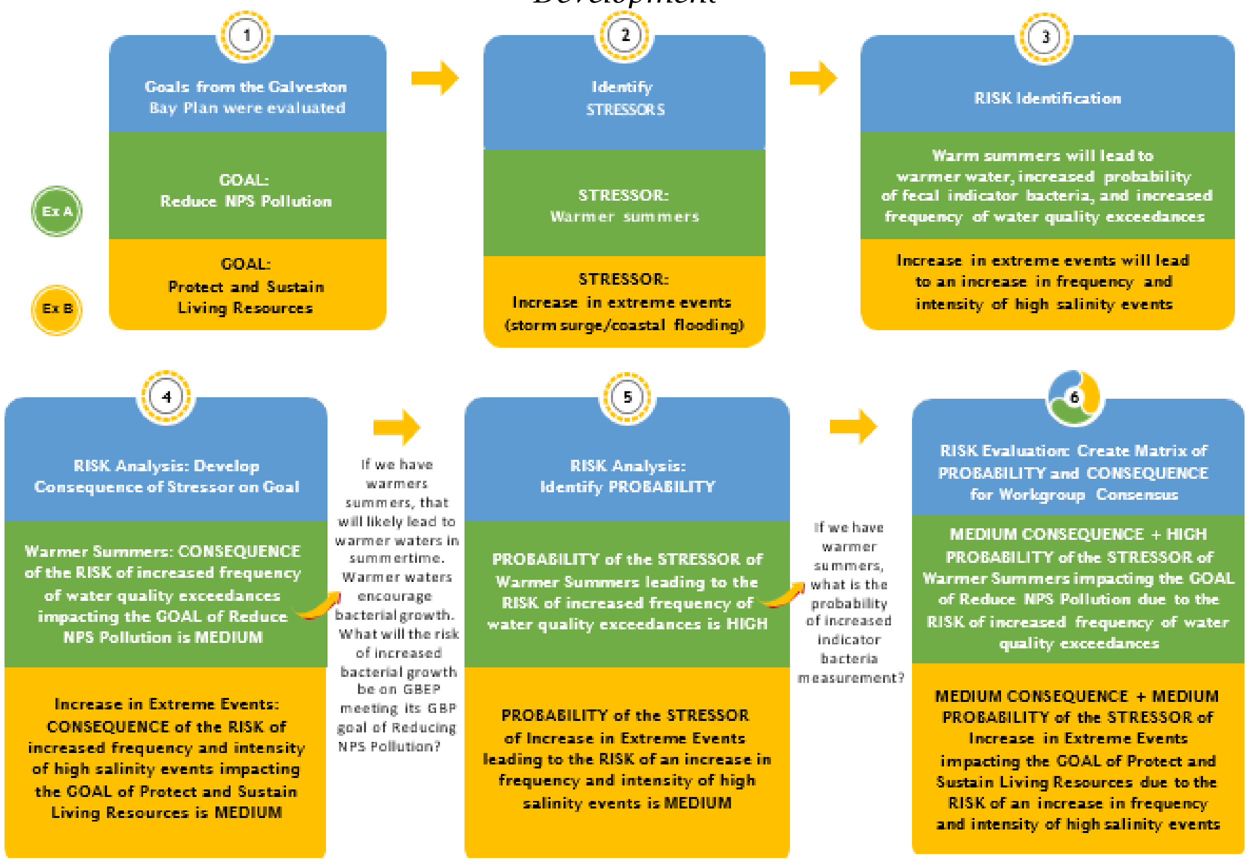
Risk Categorization: Consequence and Probability

Risks were ranked on a qualitative scale by the expert workgroup for consequences (impact) and probability (likelihood). For example, for the GBP goal of Ensure Safe Human and Aquatic Life Use: Reduce NPS and PS (including WWTFs and sanitary sewer system) Pollution, and the stressor of Warmer Summers, the workgroup identified the risk of warmer summer water leading to increased likelihood of fecal indicator bacteria and increased frequency of water quality exceedance of screening levels. This risk was evaluated as having a high probability of occurrence if the stressor of Warmer Summers occurs, and medium consequence.

Consequence was viewed as the impact the risk would have on an organization's goal were it to occur. Low consequence meant life would not be majorly disrupted if the risk were to occur; the organization could adapt and meet its goals. High consequence was viewed as a major disruption, meaning the goal would be out of reach without significant efforts/adaptation/ mitigation and may not be attainable. The results from each workgroup meeting were then developed into a series of consequence/probability matrices. For each GBP goal, the probabilities and consequences for each stressor/risk were illustrated according to all the possible combinations (high-medium-low) for the categories.

Figure 2 illustrates the risk identification and analysis process described above to create the qualification of high, medium, or low for each consequence and probability. There are five components required to create the consequence/probability matrix (blue), with specific examples listed below (Example A: green and Example B: yellow). Text between steps 4 and 5, as well as steps 5 and 6 provide further explanation of how consequences and probabilities were determined in the green example.

Figure 2: Flow Diagram of two examples from Goal to Consequence/Probability Development



In a final meeting, draft matrices resulting from the second meeting were presented to the workgroup for review, comment, and input. The resulting series of consequence/probability matrices were developed over 18 months through three expert stakeholder workgroup meetings and targeted one-on-one stakeholder follow- up discussions. Throughout the development of the stressors, risks, consequences, probabilities and the final matrices, versions and rough drafts were sent out to the GBEP subcommittee heads (the chair and vice-chair of the Water and Sediment Quality, the Monitoring and Research, the Natural Resource Uses and the Public Participation and Education subcommittees) for input, edits, and comments. The following ideas and thoughts on stressors, risks and management strategies that went into the Galveston Bay Estuary Resilience Action Plan were generated by the workgroup in the expert workgroup to reflect the most likely impacts to Galveston Bay based on their years of research and experience working in the region. Table 3 details the steps taken by the workgroup during the development of the Galveston Bay Estuary Resilience Action Plan.

Table 3: Steps Taken by Stakeholder Expert Workgroup to Develop Galveston Bay Estuary Resilience Action Plan

Actions	Descriptions
Communication & Consultation	Informing key people about Galveston Bay Estuary Resilience Assessment & asking for input ***Identified stakeholder expert workgroup, reaching out through GBEP subcommittees***
Establishing the Context	Identifying organizational goals that are susceptible to estuary stressors ***First workgroup meeting***
Risk Identification	Brainstorming about how estuary stressors will interact with organizations ***First workgroup meeting***
Risk Analysis	Developing an initial characterization of consequence and probability for each risk ***Second workgroup meeting***
Risk Evaluation	Using a consequence/probability matrix to build consensus about each risk ***Third workgroup meeting***
Establishing Context for Action	Review organization's environment and partners ***Fourth workgroup meeting***
Risk Evaluation: Deciding on a Course	Evaluating risks to determine overall approach ***Fourth workgroup meeting***
Finding and Selecting Adaptation/Mitigation Actions	Determine adaptation/mitigation actions for chosen risks to mitigate ***Fifth workgroup meeting***
Preparing an Action Plan	Develop Plan with adaptation actions and show how they will support the CCMP ***Review and sixth workgroup meeting***

In order to develop consequence and probability matrices, the workgroup progressed through the first five steps in Table 3 for seven GBP goals and the 11 estuary stressors suggested by the workgroup as the most likely to impact Galveston Bay (Table 1 and Figure 1). The creation of the consequence/probability matrices required five components as outlined below taken in context of **goals** from each of the GBP priorities (Table 1).

Quick Reference Guide 1: Roadmap to Consequence/Probability Matrices Development

1. Identification of estuary **stressors** that Galveston Bay will be facing now and in the future (identified by the stakeholder expert workgroup) (Figure 2).
2. **Identification of the risks** associated with how the stressors might impact the ability of GBEP to meet each goal.
3. Assign a high, medium, or low **consequence (or impact)** of each risk on each goal.
4. Assign a high, medium, or low **probability (or likelihood)** of the stressors affecting the ability of GBEP to meet the goals.
5. Arrange the impacts of the stressors on the ability to meet the goals in a **matrix** organized by consequence and probability.

The results of the risk evaluation are the **Consequence/ Probability Matrices by GBP Goal** (Figure 3). For each matrix category, the stressors are listed first, with the risk in bold. As an example, for the GBP Goal of Engage Communities, the workgroup identified a stressor of Land Use Change. One of the risks the workgroup identified for the stressor of Land Use Change was Increased Impervious Surfaces. The workgroup evaluated the probability of Increased Impervious Surfaces as high, and the consequence of Increased Impervious Surfaces to meeting the GBP Goal of Engage Communities as medium. Some stressors had the same risk associated with them. For example, in Figure 3, for all stressors associated with Nuisance Flooding, Increasing Extreme Event Flooding and Relative Sea Level Rise, the workgroup had identified the same risk of Increased flooding of property and habitat. Appendix B contains an assortment of Consequence/Probability Matrices sorted by: Stressor; and by consequence/probability overall, with all stressors and priorities combined.

Visualizing which risks are shared across goals, or which risks are considered both high consequence and high probability, or which risks might be most severe for a particular goal allows for targeted resource planning. For example, Figure 4 shows all risks grouped by high consequence and high probability. The ability to visualize the risks across all categories and goals that are considered both high for consequence and probability can help with adaptation/mitigation planning decisions. The matrices could be used as part of risk evaluation (assessing risks to determine which ones an organization will move forward within the action planning process), finding and selecting adaptation/mitigation actions and, possibly, developing a risk-based adaptation/mitigation action plan.

The consequence/probability matrix is a tool for visualizing how estuary stressors and their risks are categorized by experts in the field. These matrices allow GBEP and its subcommittees to evaluate priorities, concerns and issues concerning estuary resilience planning. Since risks, consequences and probabilities have been developed according to GBP goal, the GBEP can use the Galveston Bay Estuary Resilience Assessment as a guide for planning for coastal resilience that align with the GBP goals.

Figure 3: Series of Consequence/Probability Matrices for Estuary Resilience evaluated by GBP Goal

GBP Goal: Engage Communities

Likelihood (probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High		1. Land Use Change| **Increased impervious surfaces** 2. Population Increase| **Increased resource demands** 3. Relative Sea Level Rise| **Wetland loss** 4. Warmer Summers| **Heat stress** 5. Warmer Summers| Warmer Waters| **Increase in vibrio illness**	1. Nuisance Flooding|Increasing Extreme Event Flooding|Relative Sea Level Rise| **Increased flooding of property and habitat** 2. Warmer Summers|Warmer Waters| **Warmer waters lead to increased bacteria** 3. Warmer Water| **Heat Stress** 4. **Ocean Acidification| Loss of oyster reef habitat**
Medium		1. Increasing Drought| **Increase in tree loss** 2. Warmer Winters| **Increase in invasive species**	1. Increasing Extreme Event Flooding| **Stakeholders may not be able to deal with more events/damages** 2. Increasing Drought| **Decrease in water quality** 3. Relative Sea Level Rise| **Increased storm surge**
Low			1. Increasing Inland Flooding| **Wider spread of waterborne pathogens**

GBP Goal: Ensure Safe Human and Aquatic Life Use: Increase public awareness of current public health risks/Reduce risk through WBPs

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High		1. Increasing Drought| **Pollutant concentrations increase** 2. Warmer Waters| **Increased bacterial growth and bacterial load exceedances** 3. Warmer Winters| **Mosquito populations will not fall dormant with extended summers** 4. Warmer Winters| **Increased exceedances of bacteriological standards** 5. Warmer Winters| **Criteria for discharging may not be met**	1. Increasing Extreme Event Flooding|Increasing Inland Flooding| **Bacteria in flood waters** 2. Increasing Extreme Event Flooding|Increasing Inland Flooding| **Exposure to pollutants during flood events** 3. Increasing Drought| **Increase need for water conservation and restrictions** 4. Relative Sea Level Rise| **Greater coastal wetland losses could occur** 5. Warmer Summers| **Increased exceedances of bacteriological standards** 6. Warmer Waters| **Increase in vibrio illness**
Medium			1. Warmer Summers| **Increased heat stress (education)**
Low		1. Land Use Change| **Increased runoff** 2. Warmer Waters| **Water temperatures may increase toxicity of pollutants**	

GBP Goal: Ensure Safe Human and Aquatic Life Use: Reduce NPS and PS (including WWTFs and sanitary sewer system) pollution

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High	1. Increasing Extreme Event Flooding| **WWTF will go offline more often** 2. Increasing Extreme Event Flooding| **Frequency of sanitary sewers infiltration events will increase** 3. Increasing Inland Flooding| **Increased runoff from events will lead to pollutant load increase** 4. Increasing Inland Flooding| **Potential for increased overtopping and "leaking systems" releasing greater pollutants**	1. Warmer Summers| Warmer Winters| **More water for irrigation leading to increased runoff** 2. Warmer Summers| **Lead to warmer water, increased likelihood of fecal indicator bacteria and water quality exceedances**	1. Nuisance Flooding| **Septic systems and WWTF and lift stations could fail** 2. Increasing Extreme Event Flooding| **New sources of pollution** 3. Increasing Drought| **Increased water usage** 4. Increasing Inland Flooding| **Could increase erosion of streambeds** 5. Population Increase| **Increased population leads to increase in sources of NPS pollutants** 6. Relative Sea Level Rise| **High water tables will drown coastal septic systems causing them to fail** 7. Relative Sea Level Rise| **Contaminated sites may flood** 8. Relative Sea Level Rise| **Greater coastal wetland losses**
Medium	1. Ocean Acidification| **Lead to decreased pH**	1. Land Use Change| **Increase in impervious surfaces leads to increased runoff** 2. Increasing Drought| **Increasing bacteria load** 3. Population Increase| **Increased quantity and decreased quality of stormwater**	1. Relative Sea Level Rise| **Potential increase of saltwater intrusion**
Low	1. Increasing Drought| **Older "leaking systems" have less pollution due to decreased rainfall** 2. Warmer Summers| **Increased evapotranspiration**	1. Warmer Waters| **Increased bacterial growth, Increasing bacteria load exceedances** 2. Warmer Winters| **Eliminates freeze events** 3. Warmer Winters| **Lead to warmer water, increased likelihood of fecal indicator bacteria and water quality exceedances**	

GBP Goal: Inform Science-Based Decision Making

Likelihood (Probability of Occurrence)		Consequence: Low	Consequence: Medium	Consequence: High
	High	1. Warmer Winters| **Potential for prolonged time period of bacterial/pathogen presence**	1. Nuisance Flooding| **Unknowns: do chronic higher tides impact restored wetlands** 2. Increasing Extreme Event Flooding| **Reduction of positive impacts of freshwater inflow** 3. Increasing Drought| **Less freshwater inflow** 4. Increasing Drought| **Prolonged reduced freshwater has long term effects** 5. Increasing Drought| **Increased salinity in brackish habitats** 6. Increasing Drought| **Increased chances of red and brown tides** 7. Increasing Inland Flooding| **Changes in inflow regime** 8. Population Increase| **Increased demand places more pressure on available freshwater supply** 9. Relative Sea Level Rise| **Reduction of positive impacts of freshwater inflow** 10. Relative Sea Level Rise| **Increase in bacteria levels from failing septic systems** 11. Warmer Summers| Warmer Winters| **Increased bacteria levels** 12. Warmer Winters| **More & stronger tropical storms/hurricanes** 13. Warmer Winters| **Increase in invasive species in Galveston Bay** 14. Warmer Winters| **Potential for prolonged hurricane season**	1. Land Use Change| **Increase in impervious surfaces leads to increase of freshwater** 2. Increasing Extreme Event Flooding| **Potential for increased spills/contaminants entering the bay system** 3. Warmer Summers| Warmer Winters| **Increased evapotranspiration – less freshwater inflow** 4. Warmer Summers| **Potential for more & stronger tropical storms/hurricanes**
	Medium	1. Land Use Change| **Unknowns: how conversion of agricultural land impacts the Bay?** 2. Increasing Drought| **Unknowns: does drought change habitat functionality?** 3. Relative Sea Level Rise| **Salinizes brackish area** 4. Warmer Waters| **Impact dynamics of salinity stratification** 5. Warmer Waters| **Reduction in nutrient loading/productivity of estuary** 6. Population Increase| **More people to educate and promote water conservation**	1. Relative Sea Level Rise| **Increased extent of marine water may impact the freshwater balance of the bay** 2. Warmer Summers| **Essential food sources may die off** 3. Warmer Summers| **Unknowns: do warmer summers impact oyster reefs** 4. Warmer Waters| **Changes in communities to more tropical composition** 5. Warmer Winters| **Increased evapotranspiration**	1. Warmer Summers| **Heat stress to native populations** 2. Warmer Summers| **Changes in communities to more tropical composition** 3. Increasing Extreme Event Flooding| **Unknowns: how do storms impact freshwater wetlands?** 4. Warmer Waters| **Unknowns: How does warmer water impact phytoplankton community composition?**
	Low	1. Population Increase| **NPS pollution increase**	1. Warmer Waters| **More users on the water for prolonged time (extent of the year)**	1. Warmer Winters| **Changes in communities to more tropical composition**

GBP Goal: Protect and Sustain Living Resources: Conserve, restore and enhance vital habitats in the lower portion of the Galveston Bay watershed

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High	1. Increasing Drought| **Changes to sediment loads** 2. Increasing Drought| **Loss of seasonal wetlands** 3. Increasing Inland Flooding| **Low light due to increased sediment load** 4. Warmer Summers| **Increased evapotranspiration which could lead to aquatic/subtidal species composition change** 5. Warmer Summers| Warmer Winters| **Increase plant productivity, vertical accretion and carbon sequestration** 6. Warmer Waters| **Increased water temperatures could cause changes in phytoplankton community composition**	1. Nuisance Flooding| **Loss of outer marsh habitat** 2. Nuisance Flooding| **Habitat loss, conversion, and migration impact native species** 3. Nuisance Flooding| **May create unfavorable habitat conditions more frequently** 4. Increasing Extreme Event Flooding| Increasing Inland Flooding| **Movement of invasive species** 5. Increasing Drought| **Loss of tree and vegetative cover** 6. Increasing Extreme Event Flooding | **Recreational fishing pressure** 7. Relative Sea Level Rise| **Changing spatial extent of available habitat** 8. Warmer Waters| **Increase in oyster predation and parasites**	1. Increasing Extreme Event Flooding| Increasing Inland Flooding| **Increased stream erosion and sediment loads** 2. Increasing Extreme Event Flooding| Increasing Drought| **Loss of habitat** 3. Increasing Drought| **Increased evapotranspiration** 4. Population Increase| **Loss of native habitat to development** 5. Relative Sea Level Rise| **Increased extent of saline waters** 6. Relative Sea Level Rise| **Changing light attenuation** 7. Warmer Summers| **Could expand range of invasive species** 8. Warmer Waters| **Decrease in dissolved oxygen** 9. Warmer Waters| **Increased stratification** 10. Warmer Winters| **Will enhance survival of insect pests** 11. Ocean Acidification| **Unknowns: Bay oysters impacted by acidification**
Medium		1. Increasing Extreme Event Flooding| **Increase in frequency and intensity of high salinity events** 2. Increasing Drought| **Area of suitable habitat decreases** 3. Increasing Inland Flooding| **Loss of habitat** 4. Increasing Inland Flooding| **Increase in frequency, intensity of decreased salinity events** 5. Increasing Inland Flooding| **Impacts for riparian fish spawning** 6. Population Increase| **Impacts from increased human pollution** 7. Relative Sea Level Rise| **Habitat conversion to open water** 8. Increasing Inland Flooding| **Correlation with drop in salinity and increase in lesions on bottlenose dolphins** 9. Increasing Inland Flooding| **Correlation with drop in salinity and impact on sea turtles**	1. Land Use Change| **Increase in impervious surfaces leads to increased runoff** 2. Land Use Change| **Coastal barriers reduce tidal exchange** 3. Land Use Change| **Loss of native habitat due to development** 4. Relative Sea Level Rise| **Increased marsh flooding**
Low	1. Increasing Extreme Event Flooding| **Changes to nutrient supply** 2. Increasing Drought| **Availability of water for restoration and enhancement** 3. Warmer Waters| **Defining habitat characteristics like pH impacted by water temp** 4. Warmer Winters| **Increased growing season could cause plant stress if they require dormant period**	1. Increasing Inland Flooding| **Changes to nutrient supply**	1. Land Use Change| Population Increase| **Increase nutrient input and turbidity** 2. Nuisance Flooding| **Increase marsh habitat range further upslope** 3. Ocean Acidification| **Potential impacts on shellfish and other sedentary organisms**

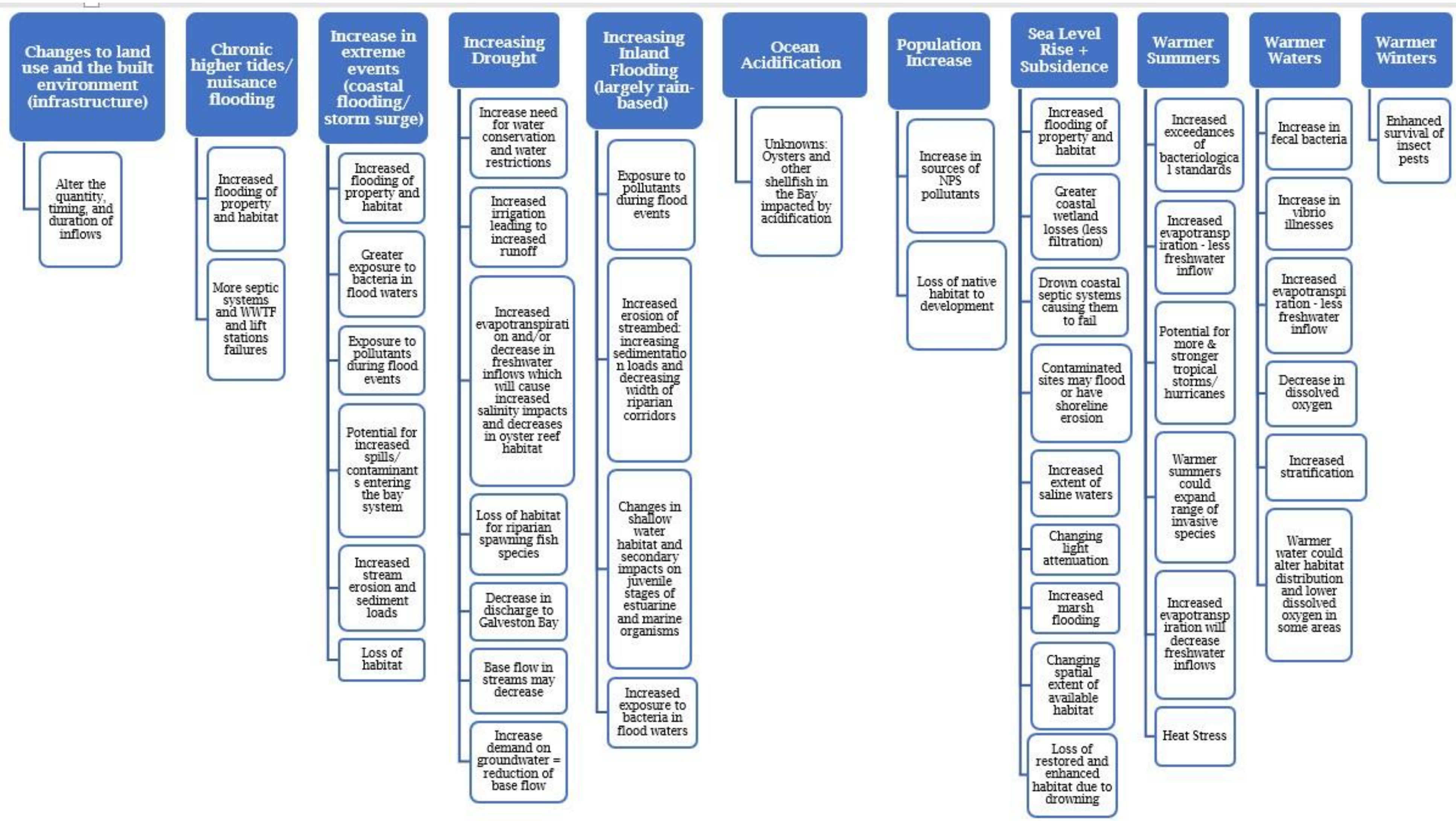
GBP Goal: Protect and Sustain Living Resources: Ensure adequate quantities of freshwater reach Galveston Bay

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High		1. Increasing Extreme Event Flooding| **Changes periodicity of freshwater inflows**	1. Increasing Drought| **Increasing demand on water resources; decrease in discharge to Galveston Bay** 2. Increasing Drought| **Base flow in streams may decrease** 3. Increasing Drought| **Increase in demand on groundwater = further reduction of base flow** 4. Warmer Summers| **Increased evapotranspiration will decrease freshwater inflows**
Medium		1. Increasing Extreme Event Flooding| **Changes periodicity of freshwater inflows** 2. Relative Sea Level Rise| **Loss of wetlands could impact quality of freshwater inflows** 3. Warmer Summers| Warmer Waters|Warmer Winters| **Increased evapotranspiration will increase salinity in upstream reaches**	1. Land Use Change| **Reservoir operations can shift the timing and amount of peak inflows** 2. Increasing Extreme Event Flooding| **Accumulated impacts from other stressors** 3. Relative Sea Level Rise| **Less availability of groundwater = more demand on surface water, decreased base flow** 4. Warmer Summers| **Harmful algal blooms are more likely to develop in warm, salty water** 5. Warmer Waters| Warmer Winters| **Increased evapotranspiration will decrease freshwater inflows**
Low		1. Increasing Extreme Event Flooding| Increasing Inland Flooding| **Changes seasonality of freshwater inflows**	

GBP Goal: Protect and Sustain Living Resources: Sustain and restore native species populations

Likelihood (Probability of Occurrence)	Low Consequence	Medium Consequence	High Consequence
High	1. Warmer Winters| **Proliferation of mangroves in Galveston Bay is likely if deep freezes occur less often**	1. Increasing Drought| **Sessile organism stress**	1. Increasing Inland Flooding| **Changes in shallow water habitat and secondary impacts of juvenile stages of estuarine and marine organisms** 2. Relative Sea Level Rise| **Increased marsh flooding** 3. Relative Sea Level Rise| **Changing spatial extent of available habitat** 4. Relative Sea Level Rise| **Loss of restored and enhanced habitat due to drowning** 5. Warmer Winters| **Could alter habitat distribution and lower dissolved oxygen in some area**
Medium	1. Warmer Winters| **Potentially more suitable for manatees and less cold stunning events for sea turtles**	1. Increasing Extreme Event Flooding| Increasing Inland Flooding| **Habitat loss, conversion, and migration hold implications for native species** 2. Relative Sea Level Rise| **Increased extent of saline waters** 3. Warmer Summers| **Heat stress to native populations** 4. Warmer Summers| Warmer Winters| **Increased salinity can impact distribution, abundance, and productivity of native species** 5. Warmer Summers| **Life cycle stages is influenced by environmental cues** 6. Warmer Summers| **Shifts in fisheries populations** 7. Warmer Waters| Warmer Winters| **Oyster reef loss to dermo and oyster drilling predators** 8. Warmer Waters| **Correlation with drop in salinity and increase in lesions on bottlenose dolphins** 9. Warmer Winters| **Could expand range of invasive species**	1. Increasing Extreme Event Flooding| **Changes in shallow water habitat and secondary impacts on juvenile estuarine and marine organisms** 2. Increasing Drought| **Species may not tolerate new drought regimes** 3. Increasing Drought| **Increasing marine and invasive species including predators, parasites, and diseases** 4. Increasing Drought| **Increased conditions for harmful algal blooms** 5. Relative Sea Level Rise| **Changing light attenuation** 6. Warmer Summers| **Increased water temperatures would increase oyster predation and parasites** 7. Warmer Summers| **Warmer water temperatures have been linked to long-term decline in blue crab abundance** 8. Warmer Winters| **Potential increase in pests**
Low		1. Increasing Extreme Event Flooding| Increasing Drought| Increasing Inland Flooding| **Potential adverse effect for secretive marsh birds like rails if drier transition habitats are not available** 2. Increasing Drought| **Increase in stranding events and inundation of freshwater habitats** 3. Increasing Drought| **Shifting vegetation community composition** 4. Warmer Winters| **Potential to increase return intervals for wildfires affect vegetation structure and use by threatened or endangered species**	
	Low	**Medium**	**High**
	Consequence		

Figure 4: High Consequence and High Probability Risks



Context for Action Plan

Using the matrices shown in Figure 3, the stakeholder expert workgroup met to identify and recommend risk evaluations and identify and select adaptation/mitigation actions. In order to continue development of the Galveston Bay Estuary Resilience Action Plan, the workgroup progressed through the last steps 6-9 as described in Table 3.

The workgroup meetings were used to assess the risks as high consequence and high probability, and likely to occur within the next 10 years. The workgroup reviewed the organizational context (GBP Goals) and identified a list of potential partners including identification of common organizational goals, objectives, or work areas where potential partners could help with the risks.

Quick Reference Guide 2: GBEP Potential Mitigation Partners **Any suggested partners listed in the Galveston Bay Estuary Resiliency Action Plan is not a commitment of funding or participation and could be subject to change **
American Bird Conservancy
Armand Bayou Nature Center
Artist Boat
Association of National Estuary Programs
Audubon Texas
Bayou Land Conservancy
Bayou Preservation Association
Black Cat GIS
CenterPoint Energy (Utilities)
Chambers County
Chambers-Liberty County Navigation District
Children's Environmental Literacy Foundation
Citizen (including community representatives and retired and emeritus stakeholders)
Citizens' Environmental Coalition
City of Houston
City of Pearland
Coastal Conservation Association - Texas
Ducks Unlimited
East Harris County Manufacturers’ Association (Axiall, LLC)
EcoRise
GBF
Galveston County
Galveston County Health District
Greater Houston Partnership (Dow Chemical)
Gulf Coast Authority
Gulf Of Mexico Alliance

Quick Reference Guide 2: GBEP Potential Mitigation Partners **Any suggested partners listed in the Galveston Bay Estuary Resiliency Action Plan is not a commitment of funding or participation and could be subject to change **
Harris County Flood Control District
HARC
Houston Audubon
Houston Parks and Recreation Department
Houston Parks Board
Houston Wilderness
H-GAC
Jeri's Seafood (Commercial Fisheries)
Coastal (formerly Katy) Prairie Conservancy
KPRC
Kuraray America Inc. (Industries)
League of Women Voters
Lee College
Lyondell Basell (Industries)
Marina Bay Harbor (Marinas)
National Oceanic and Atmospheric Association
Native Prairies of Texas Association
North American Association of Environmental Educators
NRG Energy
Port Houston
Prairie View A&M University
RESTORE Council
San Jacinto River Authority
Scenic Galveston
Sierra Club
Student Conservation Association
Texas A&M AgriLife - Extension Service
Texas A&M AgriLife - Texas Community Watershed Partners
Texas A&M Forest Service
Texas A&M Texas Water Resources Institute
Texas A&M University - College Station
Texas A&M University - Corpus Christi
TAMUG
Texas A&M University - Geochemical Environmental Research Group

Quick Reference Guide 2: GBEP Potential Mitigation Partners **Any suggested partners listed in the Galveston Bay Estuary Resiliency Action Plan is not a commitment of funding or participation and could be subject to change **
Texas Coastal Partners - Shead Conservation Solutions (Other Conservation Associates)
TCEQ
Texas Department of Agriculture
Texas Department of State Health Services
Texas Department of Transportation
GLO
Texas Master Naturalists
TPWD
Texas Railroad Commission
Texas Sea Grant
Texas State Soil and Water Conservation Board
TWDB
TNC
Trinity River Authority
Turtle Island Restoration Network
U.S. Army Corps of Engineers
U.S. Coast Guard
U.S. Department of Agriculture - Natural Resources Conservation Service
EPA
USFWS
USGS
UH
UHCL

Risk Approach

As the matrices show, many of the risks are not only related but also have the potential to build on each other and impact several of the GBP Goals. With connecting systems, a single stressor will affect more than one resource or Plan Goal. At the same time, adaptation or mitigation strategies will often mitigate the impact or risk of more than one stressor. Ranking risks as high, medium, or low enables adaptation/mitigation strategies based on prioritization. When time, money or other resources are limited, responding to risks with high consequence and high probability is the top priority because they are very likely to happen and will have high impacts when they do. Medium and low risks are not ignored, but they can be addressed in the future or as capacity allows. In addition, with connecting systems, often adaptation or mitigation actions selected for a high consequence and high probability risk will address medium and low risks as well. Each risk identified by the workgroup as high consequence and high probability, and likely to occur within the next 10 years, was evaluated for a risk approach that was determined by the workgroup as the best approach – Mitigate, Transfer, Accept, or Avoid[3].

The approach of Transfer: Assist partners with state/ federal/local assistance programs was later removed from the options at the request of the workgroup. GBEP rarely carries out projects itself; it usually supports other organizations that mitigate risks by funding and/or assisting partners to finance and do the work. Given how GBEP supports other partners in executing adaptation/mitigation actions in nearly every case, "transfer" was removed as an option for the adaptation/mitigation actions to focus on the mechanisms behind the adaptation/mitigation actions.

Table 4: Definition of Risk Approaches

Approach to Risk	***Definition of Approach to Risk***
Mitigate	Take action to lower the consequence or likelihood of the risk (or both). Address the risk or lead the effort to address the risk.
Transfer[4]	Another party has responsibility for mitigating the risk. Allow or ask others to take the lead and GBEP will assist if applicable.
Accept	Run the risk. Accept that the consequences may occur. Business as usual despite the risk. Monitor and reassess options in the future.

[3] https://www.epa.gov/cre/being-prepared-climate-change-workbook-developing-risk-based-adaptation-plans

[4] Transfer was not used in the risk-defining methodology

Avoid	Take organizational or administrative action so that GBEP will not be exposed to the risk.

The workgroup met to strategize on categorizations of risk approach. Table 4 outlines the discussion points for each risk approach. The workgroup then brainstormed a risk approach category for all the high consequence and high probability risks. Risks that were identified as mitigate or transfer were grouped for further identification of adaptation/mitigation actions. Because the group had focused on categorizing only high consequence and high probability risks, the group determined that none of the risks were avoidable. Four risks were categorized as Accept; note that the workgroup felt the best course of action was to categorize them as Accept/Monitor, feeling that the best approach on this was to keep an eye on the situation until a risk adaptation approach could be determined.

These risks were: increased stratification due to warmer waters; warm winters will enhance survival of insect pests; base flow in streams may decrease due to increasing drought and warmer water could alter habitat distribution and lower dissolved oxygen in same areas due to warmer water. The risks that were identified as accept or avoid were accepted and not evaluated further as part of the adaptation/ mitigation action strategy development.

Adaptation/Mitigation Actions

Based on the risk approaches selected in the first round of stakeholder expert workgroup meetings, the workgroup met again to determine Adaptation/ Mitigation Actions for the risks that were categorized as mitigate. In addition to risk reduction potential, the workgroup was encouraged to assess other criteria such as feasibility, effectiveness, equity, and cost- effectiveness. The goal of the adaptation and mitigation actions is that they could mitigate the risk by bringing either the consequence or probability down to a medium or low. Any suggested partners listed in the Galveston Bay Estuary Resiliency Action Plan is not a commitment of funding or participation and could be subject to change.

During the fifth meeting the workgroup brainstormed on adaptation and mitigation actions that were occurring now or should occur in the future to help protect the health of Galveston Bay. These various actions ranged from specific programs to educational opportunities to land conservation to broader monitoring and research goals. From these detailed actions, eight adaptation/mitigation action categories were discussed and decided on by the workgroup, along with examples of organizations who are currently or will be soon carrying out adaptation/ mitigation actions. The following list details these adaptation/mitigation action categories, which are also seen in Table 5. The workgroup decided to identify some responsible parties (with several specific highlighted examples below) but did not want to limit or focus on responsible parties. They opted to focus on the adaptation/mitigation actions and leave the responsible parties open for collaborative opportunities.

Quick Reference Guide 3: Pathway to Consequence/Probability Matrices Development

- **Stakeholder Outreach: Education** – Education of stakeholders in this context is meant to include both formal education and community or industry-based workshops, webinars, and similar long-form outreach activities that provide information and context in an audience-appropriate format. [Texas A&M AgriLife Extension, GBF, H-GAC, USGS, TWDB]

Quick Reference Guide 3: Pathway to Consequence/Probability Matrices Development

- Stakeholder Outreach: Education would address stressors such as:
    - Chronic Higher Tides/Nuisance Flooding
    - Increase in Extreme Events (coastal flooding/storm surge)
    - Population Increase
    - Sea Level Rise and Subsidence
    - Warmer Summers
    - Warmer Waters
    - Warmer Winters

- **Stakeholder Outreach: Alerts/Risk** – Organizations have different means and methods to alert stakeholders to risks. Posted signs, websites, text alerts, fliers. [Texas Department of State Health Services, cities, and municipalities]
    - Stakeholder Outreach: Alerts/Risk would address stressors such as:
        - Increase in Extreme Events (coastal flooding/storm surge)
        - Increasing Drought
        - Increasing Inland Flooding (largely rain-based)
        - Sea Level Rise and Subsidence
        - Warmer Summers
        - Warmer Waters
        - Warmer Winters

- **Monitoring** – Observing the system at risk to characterize how risks impact it in order to identify and execute appropriate mitigation actions if/when needed. [USGS, GLO, U.S. Army Corps of Engineers, TAMUG, UH, GBF]
    - Monitoring would address stressors such as:
        - Chronic Higher Tides/Nuisance Flooding
        - Increase in Extreme Events (coastal flooding/storm surge)
        - Increasing Drought
        - Increasing Inland Flooding (largely rain-based)
        - Sea Level Rise and Subsidence
        - Warmer Summers
        - Warmer Waters
        - Warmer Winters

- **Implementation of WBPs** – WBPs are supported by TCEQ, H-GAC, and others to bring stakeholders together to create community developed documents to identify potential sources of waterbody impairments throughout a watershed and provide a framework for implementation strategies to reduce pollution and improve overall water quality in Texas streams and rivers. Implementation measures are the next step in realizing the goals and needs of the communities. [GBEP and H-GAC fund WBPs]
    - Implementation of WBPs would address stressors such as:
        - Changes to Land Use and the Built Environment (infrastructure)
        - Chronic Higher Tides/Nuisance Flooding
        - Increase in Extreme Events (coastal flooding/storm surge)
        - Increasing Drought
        - Increasing Inland Flooding (largely rain-based)
        - Population Increase
        - Sea Level Rise and Subsidence
        - Warmer Summers
        - Warmer Waters

Quick Reference Guide 3: Pathway to Consequence/Probability Matrices Development
▪ **Preservation/Conservation/Restoration** – Preservation of lands, waters and habitats seeks to protect natural areas from use. Conservation seeks to use natural areas properly. Restoration's goal is to return natural areas to what they were or at least to functional parts of their ecosystem. [GBF, TPWD, Artist Boat, GLO, TNC] • Preservation/Conservation/Restoration would address stressors such as: ○ Increase in Extreme Events (coastal flooding/storm surge) ○ Increasing Drought ○ Increasing Inland Flooding (largely rain-based) ○ Population Increase ○ Sea Level Rise and Subsidence ○ Warmer Summers
▪ **Research** – Research is required when not enough information is known about the environment, ecosystems, or community at risk to better understand what the impacts are and if/how they should be mitigated. [USGS, HARC, TAMUG, UH, Rice University, HARC, TWDB] • Research would address stressors such as: ○ Increase in Extreme Events (coastal flooding/storm surge) ○ Increasing Drought ○ Increasing Inland Flooding (largely rain-based) ○ Sea Level Rise and Subsidence ○ Warmer Summers ○ Warmer Waters ○ Ocean Acidification
▪ **Promote Water Conservation and Reuse** – Cities, council of governments, non-profits, water agencies, and local municipal utility districts can and should promote water conservation and may provide programming. City of Houston, GBF, and others promote and provide rain barrels and workshops on how to use them. [H-GAC, GBF, TWDB promote water conservation] • Promote Water Conservation and Reuse adaptation actions would address stressors such as: ○ Changes to Land Use and the Built Environment (infrastructure) ○ Increasing Drought ○ Increasing Inland Flooding (largely rain-based) ○ Warmer Summers
▪ **Promote Native Habitat** – Special consideration should be given to preserving, conserving, restoring (including removing/preventing invasive species), monitoring, and educating the public about native habitats. [TPWD, Coastal Prairie Conservancy, Texas A&M AgriLife Extension, TNC] • Promote Native Habitat adaptation actions would address stressors such as: ○ Increasing Drought ○ Sea Level Rise and Subsidence ○ Warmer Summers ○ Warmer Waters

Table 5 outlines the stakeholder expert workgroup's list of stressors and risks Galveston Bay is facing now and in the future. With each risk, the potential adaptation/ mitigation action strategies are identified, with some specific adaptation/mitigation actions outlined. For every adaptation/mitigation action, Table 5 outlines if the adaptation/mitigation action will reduce the likelihood of the risk occurring and/or reduce the consequence of the risk should it occur. Table 5 will serve as a reference for GBEP and GBEP stakeholders to prioritize strategic initiatives and projects based on which combination of stressors, risks, and likelihoods/ consequences are the focus for implementation.

Table 5: Evaluation of Potential Adaptation/Mitigation Actions and Strategies for Galveston Bay

Stressors appear in bold type, Risks appear in italics. Stressors and Associated Risks Selected for Adaptation/Mitigation are color coded by the CCMP goals they address: purple for Engage Communities, blue for Ensure Safe Human and Aquatic Life Use, orange for Inform Science-Based Decision Making, green for Protect and Sustain Living Resources. WBPs = Watershed-based Plans.

Stressors and Associated *Risks* Selected for Adaptation/ Mitigation	Potential Adaptation/Mitigation Action Strategies	Could the action reduce likelihood of the *risk*?	Could the action reduce consequence of the *risk*?	Selected Examples of Adaptation/Mitigation Actions
Nuisance flooding, sea level rise and subsidence, and/ or extreme event flooding leading to ***increased flooding of property and habitat***	Stakeholder Outreach: Education	NO	YES	Development of resilience plans; networks to share data with stakeholders
	Monitoring	NO	YES	
Warmer summers and warmer waters leading to ***increased bacteria***	Stakeholder Outreach: Education	YES	YES	Bacteria monitoring on beaches, streams, and lakes; informing stakeholders
	Monitoring	NO	YES	
	Implementation of WBPs	YES	YES	
Warmer waters leading to ***heat stress***	Stakeholder Outreach: Education	NO	NO	Increased monitoring, informing stakeholders
	Monitoring	NO	YES	
Ocean acidification leading to ***loss of oyster reef habitat***	Research	NO	YES	Research on current state of Galveston Bay acidification; share data with stakeholders
Extreme events and inland flooding leading to ***bacteria in flood waters***	Stakeholder Outreach: Alerts/Risk	YES	YES	WBPs; water quality criteria; using genetic and traditional methods to track sources of bacteria and pathogens
	Monitoring	NO	YES	
	Implementation of WBPs	YES	YES	
Extreme events leading to ***exposure to pollutants in flood waters***	Stakeholder Outreach: Alerts/Risk	YES	YES	Wet weather monitoring
Rising sea level and subsidence leading to ***greater coastal wetland losses, resulting in less filtration of water***	Stakeholder Outreach: Education	YES	NO	Inform stakeholders of threats; WBPs; conserve coastal habitat
	Implementation of WBPs	YES	YES	
	Preservation/Conservation/ Restoration	YES	YES	GBEP and partners

Stressors and Associated *Risks* Selected for Adaptation/ Mitigation	Potential Adaptation/Mitigation Action Strategies	Could the action reduce likelihood of the *risk*?	Could the action reduce consequence of the *risk*?	Selected Examples of Adaptation/Mitigation Actions
Warmer summers leading to *increased violations of bacteriological standards*	Stakeholder Outreach: Education	YES	YES	WBPs; water quality criteria
	Implementation of WBPs	YES	YES	
Warmer waters leading to *increased vibrio illnesses (increased communication on public health risks*	Stakeholder Outreach: Alert/Risk	NO	YES	Monitoring and stakeholder alerts
	Monitoring	NO	YES	
Nuisance flooding leading to *increase in extent of tidal flooding, causing more septic systems and wastewater treatment facilities and lift stations to fail - lead to long-term pollutant load increase*	Implementation of WBPs	NO	YES	WBPs
Extreme events leading to *increase in extent of tidal flooding, leading to new sources of pollution from floating tanks, runoff, etc.*	Monitoring	NO	YES	Monitoring; research on tanks in storms
	Research	NO	YES	
Increasing drought leading to *increased human use of water for irrigation, leading to increased runoff*	Implementation of WBPs	YES	YES	WBPs; green infrastructure; water conservation programs

Stressors and Associated *Risks* Selected for Adaptation/ Mitigation	Potential Adaptation/Mitigation Action Strategies	Could the action reduce likelihood of the *risk*?	Could the action reduce consequence of the *risk*?	Selected Examples of Adaptation/Mitigation Actions
Inland flooding leading to *increased erosion of streambeds, increasing sedimentation, and decreasing width of riparian corridors, which reduces vegetated land available for filtration, increasing short-term and long-term pollutant loads*	Implementation of WBPs	YES	YES	WBPs; conserve riparian habitat; native plant restoration; soil conservation; green infrastructure
	Preservation/Conservation/ Restoration	YES	YES	
Increased population leading *to increase in pollutant sources*	Implementation of WBPs	YES	YES	WBPs; stakeholder outreach; green infrastructure; trash, litter, and microplastics prevention
	Stakeholder Outreach: Education	YES	YES	
Sea level rise and subsidence leading *to higher water tables/increase in extent in tidal flooding will drown coastal septic systems causing them to fail - lead to short-term and long-term pollutant load increases*	Implementation of WBPs	NO	YES	WBPs; stakeholder outreach; state funds to replace failing septic systems
	Stakeholder Outreach: Education	NO	YES	
Sea level rise and subsidence leading *to contaminated sites that may flood or have shoreline erosion*	Preservation/Conservation/ Restoration	YES	YES	Identify sites on the Superfund[1] National Priorities List subject to coastal influence and develop plans for protection

[1] Any protection plans will not intrude on boundaries of superfund site, and will be developed in consultation with TCEQ/EPA (appropriate parties).

Stressors and Associated *Risks* Selected for Adaptation/ Mitigation	Potential Adaptation/Mitigation Action Strategies	Could the action reduce likelihood of the *risk*?	Could the action reduce consequence of the *risk*?	Selected Examples of Adaptation/Mitigation Actions
Changes in land use and infrastructure leading to *increased impervious surfaces, resulting in increased runoff and alter the quantity, timing, and duration of inflows*	Implementation of WBPs	YES	YES	WBPs; stakeholder outreach; carbon storage research; green infrastructure
	Promote Water Conservation and Reuse	YES	YES	GBEP/Partners: WBPs, carbon storage research
Extreme events leading to *increase in the potential for spills/contaminants entering the bay system*	Implementation of WBPs	NO	YES	Development and implementation of resilience and disaster response plans; monitoring
	Monitoring	NO	YES	
Warmer summers leading to *increased evapotranspiration - less freshwater inflow, compromised water quality*	Promote Water Conservation and Reuse	YES	YES	Initiate studies on evapotranspiration in the Galveston Bay watershed
	Research	YES	YES	
Warmer waters leading to *increased evapotranspiration - less freshwater inflow, compromised water quality*	Promote Water Conservation and Reuse	YES	YES	Initiate studies on evapotranspiration in the Galveston Bay watershed; supply information to decision makers regarding inflow updates
	Research	YES	YES	
Warmer summers leading to *increase in the potential for more and stronger tropical storms/ hurricanes*	Research	NO	YES	Master plans; coastal research and monitoring; storm research and monitoring
	Monitoring	NO	YES	
	Implementation of WBPs	NO	YES	
Extreme events leading to *increased stream erosion and sediment loads*	Preservation/Conservation/ Restoration	YES	YES	Living shorelines, breakwaters, support for public and private landowners
	Stakeholder Outreach: Education	NO	YES	

Stressors and Associated *Risks* Selected for Adaptation/ Mitigation	Potential Adaptation/Mitigation Action Strategies	Could the action reduce likelihood of the *risk*?	Could the action reduce consequence of the *risk*?	Selected Examples of Adaptation/ Mitigation Actions
Inland flooding leading to *increased stream erosion and sediment loads*	Research	NO	YES	Restore/enhance riparian corridors along watershed bayous; green infrastructure
	Promote Water Conservation and Reuse	YES	YES	
	Preservation/Conservation/ Restoration	YES	YES	
Extreme events leading to *loss of habitat*	Preservation/Conservation/ Restoration	YES	YES	Land conservation and native habitat restoration project implementation
	Implementation of WBPs	YES	YES	
	Stakeholder Outreach: Education	NO	YES	
Increasing drought leading to *loss of habitat for riparian spawning fish species*	Research	YES	YES	Restore/enhance riparian corridors
	Promote Water Conservation and Reuse	YES	YES	
	Preservation/Conservation/ Restoration	YES	YES	
Population increase leading to *loss of native habitat due to development*	Stakeholder Outreach: Education	YES	YES	Land conservation and native habitat preservation; promote benefits of native habitat to stakeholders
	Preservation/Conservation/ Restoration	YES	YES	
Inland flooding leading to *changes in shallow water habitat and secondary impacts on juvenile stages of estuarine and marine organisms*	Preservation/Conservation/ Restoration	NO	YES	Habitat restoration, and shoreline enhancement projects that restore rookery islands, intertidal marsh, and shallow water habitats to sustain and restore native species populations; land conservation
	Monitoring	NO	YES	

Stressors and Associated *Risks* Selected for Adaptation/ Mitigation	Potential Adaptation/Mitigation Action Strategies	Could the action reduce likelihood of the *risk?*	Could the action reduce consequence of the *risk?*	Selected Examples of Adaptation/Mitigation Actions
Sea level rise and **subsidence** leading to *increased marsh flooding*	Preservation/Conservation/ Restoration	NO	YES	Habitat acquisition/ restoration, and enhancement projects that allow for marsh migration to sustain and restore native species populations
	Stakeholder Outreach: Education	NO	YES	
	Monitoring	NO	YES	
Sea level rise and subsidence leading to *changing spatial extent of available habitat*	Preservation/Conservation/ Restoration	NO	YES	Habitat acquisition projects that allow for marsh migration to sustain and restore native species populations; baseline and gap analysis of conservation projects
	Monitoring	NO	YES	
	Promote Native Habitat	NO	YES	
Sea level rise and subsidence leading to *loss of restored and enhanced habitat due to drowning*	Preservation/Conservation/ Restoration	YES	YES	Habitat enhancement and restoration projects that sustain and restore native species populations; wetland restoration and adaptive management on prior projects
	Monitoring	YES	YES	
	Promote Native Habitat	NO	YES	
Warmer waters leading to *altered habitat distribution and lower dissolved oxygen*	Monitoring	NO	YES	Intertidal marsh and shoreline enhancement/ restoration projects to sustain and restore native species populations by recreating historic marsh complexes and reducing open water

Stressors and Associated Risks Selected for Adaptation/ Mitigation	Potential Adaptation/Mitigation Action Strategies	Could the action reduce likelihood of the *risk?*	Could the action reduce consequence of the *risk?*	Selected Examples of Adaptation/Mitigation Actions
Increasing drought leading to *increased evapotranspiration and/or decrease in freshwater inflows which will cause increased salinity impacts and decreases in oyster reef habitat*	Research	YES	YES	Reef restoration in upper reaches of Galveston Bay; advocate for additional/ or base level inflow and preserve native habitat
	Promote Water Conservation and Reuse	YES	YES	
	Preservation/Conservation/ Restoration	YES	YES	
Sea level rise and **subsidence** leading to *increased extent of saline waters*	Preservation/Conservation/ Restoration	NO	YES	Conserving lands to prevent saltwater intrusion into freshwater wetlands
	Research	NO	YES	
Increasing drought leading to *increasing demand on water resources; decrease in discharge to Galveston Bay*	Promote Water Conservation and Reuse	YES	YES	Support for the statewide environmental flows process; regional ecological plans
	Implementation of WBPs	YES	YES	
Increasing drought leading to *decrease in base flow of streams*	Monitoring	NO	YES	Partner participation in the regional water planning processes to ensure the rules that govern the regional water plans better protect water for wildlife
Increasing drought leads to *increased demand on groundwater, leading to further reduction of base flow*	Promote Water Conservation and Reuse	YES	YES	Partner participation in the regional water planning processes to ensure the rules that govern the regional water plans better protect water for wildlife
	Implementation of WBPs	NO	YES	

Stressors and Associated *Risks* Selected for Adaptation/ Mitigation	Potential Adaptation/Mitigation Action Strategies	Could the action reduce likelihood of the *risk*?	Could the action reduce consequence of the *risk*?	Selected Examples of Adaptation/Mitigation Actions
Warmer summers lead to *increased evapotranspiration, which will decrease freshwater inflows*	Promote Water Conservation and Reuse	YES	YES	Riparian restoration; green infrastructure; promote native habitat
	Preservation/Conservation/ Restoration	YES	YES	
Sea level rise and subsidence *leads to changing light attenuation*	Preservation/Conservation/ Restoration	NO	YES	Refuges; living shorelines to prevent suspended solids from erosion from impacting light attenuation
	Research	NO	YES	
Warmer summers could *expand range of invasive species*	Stakeholder Outreach: Alerts/Risk	YES	YES	Supporting projects that manage invasive species range and spread; managing invasive species on properties/ public lands
	Stakeholder Outreach: Education	YES	YES	
	Monitoring	YES	YES	
	Promote Native Habitat	YES	YES	
Warmer waters lead to *a decrease in dissolved oxygen*	Stakeholder Outreach: Education	NO	YES	Monitoring with water quality team for education activities; educating marinas about design best practices to increase flow
	Monitoring	NO	YES	
	Research	YES	YES	
Warmer waters lead to *increased stratification*	Monitoring	NO	YES	Monitoring water temperature and stratification
Warmer winters leads to *enhanced survival of insect pests*	Stakeholder Outreach: Alerts/Risk	YES	YES	Follow up with monitoring organizations and with species of concern (like Emerald Ash Borer)
	Stakeholder Outreach: Education	NO	YES	
	Monitoring	NO	YES	
	Promote Native Habitat	YES	YES	
Ocean acidification leading to *potential impacts on shellfish and other sedentary organisms that require calcium for exoskeleton*	Research	NO	YES	Research on current state of Galveston Bay acidification

Incorporating Adaptation/Mitigation Actions in the CCMP

Many of the adaptation/mitigation actions and strategies discussed above fit within the priorities and goals of the CCMP, which serves as GBEP's master planning document. The connections between the risks and the actions that will reduce the likelihood and/or consequences of those risks will facilitate prioritization and implementation of adaptation/mitigation actions by GBEP and its partners (Table 6).

Below are several visual representations of the relationships between adaptation/mitigation actions and the GBP priorities and goals (Figure 5, Table 7). Many adaptation/mitigation actions could serve multiple GBP goals and mitigate several risks. Table 6 shows a detailed view of stressors, risks and potential adaptation/mitigation actions categorized by impact to the Galveston Bay CCMP goals.

Figure 5: Sankey Chart showing the relationships between stressors and adaptation/mitigation action grouping, color coded by GBP Priorities

(purple)	**Engage Communities**
(light blue)	**Ensure Safe Human and Aquatic Life Use**
(green)	**Protect and Sustain Living Resources**
(orange)	**Inform Science-Based Decision Making**

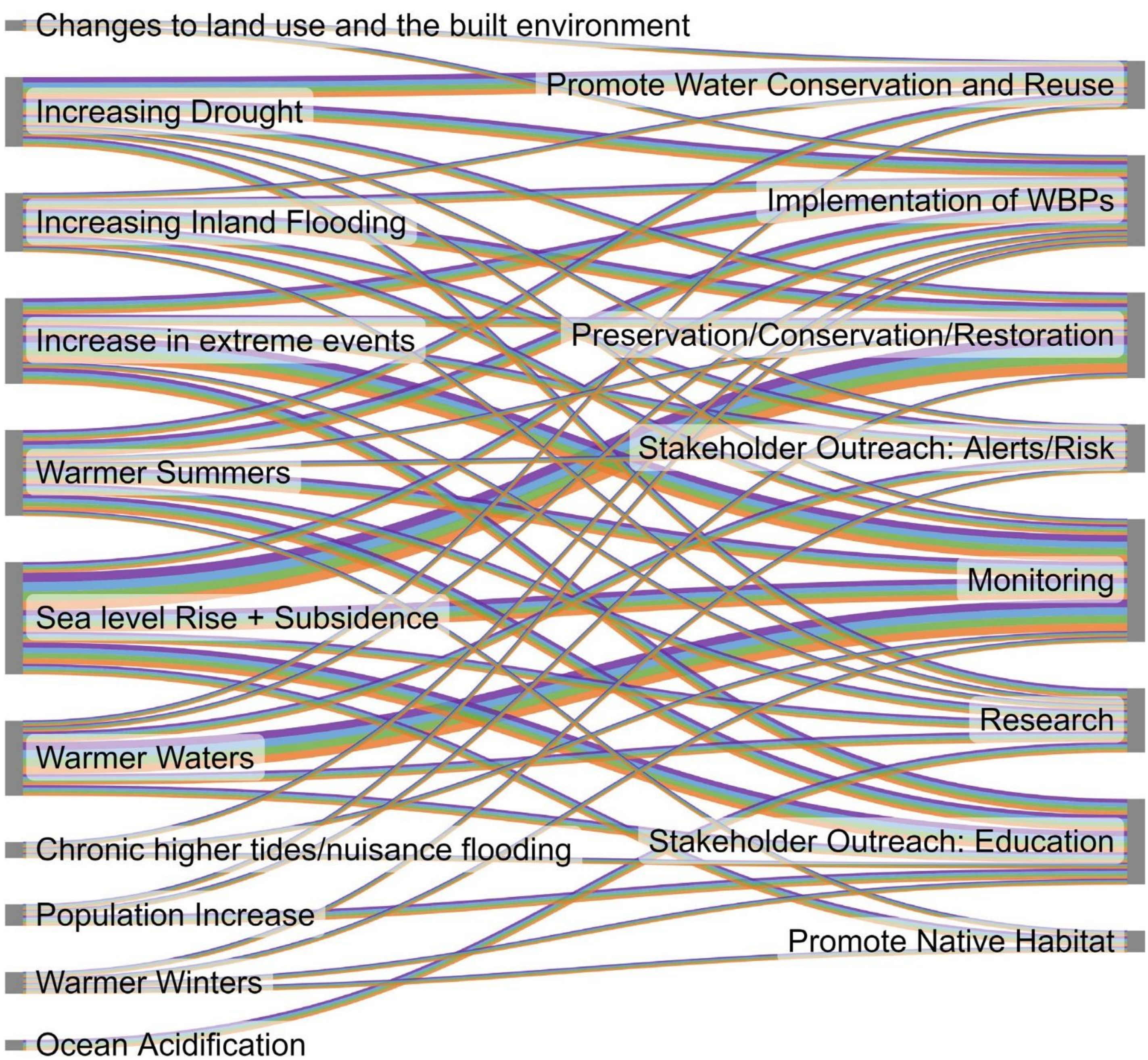


Table 6: Adaptation/Mitigation Strategy Groupings vs. GBP Goals

Adaptation/Mitigation Grouping	Engage Communities	Ensure Safe Human and Aquatic Life Use: Increase public awareness of current public health risks/Reduce risk through WBPs	Ensure Safe Human and Aquatic Life Use: Reduce NPS and PS (including WWTFs and sanitary sewer system) pollution	Inform Science -Based Decision Making	Protect and Sustain Living Resources: Conserve, restore, and enhance vital habitats in the lower portion of the Galveston Bay watershed.	Protect and Sustain Living Resources: Ensure adequate quantities of freshwater reach Galveston Bay	Protect and Sustain Living Resources: Sustain and restore native species populations
Stakeholder Outreach: Education	X	X	X		X		X
Stakeholder Outreach: Alerts/Risk		X			X		
Monitoring	X	X	X	X	X		X
Implementation of WBPs	X	X	X	X	X	X	
Preservation/Conservation/Restoration		X	X	X	X	X	X
Research			X	X	X		
Promote Water Conservation and Reuse				X	X	X	
Promote Native Habitat							X

Table 7: Adaptation/Mitigation Strategy Groupings vs. Stressors

Stressors	Chronic higher tides/nuisance flooding	Increase in extreme events (coastal flooding/storm surge)	Sea Level Rise + subsidence	Warmer Summers	Warmer Waters	Increasing Drought	Increasing Inland Flooding (largely rain-based)	Population Increase	Changes in land use and the built environment (infrastructure)	Ocean Acidification
Adaptation/Mitigation Grouping										
Stakeholder Outreach: Education	X	X	X	X	X			X		
Stakeholder Outreach: Alerts/Risk		X		X	X	X	X			
Monitoring	X	X	X	X	X		X			
Implementation of Watershed Based Plans	X	X	X	X		X	X	X	X	
Preservation/Conservation/Restoration		X	X	X			X	X		
Research		X		X	X	X	X			X
Promote Water Conservation and Reuse				X	X	X	X		X	
Promote Native Habitat				X			X		X	

Tracking Projects that Include Adaptation/Mitigation Actions

The adaptation/mitigation action groupings above address adaptation/mitigation actions to mitigate the impacts of estuary stressors on CCMP goals and priorities. In order to ensure the successful implementation of the Galveston Bay Estuary Action Plan, the adaptation/mitigation actions should be tracked over time. For future projects that include adaptation/mitigation actions, the resilience risks that are addressed and the frequency of reporting should be tracked, along with responsible parties and steps (Table 8). At the same time, actions that are aimed at specific risk reduction should be tracked (Table 9). Ideally, future projects and proposals should identify which risks are likely to be addressed by the goals of the project and which adaptation/mitigation actions will be taken and tracked over time. Project tracking with these metrics will enable GBEP and its stakeholders to integrate the Galveston Bay Estuary Resilience Action Plan into the CCMP and the projects that aim to support it.

Table 8: Tracking Selected Adaptation/Mitigation Actions

Adaptation/ Mitigation	Risk(s) addressed	Responsible party(ies)	Next steps	Reporting frequency
1.				
2.				
3.				
4.				

Table 9: Example: Tracking Risk Reductions

Risk selected for adaptation/mitigation	Action(s) employed/completed
1.	
2.	
3.	
4.	

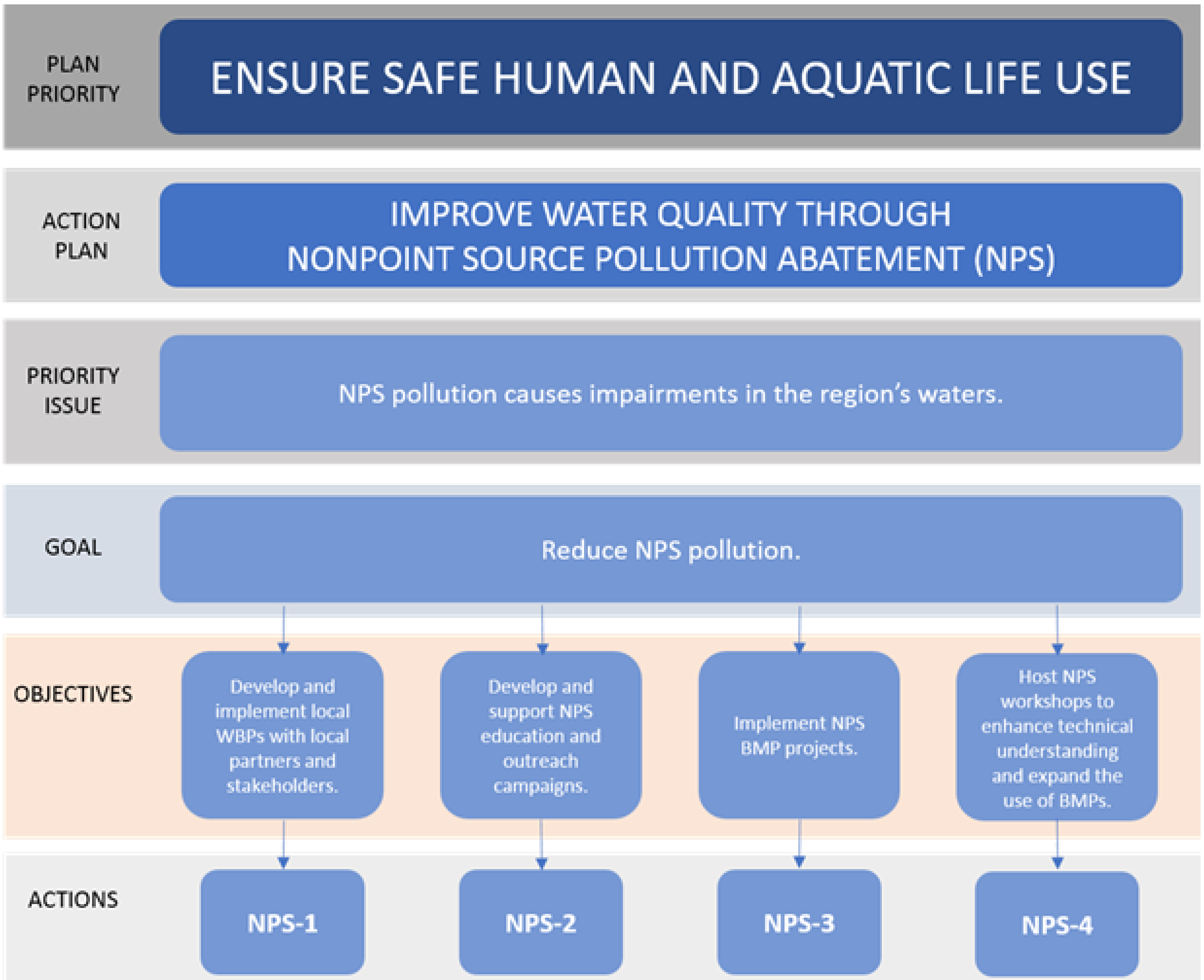
Conclusions

The future conservation and protection of Galveston Bay will be dependent on stakeholders who have the knowledge, funding, and the will to adapt to changing conditions and plan and act accordingly. GBEP and its stakeholder experts have the knowledge, and now in the Galveston Bay Estuary Resilience Action Plan, a list of estuary resilience stressors, risks, and appropriate adaptation/mitigation actions to protect the GBEP GBP's goals and ensure a resilient Galveston Bay.

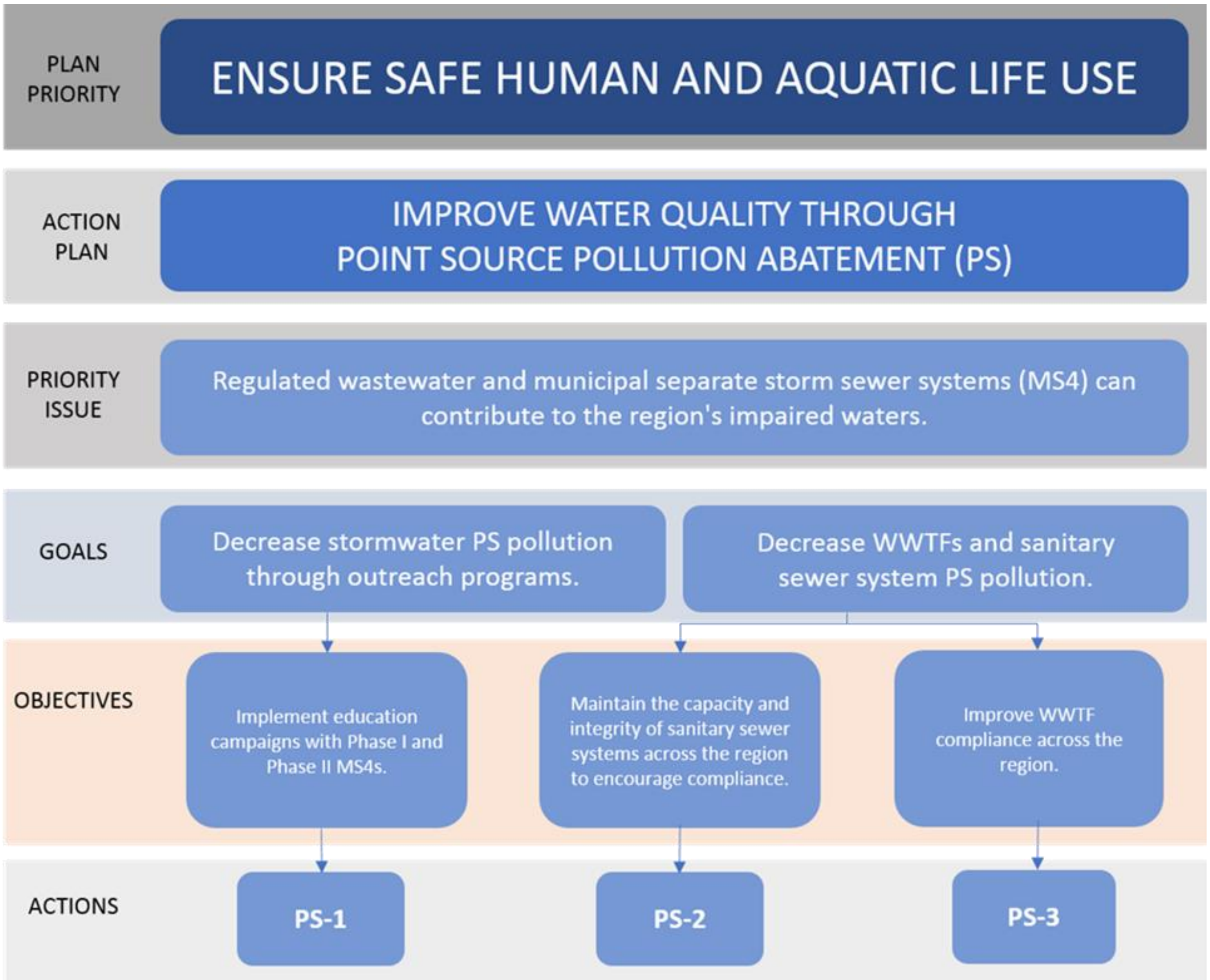
The adaptation/mitigation actions identified and discussed above and the risks that will necessitate their implementation will also be included in the updated CCMP. GBEP's partners have already implemented some of these actions and strategies and others are in development. Including estuary resilience stressors and adaptation/mitigation strategies will make it easier to prioritize and fund projects that will improve the resilience of Galveston Bay.

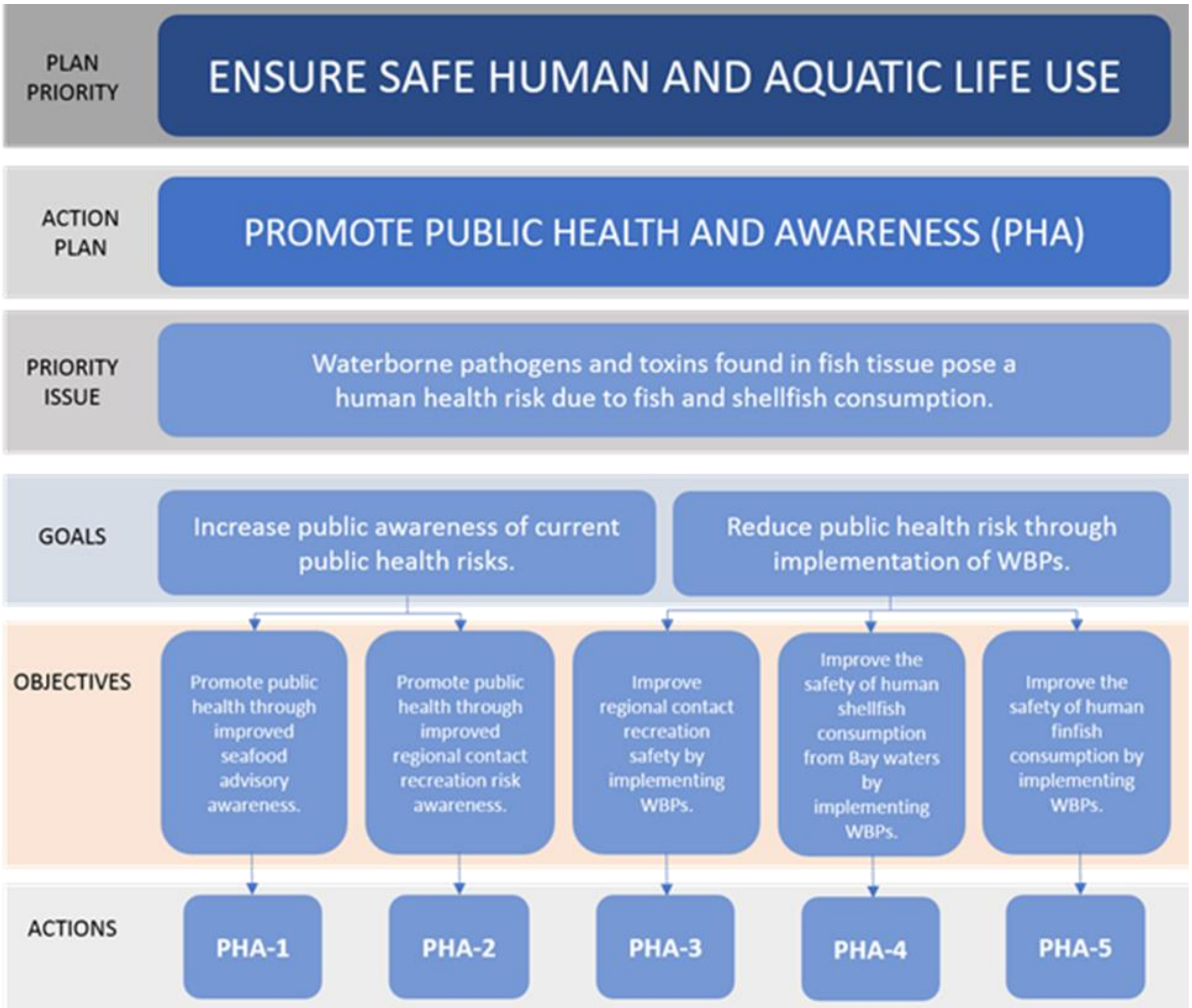
Appendix A

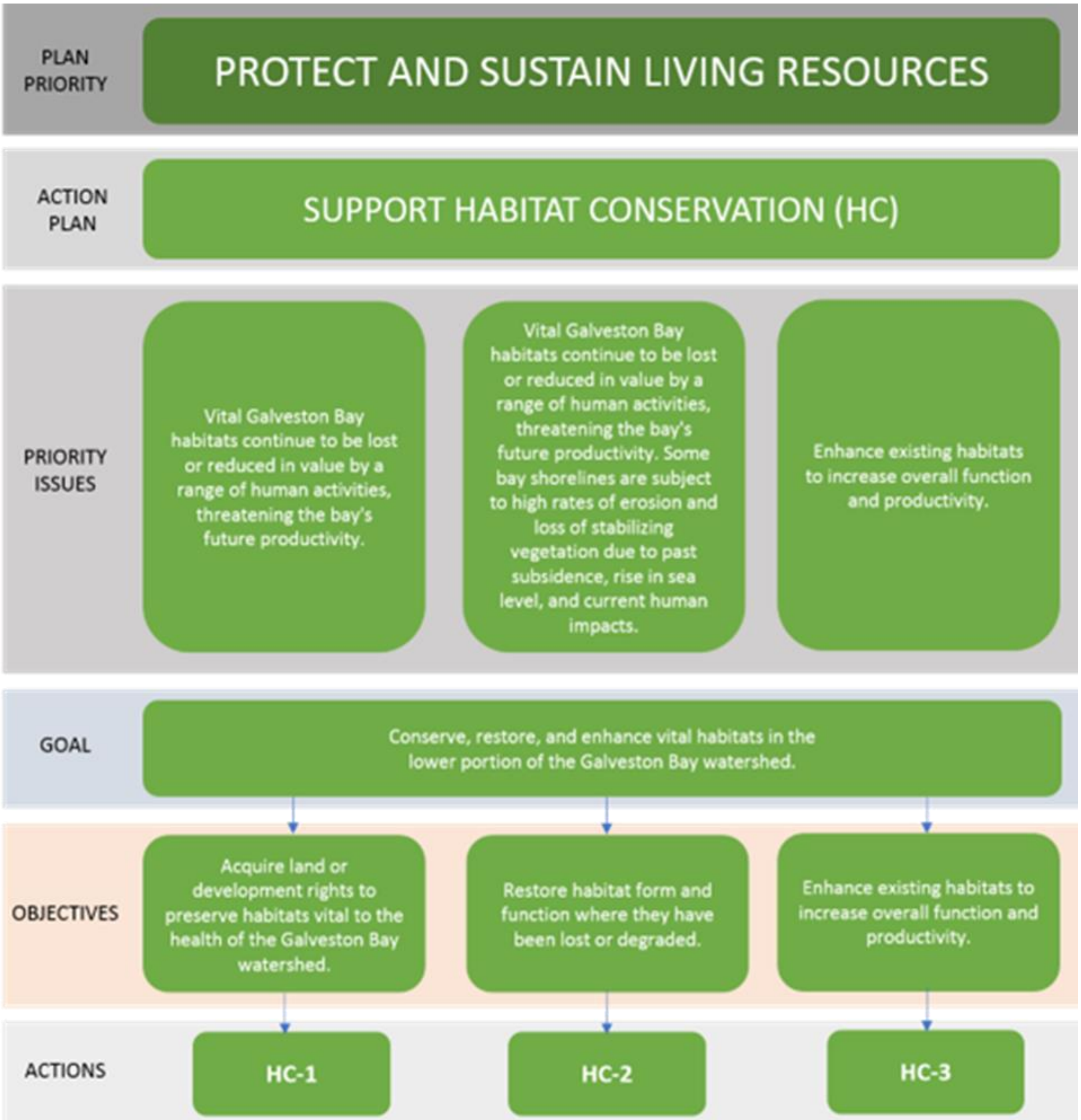
GBP-Plan Priorities and Action Plans (Figures from the *Galveston Bay Plan, 2nd Edition*[5]

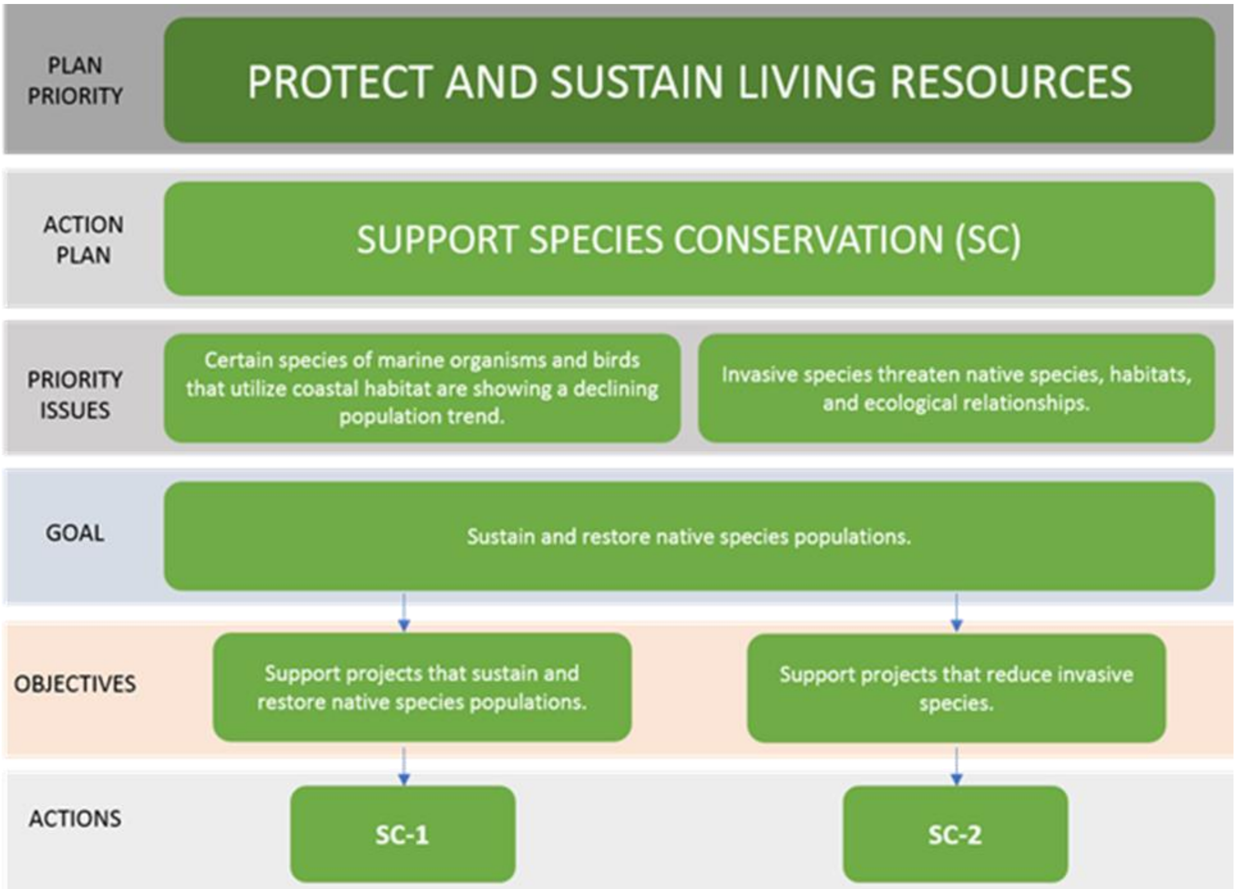


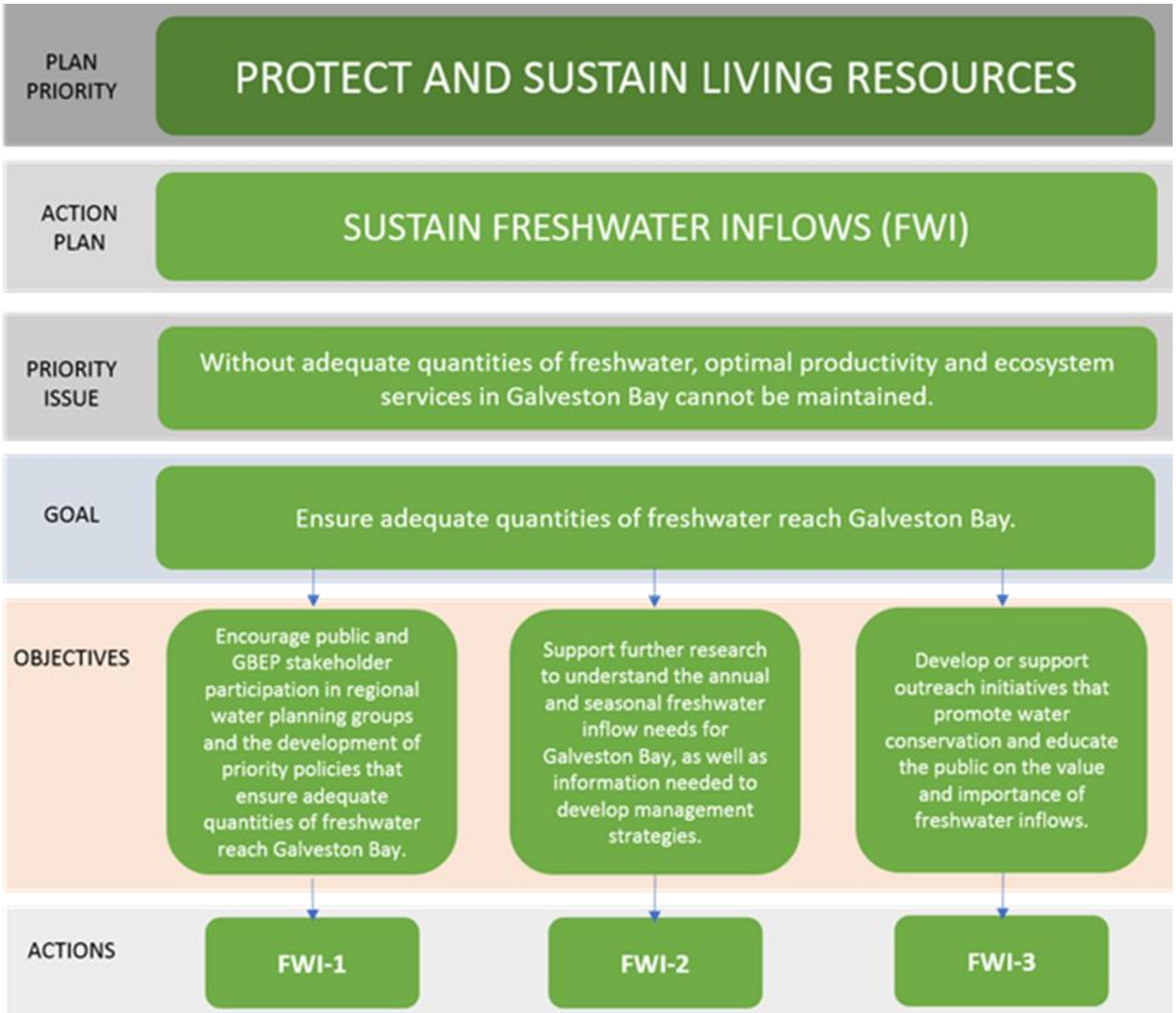
[5] https://gbep.texas.gov/galveston-bay-plan/

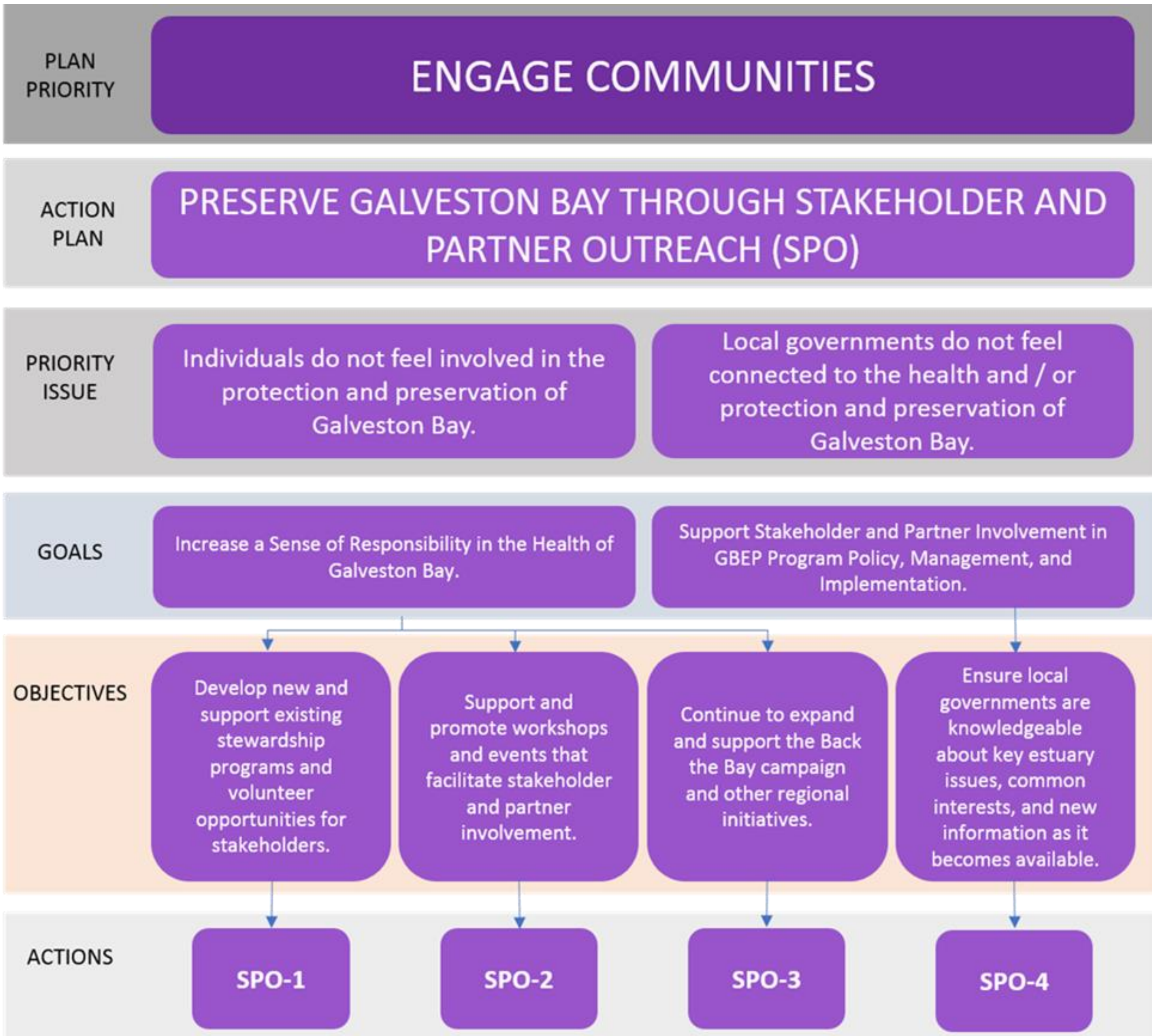

PLAN PRIORITY
ENSURE SAFE HUMAN AND AQUATIC LIFE USE
ACTION PLAN
IMPROVE WATER QUALITY THROUGH POINT SOURCE POLLUTION ABATEMENT (PS)
PRIORITY ISSUE
Regulated wastewater and municipal separate storm sewer systems (MS4) can contribute to the region's impaired waters.
GOALS
Decrease stormwater PS pollution through outreach programs.
Decrease WWTFs and sanitary sewer system PS pollution.
OBJECTIVES
Implement education campaigns with Phase I and Phase II MS4s.
Maintain the capacity and integrity of sanitary sewer systems across the region to encourage compliance.
Improve WWTF compliance across the region.
ACTIONS
PS-1
PS-2
PS-3

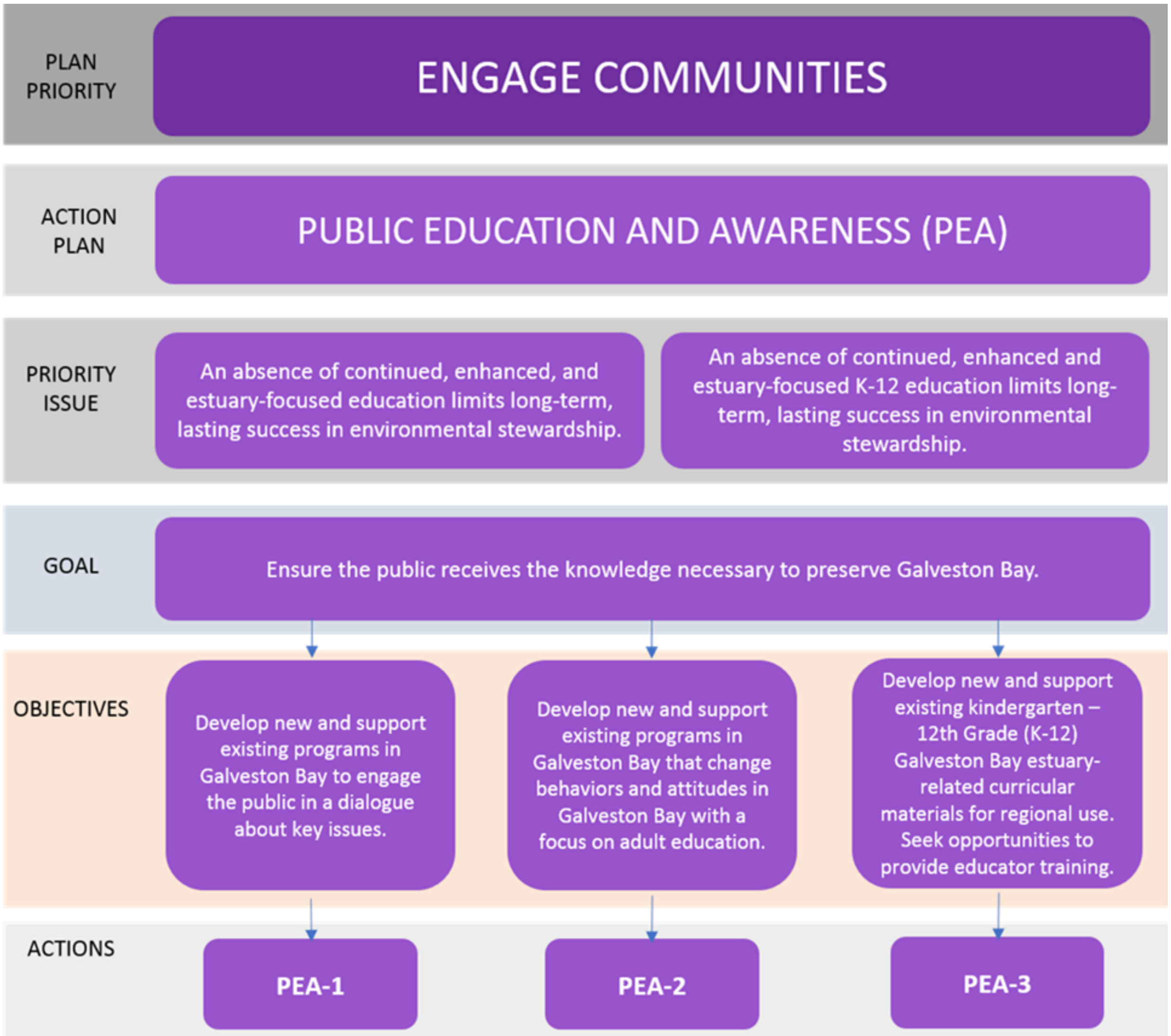

PLAN PRIORITY
ENSURE SAFE HUMAN AND AQUATIC LIFE USE
ACTION PLAN
PROMOTE PUBLIC HEALTH AND AWARENESS (PHA)
PRIORITY ISSUE
Waterborne pathogens and toxins found in fish tissue pose a human health risk due to fish and shellfish consumption.
GOALS
Increase public awareness of current public health risks.
Reduce public health risk through implementation of WBPs.
OBJECTIVES
Promote public health through improved seafood advisory awareness.
Promote public health through improved regional contact recreation risk awareness.
Improve regional contact recreation safety by implementing WBPs.
Improve the safety of human shellfish consumption from Bay waters by implementing WBPs.
Improve the safety of human finfish consumption by implementing WBPs.
ACTIONS
PHA-1
PHA-2
PHA-3
PHA-4
PHA-5

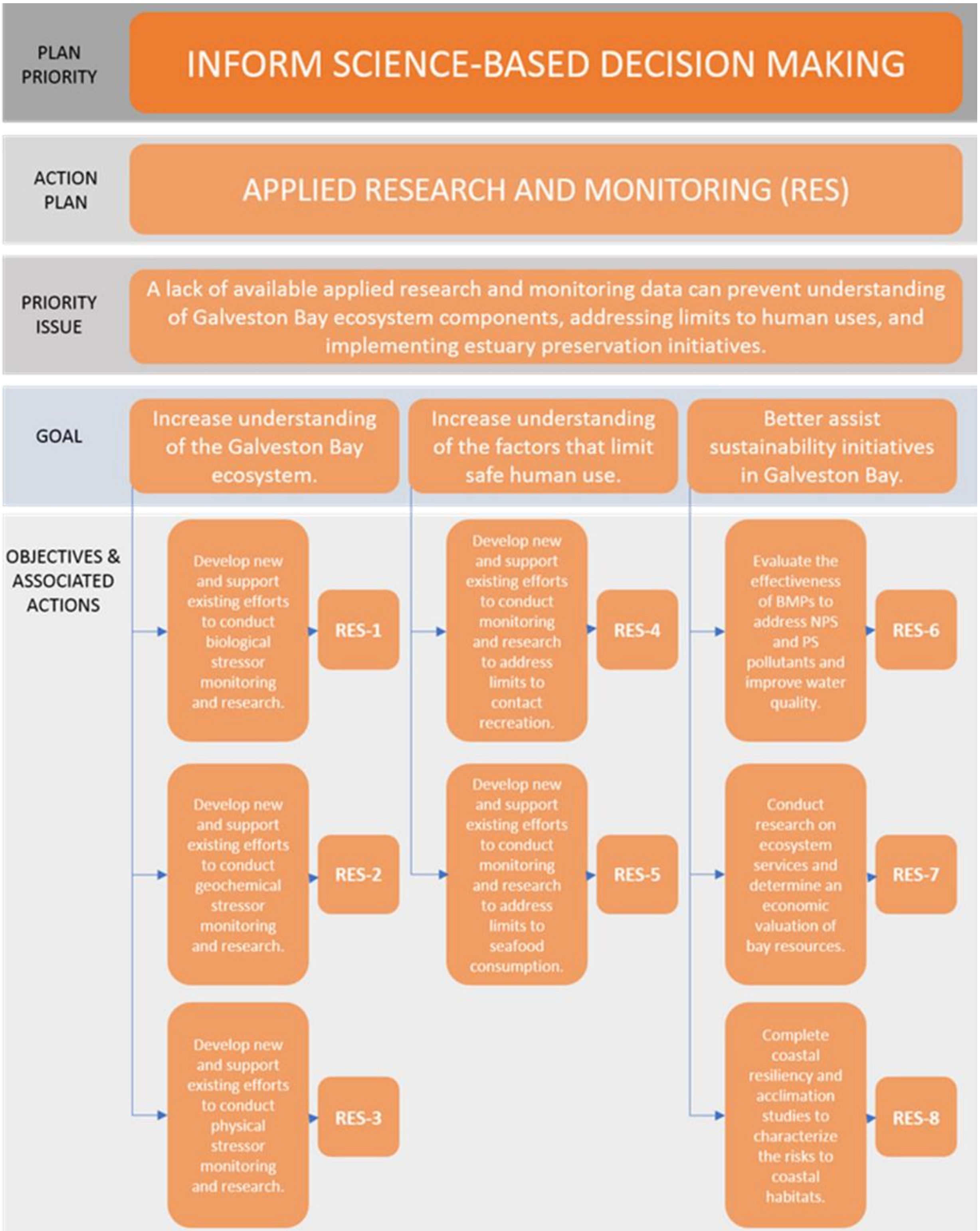

PLAN PRIORITY
PROTECT AND SUSTAIN LIVING RESOURCES
ACTION PLAN
SUPPORT HABITAT CONSERVATION (HC)
PRIORITY ISSUES
Vital Galveston Bay habitats continue to be lost or reduced in value by a range of human activities, threatening the bay's future productivity.
Vital Galveston Bay habitats continue to be lost or reduced in value by a range of human activities, threatening the bay's future productivity. Some bay shorelines are subject to high rates of erosion and loss of stabilizing vegetation due to past subsidence, rise in sea level, and current human impacts.
Enhance existing habitats to increase overall function and productivity.
GOAL
Conserve, restore, and enhance vital habitats in the lower portion of the Galveston Bay watershed.
OBJECTIVES
Acquire land or development rights to preserve habitats vital to the health of the Galveston Bay watershed.
Restore habitat form and function where they have been lost or degraded.
Enhance existing habitats to increase overall function and productivity.
ACTIONS
HC-1
HC-2
HC-3

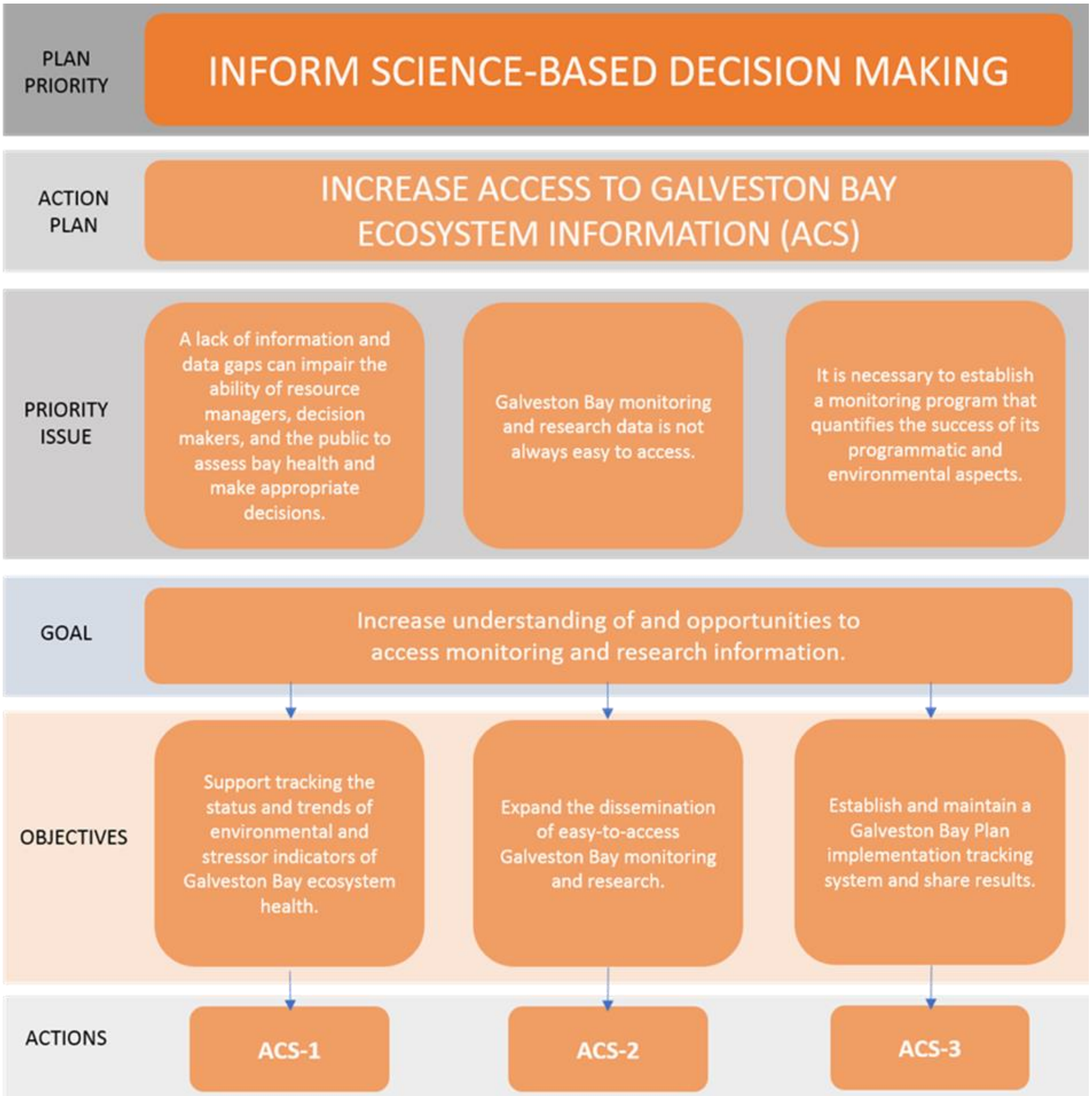

PLAN PRIORITY
PROTECT AND SUSTAIN LIVING RESOURCES
ACTION PLAN
SUPPORT SPECIES CONSERVATION (SC)
PRIORITY ISSUES
Certain species of marine organisms and birds that utilize coastal habitat are showing a declining population trend.
Invasive species threaten native species, habitats, and ecological relationships.
GOAL
Sustain and restore native species populations.
OBJECTIVES
Support projects that sustain and restore native species populations.
Support projects that reduce invasive species.
ACTIONS
SC-1
SC-2


PLAN PRIORITY
PROTECT AND SUSTAIN LIVING RESOURCES
ACTION PLAN
SUSTAIN FRESHWATER INFLOWS (FWI)
PRIORITY ISSUE
Without adequate quantities of freshwater, optimal productivity and ecosystem services in Galveston Bay cannot be maintained.
GOAL
Ensure adequate quantities of freshwater reach Galveston Bay.
OBJECTIVES
Encourage public and GBEP stakeholder participation in regional water planning groups and the development of priority policies that ensure adequate quantities of freshwater reach Galveston Bay.
Support further research to understand the annual and seasonal freshwater inflow needs for Galveston Bay, as well as information needed to develop management strategies.
Develop or support outreach initiatives that promote water conservation and educate the public on the value and importance of freshwater inflows.
ACTIONS
FWI-1
FWI-2
FWI-3


PLAN PRIORITY
ENGAGE COMMUNITIES
ACTION PLAN
PRESERVE GALVESTON BAY THROUGH STAKEHOLDER AND PARTNER OUTREACH (SPO)
PRIORITY ISSUE
Individuals do not feel involved in the protection and preservation of Galveston Bay.
Local governments do not feel connected to the health and / or protection and preservation of Galveston Bay.
GOALS
Increase a Sense of Responsibility in the Health of Galveston Bay.
Support Stakeholder and Partner Involvement in GBEP Program Policy, Management, and Implementation.
OBJECTIVES
Develop new and support existing stewardship programs and volunteer opportunities for stakeholders.
Support and promote workshops and events that facilitate stakeholder and partner involvement.
Continue to expand and support the Back the Bay campaign and other regional initiatives.
Ensure local governments are knowledgeable about key estuary issues, common interests, and new information as it becomes available.
ACTIONS
SPO-1
SPO-2
SPO-3
SPO-4


PLAN PRIORITY
ENGAGE COMMUNITIES
ACTION PLAN
PUBLIC EDUCATION AND AWARENESS (PEA)
PRIORITY ISSUE
An absence of continued, enhanced, and estuary-focused education limits long-term, lasting success in environmental stewardship.
An absence of continued, enhanced and estuary-focused K-12 education limits long-term, lasting success in environmental stewardship.
GOAL
Ensure the public receives the knowledge necessary to preserve Galveston Bay.
OBJECTIVES
Develop new and support existing programs in Galveston Bay to engage the public in a dialogue about key issues.
Develop new and support existing programs in Galveston Bay that change behaviors and attitudes in Galveston Bay with a focus on adult education.
Develop new and support existing kindergarten – 12th Grade (K-12) Galveston Bay estuary-related curricular materials for regional use. Seek opportunities to provide educator training.
ACTIONS
PEA-1
PEA-2
PEA-3


PLAN PRIORITY
INFORM SCIENCE-BASED DECISION MAKING
ACTION PLAN
APPLIED RESEARCH AND MONITORING (RES)
PRIORITY ISSUE
A lack of available applied research and monitoring data can prevent understanding of Galveston Bay ecosystem components, addressing limits to human uses, and implementing estuary preservation initiatives.
GOAL
Increase understanding of the Galveston Bay ecosystem.
Increase understanding of the factors that limit safe human use.
Better assist sustainability initiatives in Galveston Bay.
OBJECTIVES & ASSOCIATED ACTIONS
Develop new and support existing efforts to conduct biological stressor monitoring and research.
RES-1
Develop new and support existing efforts to conduct geochemical stressor monitoring and research.
RES-2
Develop new and support existing efforts to conduct physical stressor monitoring and research.
RES-3
Develop new and support existing efforts to conduct monitoring and research to address limits to contact recreation.
RES-4
Develop new and support existing efforts to conduct monitoring and research to address limits to seafood consumption.
RES-5
Evaluate the effectiveness of BMPs to address NPS and PS pollutants and improve water quality.
RES-6
Conduct research on ecosystem services and determine an economic valuation of bay resources.
RES-7
Complete coastal resiliency and acclimation studies to characterize the risks to coastal habitats.
RES-8


PLAN PRIORITY
INFORM SCIENCE-BASED DECISION MAKING
ACTION PLAN
INCREASE ACCESS TO GALVESTON BAY ECOSYSTEM INFORMATION (ACS)
PRIORITY ISSUE
A lack of information and data gaps can impair the ability of resource managers, decision makers, and the public to assess bay health and make appropriate decisions.
Galveston Bay monitoring and research data is not always easy to access.
It is necessary to establish a monitoring program that quantifies the success of its programmatic and environmental aspects.
GOAL
Increase understanding of and opportunities to access monitoring and research information.
OBJECTIVES
Support tracking the status and trends of environmental and stressor indicators of Galveston Bay ecosystem health.
Expand the dissemination of easy-to-access Galveston Bay monitoring and research.
Establish and maintain a Galveston Bay Plan implementation tracking system and share results.
ACTIONS
ACS-1
ACS-2
ACS-3

Appendix B

Consequence/Probability Matrix Organized by Stressor and by Consequence/Probability for All Categories and Stressors

These are the IDs for the GBP Plan Goals and Stressors used in the CP Matrices

GBP Priority	GBP Goal ID
Engage Communities	ECG
Ensure Safe Human and Aquatic Life Use: Increase public awareness of current public health risks/Reduce risk through WBPs	SAGWBP
Ensure Safe Human and Aquatic Life Use: Reduce NPS and PS (including WWTF and sanitary sewer system) pollution	SAGWNPS
Inform Science - Based Decision Making	ISG
Protect and Sustain Living Resources: Conserve, restore, and enhance vital habits in the lower portion of the Galveston Bay watershed.	PSGCRE
Protect and Sustain Living Resources: Ensure adequate quantities of freshwater reach Galveston Bay	PSGFI
Protect and Sustain Living Resources: Sustain and restore native species populations	PSGNS

Stressor	Stressor ID
Changes to Land Use and the Built Environment (infrastructure)	LU
Chronic Higher Tides/Nuisance Flooding	NF
Increase In Extreme Events (coastal flooding/storm surge)	EE
Increasing Drought	ID
Increasing Inland Flooding (largely rain- based)	IF
Ocean Acidification	OA
Population Increase	PI
Sea Level Rise and Subsidence	SL
Warmer Summers	WS
Warmer Waters	WH
Warmer Winters	WW

Consequence/Probability Matrix by Stressor

Stressor: Warmer Summers

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High	1. PSGCRE| Increased evapotranspiration which could lead to aquatic/subtidal species composition change 2. PSGCRE| Warmer summers will increase plant productivity, vertical accretion, and carbon sequestration. This should accelerate as mangroves become more predominant.	1. ECG| Heat stress 2. ECG| Increase in vibrio illnesses 3. SAGWNPS| Using more water for irrigation leading to increased runoff 4. SAGWNPS| Warmer summers will lead to warmer water, increased likelihood of fecal indicator bacteria, and increased frequency of water quality exceedances 5. ISG| Warmer waters lead to increased bacteria	1. ECG| Warmer waters = increased bacteria 2. SAGWBP| Increased exceedances of bacteriological standards 3. ISG| Increased evapotranspiration - less freshwater inflow, compromised water quality 4. ISG| Potential for more & stronger tropical storms/hurricanes 5. PSGCRE| Warmer summers could expand range of invasive species. 6. PSGFI| Increased evapotranspiration will decrease freshwater inflows
Medium		1. ISG| Essential food sources may die off 2. ISG| How warmer summers impact oyster reefs 3. PSGFI| Increased evapotranspiration will increase salinity in upstream reaches 4. PSGNS| Heat stress to native populations and metabolic costs/mortality; changes to food webs 5. PSGNS| Increased salinity (from increased evaporation and decreased freshwater inflow) can impact the distribution, abundance, and productivity of native species 6. PSGNS| Life cycle stages (e.g., spawning) is influenced by environmental cues (temperature) 7. PSGNS| Shifts in fisheries populations, likely continued decreases in flounder but potential increases in range for snook and pompano	1. SAGWBP| Increased heat stress (education) 2. ISG| Heat stress to native populations 3. ISG| Changes in communities to more tropical composition 4. PSGFI| Harmful algal blooms are more likely to develop in warm, salty water. 5. PSGNS| Increased water temperatures would increase oyster predation and parasites 6. PSGNS| Warmer water temperatures have been linked to long-term decline in blue crab abundance and negative effects on white shrimp
Low	1. SAGWNPS| Increased evapotranspiration – compromised integrity of water bodies		

Stressor: Warmer Winters

Likelihood (probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High	1. ISG| **Potential for prolonged time period of bacterial/pathogen presence** 2. PSGCRE| **Increase plant productivity, vertical accretion, and carbon sequestration. This should accelerate as mangroves become more prominent** 3. PSGNS| **Proliferation of mangroves in Galveston Bay is likely if deep freezes occur less often**	1. SAGWBP| **Mosquito populations will not fall dormant as long with extended summers** 2. SAGWBP| **Increased violations of bacteriological standards.** 3. SAGWBP| **Criteria for discharging may not be met** 4. SAGWNPS| **Extended growing season leading to increased irrigation and runoff** 5. ISG| **Potential for prolonged Hurricane season**	1. PSGCRE| **Warm winters will enhance survival of insect pests.** 2. ISG| **Warmer winters impact on invasive species in Galveston Bay (loss of freeze)**
Medium	1. PSGNS| **Potentially more suitable for manatees and less cold stunning events for sea turtles**	1. ECG| **Increase in invasive species** 2. ISG| **Increased evapotranspiration - less freshwater inflow, less water availability** 3. PSGFI| **Increased evapotranspiration will increase salinity in upstream reaches** 4. PSGNS| **Warmer winters could expand range of invasive species; more temperate native species will move north** 5. PSGNS| **Increased salinity (from increased evaporation and decreased freshwater inflow) can impact the distribution, abundance, and productivity of native species** 6. PSGNS| **Oyster reef loss to dermo and drilling predators**	1. PSGFI| **Increased evapotranspiration will decrease freshwater inflows** 2. PSGNS| **Potential increase in pests affecting crops and native habitats and wildlife**
Low	1. PSGCRE| **Increased growing season could cause plant stress if they require a dormant period.**	1. SAGWNPS| **Eliminates freeze events that would normally prohibit long-term establishment of invasive species.** 2. SAGWNPS| **Warmer winters will lead to warmer water, increased likelihood of fecal indicator bacteria, and increased frequency of water quality violations.** 3. PSGNS| **Potential to increase return intervals for wildfires affecting vegetation structure and use by threatened or endangered species**	1. ISG| **Changes in communities to more tropical composition**

Stressor: Warmer Waters

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High	1. PSGCRE| **Increased water temperatures could cause changes in phytoplankton community composition**	1. ECG| **Increase in vibrio illnesses** 2. SAGWBP| **Increased bacterial growth, increasing bacteria load exceedances.** 3. ISG| **Warmer waters lead to increased bacteria & potentially other pathogens** 4. PSGCRE| **Increase in oyster predation and parasites**	1. ECG| **Heat Stress** 2. ECG| **Warmer waters lead to increased bacteria** 3. SAGWBP| **Increase in vibrio illnesses (increased communication on public health risks)** 4. ISG| **Increased evapotranspiration - less freshwater inflow; compromised water quality** 5. PSGCRE| **Decrease in dissolved oxygen** 6. PSGCRE| **Increased stratification** 7. PSGNS| **Warmer water could alter habitat distribution and lower dissolved oxygen in some area** 8. ISG| **Potential for more & stronger tropical storms/hurricanes**
Medium	1. ISG| **Warmer water may affect the dynamics of salinity stratification (and possibly circulation?) within the estuary (warmer water expands)** 2. ISG| **Reduction in nutrient loading and productivity of estuary**	1. ISG| **Changes in communities to more tropical composition** 2. PSGFI| **Increased evapotranspiration will increase salinity in upstream reaches** 3. PSGNS| **Oyster reef loss to dermo and oyster drilling predators** 4. PSGNS| **Correlation with drop in salinity and increase in lesions on bottlenose dolphins**	1. ISG| **Unknowns: how does warmer water impact phytoplankton community composition?** 2. PSGFI| **Increased evapotranspiration will decrease freshwater inflows**
Low	1. PSGCRE| **Defining habitat characteristics like pH may be affected by water temperature**	1. SAGWBP| **Warmer temperatures may increase toxicity of pollutants due to increased metabolism rates** 2. SAGWNPS| **Increased bacterial growth, increasing bacteria load exceedances.** 3. ISG| **More users on the water for prolonged time (extent of the year) increasing exposure to contaminants/potential minor spills through accidents of small boats**	

Stressor: Increasing Drought

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High	1. PSGCRE| changes to sediment loads 2. PSGCRE| loss of seasonal wetlands	1. SAGWBP| Pollutant concentrations increase (less dilution) 2. SAGWNPS| Pollutant concentrations increase 3. SAGWNPS| Increased soil shrinkage will cause pipes to shift and crack leading to greater inflow and infiltration (I&I). 4. ISG| Less inflow - decimation of upper bay assemblages - Rangia, Vallisneria and oysters due to increased parasitism 5. ISG| Prolonged reduced freshwater input has long-term effects 6. ISG| Increased salinity in brackish habitats + salinization of freshwater habitats --> loss of submerged aquatic veg 7. ISG| Increased chances of red & brown tides 8. PSGCRE| loss of ephemeral species and ephemeral habitats 9. PSGCRE| Loss of tree and vegetative cover 10. PSGNS| Sessile organism stress	1. SAGWBP| Increased Water conservation/ restrictions 2. SAGWNPS| Increased irrigation = increased runoff 3. PSGCRE| Increased evapotranspiration and/or decrease in freshwater inflows = increased salinity and decreases in oyster reef habitat 4. PSGCRE| loss of habitat for riparian spawning fish species 5. PSGFI| Increasing demand on water resources; decrease in discharge to Galveston Bay 6. PSGFI| Base flow in streams may decrease 7. PSGFI| Increase demand on groundwater = further reduction of base flow
Medium	1. ISG| Unknowns: does drought change habitat functionality?	1. ECG| Increase in tree loss 2. SAGWNPS| Increasing bacteria load (less dilution) 3. PSGCRE| Area of suitable habitat decreases and limited to upper portion of estuaries.	1. ECG| Decrease in water quality - less for dilution 2. PSGNS| Species may not tolerate new drought regimes 3. PSGNS| Increasing marine and invasive species including predators, parasites, and diseases 4. PSGNS| Increased favorable conditions for harmful algal blooms
Low	1. SAGWNPS| Older systems might have less pollution during a drought than a heavy rain event 2. PSGCRE| less water for restoration and enhancement	1. PSGNS| Increase in stranding events (e.g. marine mammals) and inundation of freshwater habitats. 2. PSGNS| Adverse effect for secretive marsh birds like rails in salt marshes if transition habitats not available. 3. PSGNS| Shifting vegetation community composition	

Stressor: Changes to Land Use and The Built Environment (Infrastructure)

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High		1. ECG| Increased impervious surfaces	1. IS| Increase in impervious surfaces leads to increased runoff of freshwater, will lead to more flashy system. Changes to land use and infrastructure (e.g., increase in impervious cover, increase in reservoir storage, reservoir operations, etc.) alter the quantity, timing, and duration of inflows.
Medium	1. ISG| Unknowns: how does conversion of agricultural land impact Galveston Bay?	1. SAGWNPS| Increase in impervious surfaces leads to increased runoff and alters pollutant pathways and residence time	1. PSGCRE| Increase in impervious surfaces leads to increased runoff and sediment loading instream and downstream estuary and covering of bottom plant communities 2. PSGCRE| Coastal barriers reduce tidal exchange and ultimately alter salinity and circulation patterns that influence habitats and the species inhabiting them 3. PSGCRE| Loss of native habitat due to development 4. PSGCRE| Reservoir operations can shift the timing and amount of peak inflows
Low		1. SAGWBP| Increased runoff 2. SAGWNPS| Loss of agriculture lands could change types and seasonality of NPS pollution	1. PSGCRE| Increased nutrient input and turbidity --> decrease in seagrass and oysters

Stressor: Increasing Inland Flooding (largely rain-based)

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High		1. SAGWNPS| May cause more septic systems to fail - lead to long-term pollutant load increase 2. ISG| Changes in inflow regime which affects oyster and other species 3. PSGCRE| movement of invasive species (+/-)	1. SAGWBP| Bacteria in flood waters 2. SAGWBP| Exposure to pollutants during flood 3. SAGWNPS| Could increase erosion of streambeds, increasing sedimentation and decreasing width of riparian corridors 4. PSGCRE| Increased stream erosion and sediment loads 5. PSGNS| Changes in shallow water habitat and secondary impacts on juvenile stages of estuarine and marine organisms 6. ISG| Correlation with increase in lesions on bottlenose dolphins
Medium		1. ISG| Unknowns: Impacts on estuarine wetland 2. ISG| Unknowns: how are superfund sites impacted by increased flooding? 3. PSGCRE| loss of habitat 4. PSGCRE| increase in frequency and intensity of decreased salinity events 5. PSGCRE| impacts for riparian fish spawning 6. PSGFI| Changes periodicity of freshwater inflows 7. PSGNS| Habitat loss, conversion, and migration hold implications for native species	1. SAGWNPS| Contaminated sites may flood and discharge offsite
Low	1. SAGWNPS| Increased runoff: short-term pollutant load increase 2. SAGWNPS| Potential for increased overtopping and "leaking systems" releasing more pollutants 3. PSGCRE| low light due to increased sediment load	1. PSGCRE| changes to nutrient supply 2. PSGFI| Changes seasonality of freshwater inflows 3. PSGNS| Potential adverse effect for secretive marsh birds like rails in salt marshes if transition habitats are not available	1. ECG| Wider spread of waterborne pathogens

Stressor: Increase in extreme events (coastal flooding/storm surge)

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High	1. SAGWNPS| **WWTF will go offline more often during intense events** 2. SAGWNPS| **Frequency of sanitary sewers infiltration events will increase (increased inundation of septic systems)**	1. ISG| **Reduction of positive impacts of freshwater inflow** 2. PSGCRE| **movement of invasive species** 3. PSGFI| **Changes periodicity of freshwater inflows**	1. ECG| **Increased flooding of property and habitat** 2. SAGWBP| **Bacteria in flood waters** 3. SAGWBP| **Exposure to pollutants during flood events** 4. SAGWNPS| **Increase in extent in tidal flooding could lead to new sources of pollution from floating tanks, runoff etc;** 5. ISG| **Potential for increased spills/contaminants entering the bay system** 6. PSGCRE| **Increased stream erosion and sediment loads** 7. PSGCRE| **loss of habitat**
Medium		1. PSGCRE| **increase in frequency and intensity of high salinity events** 2. PSGNS| **Habitat loss, conversion, and migration hold implications for native species**	1. ECG| **Stakeholders may not have funds & time to partner due to dealing with more events/damages, etc.** 2. ISG| **Unknowns: how do storms impact freshwater wetlands?** 3. PSGFI| **Accumulated impacts from other stressors (e.g., pollution)** 4. PSGNS| **Changes in shallow water habitat and secondary impacts on juvenile stages of estuarine and marine organisms**
Low	1. PSGCRE| **changes to nutrient supply**	1. PSGFI| **Changes seasonality of freshwater inflows** 2. PSGNS| **Potential adverse effect for secretive marsh birds like rails in salt marshes if transition habitats are not available**	

Stressor: Sea Level Rise + Subsidence

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High		1. ECG| Wetland loss 2. ISG| Reduction of positive impacts of freshwater inflow due to increased intrusion of saltwater. 3. ISG| Increase in bacteria levels from failing septic systems? 4. PSGCRE| changing spatial extent of available habitat	1. ECG| Increased flooding of property and habitat 2. SAGWBP| Greater coastal wetland losses could occur (less filtration) 3. SAGWNPS| Higher water tables/increase in extent in tidal flooding will drown coastal septic systems causing them to fail - lead to short-term and long-term pollutant load increases 4. SAGWNPS| Contaminated sites may flood or have shoreline erosion 5. SAGWNPS| Greater coastal wetland losses (less filtration) 6. PSGCRE| Increased extent of saline waters 7. PSGCRE| Changing light attenuation 8. PSGNS| Increased marsh flooding 9. PSGNS| changing spatial extent of available habitat 10. PSGNS| loss of restored and enhanced habitat due to drowning
Medium	1. ISG| Salinizes brackish areas --> increases the demand for freshwater to maintain salinity regimes	1. ISG| Increased extent of marine water may impact the freshwater balance of the bay 2. PSGCRE| habitat conversion to open water 3. PSGFI| Loss of wetlands could impact quality of freshwater inflows 4. PSGNS| Increased extent of saline waters	1. ECG| Increased storm surge 2. SAGWNPS| Potential increase of saltwater intrusion into wastewater pipelines, increasing water load and overwhelming water treatment capacity 3. PSGCRE| Increased marsh flooding 4. PSGFI| Less availability of groundwater (due to subsidence and saltwater intrusion) = more demand on surface water, decreased base flow 5. PSGNS| Changing light attenuation
Low			

Stressor: Chronic higher tides/nuisance flooding

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High		1. SAGWNPS|**Increase in extent in tidal flooding could lead to new sources of pollution** 2. ISG|**Unknowns: how do chronic higher tides impact restored wetlands** 3. PSGCRE|**Loss of outer marsh habitat; uncertainty of ability of wetland to migrate inland** 4. PSGCRE|**Habitat loss, conversion, and migration hold implications for native species** 5. PSGCRE|**May create unfavorable habitat conditions more frequently**	1. ECG|**Increased flooding of property and habitat** 2. SAGWNPS|**Increase in extent in tidal flooding could cause more septic systems and WWTF and lift stations to fail - lead to long-term pollutant load increase**
Medium		1. ISG|**Reduction of positive impacts of freshwater inflow due to increased intrusion of saltwater.**	1. SAGWNPS|**Potential increase of saltwater intrusion into wastewater pipelines, increasing water load and overwhelming water treatment capacity**
Low		1. ISG|**Increased influx of marine water on a more frequent basis may impact the freshwater balance**	1. PSGCRE|**Increase marsh habitat range further upslope**

Stressor: Acidification

Likelihood (probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High			1. PSGCRE | **Unknowns: Oysters in the Bay impacted by acidification** 2. **ECG| Unknowns: Loss of oyster reef habitat**
Medium	1. SAGWNPS| **Ocean Acidification will lead to decreased pH which could impact mobilization of pollutants (e.g. metals)**		
Low		1. ISG| **Healthy freshwater flows needed to maintain pH balance in bays** 2. ISG| **Estuary acidification increases when riverine alkalinity export is reduced. Then reduced alkalinity export from the bays can decrease the buffer capacity of adjacent coastal ocean against future acidification.** 3. ISG| **Unknowns: does acidification in Galveston Bay impact oyster reefs?**	1. PSGCRE| **Potential impacts on shellfish and other sedentary organisms that require calcium for exoskeleton**

Stressor: Population Increase

Likelihood (Probability of Occurrence)	Consequence: Low	Consequence: Medium	Consequence: High
High		1. ECG| **Increased resource demands** 2. SAGWNPS| **WWTF capacity may become an issue in already dense areas where expansion may be difficult.** 3. ISG| **Increased demand places more pressure on available supply.** 4. PSGCRE| **Increased recreational fishing pressure and trampling**	1. SAGWNPS| **Increased population leads to increase in sources of NPS pollutants** 2. PSGCRE| **Loss of native habitat to development**
Medium	1. ECG| **More people to educate and promote water conservation.**	1. SAGWNPS| **Increased quantity and decreased quality of stormwater from developed land VS undeveloped prairie or bottomland forest** 2. PSGCRE| **Impacts from possible increased human-caused pollution***	
Low			1. PSGCRE| **Increased nutrient input and turbidity --> decrease in seagrass and oysters**

Consequence/Probability Matrix by All Categories and Stressors

All Risks Grouped: High Consequence, High Likelihood

1. EC|ECG|NF|EE|SL| **Increased flooding of property and habitat**
2. EC|ECG|WS|WH| **Warmer waters lead to increased bacteria**
3. EC|ECG|WH|**Heat Stress**
4. SA|SAGWBP|EE|IF| **Bacteria in flood waters**
5. SA|SAGWBP|EE|IF| **Exposure to pollutants during flood events**
6. SA|SAGWBP|ID|**Increase need for water conservation and water restrictions**
7. SA|SAGWBP|SL|**Greater coastal wetland losses could occur (less filtration)**
8. SA|SAGWBP|WS|**Increased violations of bacteriological standards**
9. SA|SAGWBP|WH|**Increase in vibrio illnesses**
10. SA|SAGWNPS|NF|**Increase in extent in tidal flooding could cause more waste water infrastructure to fail**
11. SA|SAGWNPS|EE|**Increase in extent in tidal flooding could lead to new sources of pollution from floating tanks, runoff etc;**
12. SA|SAGWNPS|ID|**Increased human use of water for irrigation leading to increased runoff**
13. SA|SAGWNPS|IF|**Increase erosion of streambeds, increasing sedimentation reducing vegetated land available for filtration**
14. SA|SAGWNPS|PI|**Increased population leads to increase in sources of NPS pollutants**
15. SA|SAGWNPS|SL|**Higher water tables/increase in extent in tidal flooding will drown coastal septic systems causing them to fail**
16. SA|SAGWNPS|SL|**Contaminated sites may flood or have shoreline erosion**
17. SA|SAGWNPS|SL|**Greater coastal wetland losses (less filtration)**
18. SA|SAGWM{S|PA| **Unknowns: acidification in Galveston Bay impact oyster reefs**
19. IS|ISG|LU|**Changes to land use and infrastructure alter the quantity, timing, and duration of inflows.**
20. IS|ISG|EE|**Potential for increased spills/contaminants entering the bay**
21. IS|ISG|WS|**Increased evapotranspiration - less inflow, compromised water quality**
22. IS|ISG|WS|**Potential for more & stronger tropical storms/Hurricanes**
22. PS|PSGCRE|EE|IF| **Increased stream erosion and sediment loads**
23. PS|PSGCRE|EE|**Loss of habitat**
24. PS|PSGCRE|OA|**Unknown: Oysters in the Bay impacted by acidification**
25. PS|PSGCRE|ID|**Increased evapotranspiration and/or decrease in freshwater inflows - increased salinity, decreases in oyster reef**
26. PS|PSGCRE|ID|**Loss of habitat for riparian spawning fish**
27. PS|PSGCRE|PI|**Loss of native habitat to development**
28. PS|PSGCRE|SL|**Increased extent of saline waters**
29. PS|PSGCRE|SL|**Changing light attenuation**
30. PS|PSGCRE|WS|**Warmer summers could expand range of invasive species.**
31. PS|PSGCRE|WH|**Decrease in DO**
32. PS|PSGCRE|WH|**Increased stratification**
33. PS|PSGCRE|WW|**Warm winters enhance survival of insect pests.**
34. PS|PSGCRE|OA| **Unknown impacts regarding oysters and bay**
35. PS|PSGFI|ID|**Increasing demand on water resources; decrease in discharge to Galveston Bay**
36. PS|PSGFI|ID|**Base flow in streams may decrease**
37. PS|PSGFI|ID|**Increase demand on groundwater = further reduction of base flow**
38. PS|PSGFI|WS|**Increased evapotranspiration will decrease freshwater inflows**
39. PS|PSGNS|IF|**Changes in shallow water habitat and secondary impacts on juvenile stages of estuarine and marine organisms**
40. PS|PSGNS|SL|**Increased marsh flooding**
41. PS|PSGNS|SL|**changing spatial extent of available habitat**
42. PS|PSGNS|SL|**Loss of restored and enhanced habitat due to drowning**
43. PS|PSGNS|WH|**Warmer water could alter habitat distribution and lower dissolved oxygen in some area**

Consequence/Probability Matrix by All Categories and Stressors

All Risks Grouped: High Consequence, Medium Likelihood

1. EC|ECG|EE|**Stakeholders may not have funds & time to partner due to dealing with more events/damages, etc.**
2. EC|ECG|ID|**Decrease in water quality - less water for dilution**
3. EC|ECG|SL|**Increased storm surge**
4. SA|SAGWNPS|NF|PI| **Potential increase of saltwater intrusion into wastewater pipelines, increasing water load and overwhelming water treatment capacity**
5. SA|SAGWNPS|IF|**Contaminated sites may flood and discharge offsite**
6. IS|ISG|EE|**Unknowns: how do storms impact freshwater wetlands?**
7. IS|ISG|WS|**Changes in communities to more tropical composition**
8. IS|ISG|WH|**Unknowns: how does warmer water impact phytoplankton community composition?**
9. IS|ISG|WW|**Increased evapotranspiration - less freshwater inflow, less water availability**
10. PS|PSGCRE|LU|**Increase in impervious surfaces leads to increased runoff and sediment loading instream and downstream estuary and covering of bottom plant communities**
11. PS|PSGCRE|LU|**Coastal barriers reduce tidal exchange and ultimately alter salinity and circulation patterns that influence habitats and the species inhabiting them**
12. PS|PSGCRE|LU|**Loss of native habitat due to development**
13. PS|PSGCRE|SL|**Increased marsh flooding**
14. PS|PSGFI|LU|**Reservoir operations can shift the timing and amount of peak inflows**
15. PS|PSGFI|EE|**Accumulated impacts from other stressors (e.g., pollution)**
16. PS|PSGFI|SL|**Less availability of groundwater (due to subsidence and saltwater intrusion) = more demand on surface water, decreased base flow**
17. PS|PSGFI|WS|**Harmful algal blooms are more likely to develop in warm, salty water.**
18. PS|PSGFI|WH|WW|**Increased evapotranspiration will decrease freshwater inflows**
19. PS|PSGNS|EE|**Changes in shallow water habitat and secondary impacts on juvenile stages of estuarine and marine organisms**
20. PS|PSGNS|ID|**Species may not tolerate new drought regimes**
21. PS|PSGNS|ID|**Increasing marine and invasive species including predators, parasites, and diseases**
22. PS|PSGNS|ID|**Increased favorable conditions for harmful algal blooms**
23. PS|PSGNS|SL|**Changing light attenuation**
24. PS|PSGNS|WS|**Increased water temperatures would increase oyster predation and parasites**
25. PS|PSGNS|WS|**Warmer water temperatures have been linked to long-term decline in blue crab abundance and negative effects on white shrimp**
26. PS|PSGNS|WW|**Potential increase in pests affecting crops and native habitats and wildlife**
27. SA|SAGWBP|WS|**Increased heat stress (education)**
28. IS|ISG|WS|**Heat stress to native populations**

Consequence/Probability Matrix by All Categories and Stressors

All Risks Grouped: High Consequence, Low Likelihood

1. EC|ECG|IF|**Wider spread of waterborne pathogens**
2. IS|ISG|WW|**Changes in communities to more tropical composition**
3. PS|PSGCRE|LU|PI| **Increased nutrient input and turbidity --> decrease in seagrass and oysters**
4. PS|PSGCRE|NF|**increase marsh habitat range further upslope**
5. PS|PSGCRE|OA|**Potential impacts on shellfish and other sedentary organisms that require calcium for exoskeleton**
6. PS|PSGCRE|PI|**Increased nutrient input and turbidity --> decrease in seagrass and oysters**

Consequence/Probability Matrix by All Categories and Stressors

All Risks Grouped: Medium Consequence, High Likelihood

1. IS|ISG|WH|**Increased evapotranspiration - less freshwater inflow; compromised water quality**
2. EC|ECG|LU|**Increased impervious surfaces**
3. EC|ECG|PI|**Increased resource demands**
4. EC|ECG|SL|**Wetland loss**
5. EC|ECG|WS|**Heat stress**
6. EC|ECG|WS|WH| **Increase in vibrio illnesses**
7. SA|SAGWBP|SAGWNPS| ID|**Pollutant concentrations increase (less dilution)**
8. SA|SAGWBP|WH|WW|**Increased bacterial growth, increasing bacteria load violations.**
9. SA|SAGWBP|WW|**Mosquito populations will not fall dormant as long with extended summers**
10. SA|SAGWBP|WW|**Criteria for discharging may not be met**
11. SA|SAGWNPS|NF|**Increase in extent in tidal flooding could lead to new sources of pollution**
12. SA|SAGWNPS|ID|**Increased soil shrinkage will cause pipes to shift and crack leading to greater I&I.**
13. SA|SAGWNPS|IF|**May cause more septic systems to fail - lead to long-term pollutant load increase**
14. SA|SAGWNPS|PI|WWTF **capacity may become an issue in already dense areas where expansion may be difficult.**
15. SA|SAGWNPS|WS|**Using more water for irrigation leading to increased runoff**
16. SA|SAGWNPS|WS|**Increased likelihood of fecal indicator bacteria, and increased frequency of water quality violations**
17. SA|SAGWNPS|WW|**Extended growing season = increased irrigation/runoff**
18. IS|ISG|NF|**Unknowns: how do chronic higher tides impact restored wetlands**
19. IS|ISG|EE|**Reduction of positive impacts of freshwater inflow**
20. IS|ISG|ID|**Less freshwater inflow - decimation of upper bay assemblages - Rangia, Vallisneria and also bay wide oysters due to increased parasitism**
21. IS|ISG|ID|**Prolonged reduced freshwater input has long-term effects and impacts the time it takes for the inflow regime to return to "normal" conditions**
22. IS|ISG|ID|**Increased salinity in brackish habitats and freshwater habitats --> loss of submerged aquatic vegetation**
23. IS|ISG|ID|**Increased chances of red & brown tides**
24. IS|ISG|IF|**Changes in inflow regime which affects oyster and other species**
25. IS|ISG|PI|**Increased demand places more pressure on available supply.**
26. IS|ISG|SL|**Reduction of positive impacts of freshwater inflow due to increased intrusion of saltwater.**
27. IS|ISG|SL|**Increase in bacteria levels from failing septic systems**
28. IS|ISG|WS|WH|**Warmer waters lead to increased bacteria**
29. IS|ISG|WH|WW|**Potential for more & stronger tropical storms/Hurricane**
30. PS|PSGCRE|NF|**Loss of outer marsh habitat; uncertainty of ability of wetland to migrate inland**
31. PS|PSGCRE|NF|**Habitat loss, conversion, and migration impacts native species**
32. PS|PSGCRE|NF|**May create unfavorable habitat conditions more frequently**
33. PS|PSGCRE|EE|IF|**Movement of invasive species**
34. PS|PSGCRE|ID|**loss of ephemeral species and ephemeral habitats**
35. PS|PSGCRE|ID|**Loss of tree and vegetative cover**
36. PS|PSGCRE|PI|**Increased recreational fishing pressure and trampling**
37. PS|PSGCRE|SL|**changing spatial extent of available habitat**
38. PS|PSGCRE|WH|**Increase in oyster predation and parasites**
39. PS|PSGFI|EE|**Changes periodicity of freshwater inflows**
40. PS|PSGNS|ID|**Sessile organism stress**
41. IS|ISG|WW|**Warmer winters increase invasive species in Galveston Bay**

Consequence/Probability Matrix by All Categories and Stressors

All Risks Grouped: Medium Consequence, Medium Likelihood

1. EC|ECG|ID|**Increase in tree loss**
2. EC|ECG|WW|**Increase in invasive species**
3. SA|SAGWNPS|LU|**Increase in impervious surfaces leads to increased runoff and alters pollutant pathways and residence time**
4. SA|SAGWNPS|ID|**Increasing bacteria load (less dilution)**
5. SA|SAGWNPS|PI|**Increased quantity and decreased quality of stormwater from developed land VS undeveloped prairie or bottomland forest**
6. IS|ISG|NF|**Reduction of positive impacts of freshwater inflow due to increased intrusion of saltwater.**
7. IS|ISG|IF|**Unknowns: Impacts on estuarine wetland habitat**
8. IS|ISG|IF|**Unknowns: how are superfund sites impacted by increased flooding?**
9. IS|ISG|SL|**Increased extent of marine water may impact the freshwater balance of the bay**
10. IS|ISG|WS|**Essential food sources may die off – food web impacts**
11. IS|ISG|WS|**Unknowns: do warmer summers impact oyster reefs?**
12. IS|ISG|WH|**Changes in communities to more tropical composition**
13. PS|PSGCRE|EE|**Increase in frequency and intensity of high salinity events**
14. PS|PSGCRE|ID|**Area of suitable habitat decreases and limited to upper portion of estuaries**
15. PS|PSGCRE|IF|**Loss of habitat**
16. PS|PSGCRE|IF|**Increase in frequency and intensity of decreased salinity events**
17. PS|PSGCRE|IF|**Impacts for riparian fish spawning**
18. PS|PSGCRE|IF|**Impacts for salinity and bottlenose dolphins**
19. PS|PSGCRE|IF|**Impacts for salinity and sea turtles**
20. PS|PSGCRE|PI|**Impacts from possible increased human-caused pollution**
21. PS|PSGCRE|SL|**habitat conversion to open water**
22. PS|PSGFI|IF|**Changes periodicity of freshwater inflows**
23. PS|PSGFI|SL|**Loss of wetlands could impact quality of freshwater inflows**
24. PS|PSGFI|WS|WH|WW|**Increased evapotranspiration will increase salinity in upstream reaches**
25. PS|PSGNS|EE|IF|**Habitat loss, conversion, and migration hold implications for native species**
26. PS|PSGNS|SL|**Increased extent of saline waters**
27. PS|PSGNS|WS|**Heat stress to native populations and metabolic costs/mortality; changes to food webs**
28. PS|PSGNS|WS|WW|**Increased salinity (from increased evaporation and decreased freshwater inflow) can impact the distribution, abundance, and productivity of native species**
29. PS|PSGNS|WS|**Life cycle stages (e.g., spawning) is influenced by environmental cues such as temperature**
30. PS|PSGNS|WS|**Shifts in fisheries populations, likely continued decreases in flounder but potential increases in range for snook and pompano**
31. PS|PSGNS|WH|WW|**Oyster reef loss to dermo and oyster drilling predators**
32. PS|PSGNS|WH|**Correlation with drop in salinity and increase in lesions on bottlenose dolphins**
33. PS|PSGNS|WW|**Warmer winters could expand range of invasive species; more temperate native species will move north**

Consequence/Probability Matrix by All Categories and Stressors

All Risks Grouped: Medium Consequence, Low Likelihood

1. SA|SAGWBP|LU|**Increased runoff**
2. SA|SAGWBP|WH|**Warmer temperatures may increase toxicity of pollutants due to increased metabolism rates**
3. SA|SAGWNPS|LU|**Loss of agriculture lands could change types and seasonality of NPS pollution**
4. SA|SAGWNPS|WH|**Increased bacterial growth, increasing bacteria load violations**
5. SA|SAGWNPS|WW|**Eliminates freeze events that would normally prohibit long-term establishment of invasive species**
6. SA|SAGWNPS|WW|**Warmer winters will lead to warmer water, increased likelihood of fecal indicator bacteria, and increased frequency of water quality violations**
7. IS|ISG|NF|**Increased influx of marine water on a more frequent basis may impact the freshwater balance**
8. IS|ISG|OA|**Healthy freshwater flows needed to maintain pH balance in bays**
9. IS|ISG|OA|**Estuary acidification increases when riverine alkalinity export is reduced. Then reduced alkalinity export from the bays can decrease the buffer capacity of adjacent coastal ocean against future acidification**
10. IS|ISG|OA|**Unknowns: does acidification in Galveston Bay impact oyster reefs?**
11. IS|ISG|WH|**More users on the water for prolonged time (extent of the year) increasing exposure to contaminants/potential minor spills through accidents of small boats**
12. PS|PSGCRE|IF|**Changes to nutrient supply**
13. PS|PSGFI|EE|IF **Changes seasonality of freshwater inflows**
14. PS|PSGNS|EE|IF|ID|**Potential adverse effect for secretive marsh birds like rails in salt marshes if drier transition habitats are not available**
15. PS|PSGNS|ID|**Increase in stranding events (e.g. marine mammals) and inundation of freshwater habitats**
16. PS|PSGNS|ID|**Shifting vegetation community composition**
17. PS|PSGNS|WW|**Potential to increase return intervals for wildfires affecting vegetation structure and use by threatened or endangered species**

Consequence/Probability Matrix by All Categories and Stressors

All Risks Grouped: Low Consequence, High Likelihood

1. SA|SAGWNPS|EE|WWTF **offline more often during intense events**
2. SA|SAGWNPS|EE|**Frequency of sanitary sewers infiltration events will increase SA|SAGWNPS|IF|Increased runoff from event will lead to short-term pollutant load increase**
3. SA|SAGWNPS|IF|**Potential for increased overtopping and "leaking systems"**
4. EC|ECG|PI|**More people to educate and promote water conservation.**
5. IS|ISG|WW|**Potential for prolonged time period of bacterial/pathogen presence**
6. PS|PSGCRE|ID|**Changes to sediment loads**
7. PS|PSGCRE|ID|**Loss of seasonal wetlands**
8. PS|PSGCRE|IF|**Low light due to increased sediment load**
9. PS|PSGCRE|WS|**Increased evapotranspiration which could lead to aquatic/subtidal species composition change**
10. PS|PSGCRE|WS|WW|**Increased plant productivity, vertical accretion, and carbon sequestration.**
11. PS|PSGCRE|WH|**Increased water temperatures could cause changes in phytoplankton community composition**
12. PS|PSGNS|WW|**Proliferation of mangroves in Galveston Bay is likely if deep freezes occur less often**

All Risks Grouped: Low Consequence, Medium Likelihood

1. SA|SAGWNPS|OA|**Ocean Acidification will lead to decreased pH which could impact mobilization of pollutants (e.g. metals)**
2. IS|ISG|LU|**Unknowns: how does conversion of agricultural land impact Galveston Bay?**
3. IS|ISG|ID|**Unknowns: does drought change habitat functionality?**
4. IS|ISG|SL|**Salinizes brackish areas --> increases the demand for freshwater to maintain salinity regimes**
5. IS|ISG|WH|**Warmer water may affect the dynamics of salinity stratification (and possibly circulation?) within the estuary (warmer water expands)**
6. IS|ISG|WH|**Reduction in nutrient loading and productivity of estuary**
7. PS|PSGNS|WW|**Potentially more suitable for manatees and less cold stunning events for sea turtles**

All Risks Grouped: Low Consequence, Low Likelihood

1. SA|SAGWNPS|ID|**Older leaking systems have less pollution w/decreased rainfall**
   SA|SAGWNPS|WS|**Increased evapotranspiration – compromised integrity of water bodies**
2. IS|ISG|PI|**NPS pollution increase**
3. PS|PSGCRE|EE|**Changes to nutrient supply**
4. PS|PSGCRE|ID|**Availability of water for restoration and enhancement**
5. PS|PSGCRE|WH|**Defining habitat characteristics like pH may be affected by water temperature**
6. PS|PSGCRE|WW|**Increased growing season could cause plant stress if they require a dormant period**
7. SA|SAGWNPS|OA|**Ocean Acidification will lead to decreased pH which could impact mobilization of pollutants (e.g. metals)**
8. IS|ISG|LU|**Unknowns: how does conversion of agricultural land impact Galveston Bay?**
9. IS|ISG|ID|**Drought changes habitat functionality**
10. IS|ISG|SL|**Salinizes brackish areas --> increases the demand for freshwater to maintain salinity regimes**
11. IS|ISG|WH|**Warmer water may affect the dynamics of salinity stratification**
12. IS|ISG|WH|**Reduction in nutrient loading and productivity of estuary**
13. PS|PSGNS|WW|**Potentially more suitable for manatees and less cold stunning events for sea turtles**