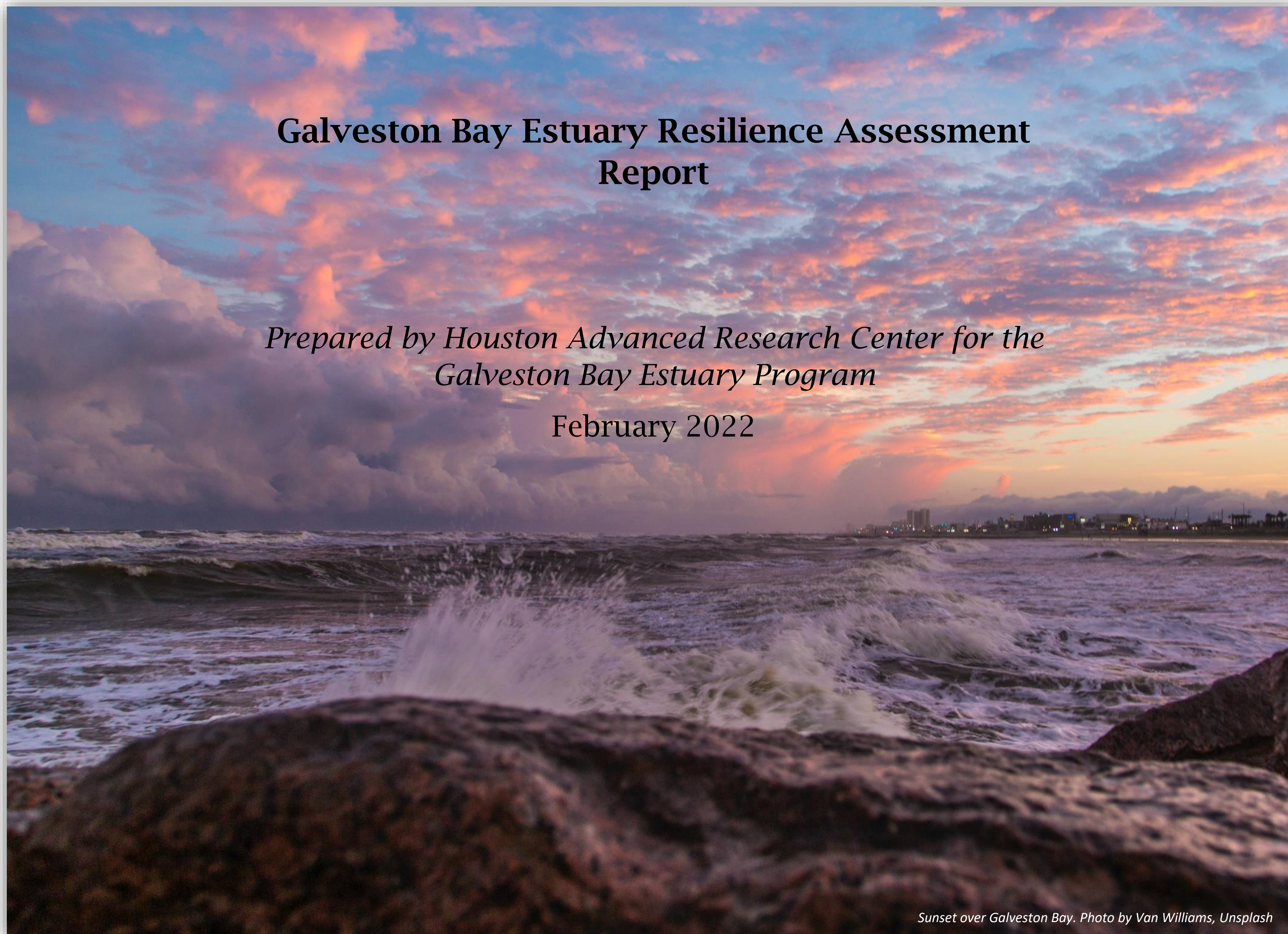
# Galveston Bay Estuary Resilience Assessment Report

*Prepared by Houston Advanced Research Center for the Galveston Bay Estuary Program*

February 2022



*Sunset over Galveston Bay. Photo by Van Williams, Unsplash*

# Texas Commission on Environmental Quality (TCEQ) Grant Agreement 582-19-90217

## Estuary Resilience Assessment

### Deliverable: Final Galveston Bay Estuary Resilience Assessment

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*Prepared by*
Geotechnology Research Institute
Houston Advanced Research Center (HARC)
Dr. Stephanie Glenn and Dr. Erin Kinney
8801 Gosling Drive
The Woodlands, Texas 77381

*Prepared for*

TCEQ
Galveston Bay Estuary Program (GBEP)
Lindsey Lippert, Project Manager
17041 El Camino Real, Ste. 210
Houston, Texas 77058

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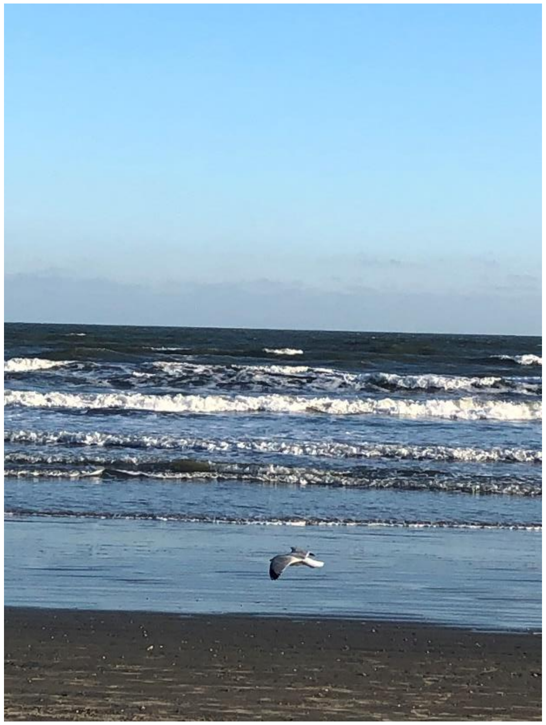

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A PROGRAM OF THE TCEQ

*The Galveston Bay Estuary Resilience Assessment is a stakeholder-driven project; the ideas and thoughts on stressors, risks, and management strategies were generated by stakeholders in the expert work group and do not necessarily reflect the official policy or position of TCEQ.*

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 in the future. 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 Assessment is a stakeholder-driven project with the purpose of assessing a series of coastal resilience criteria against the goals, objectives, and actions in *The Galveston Bay Plan, 2nd Edition* (GBP). This report is meant to compliment the GBP and provide resiliency adaptation recommendations for implementers of the GBP. This report was developed in coordination with subject matter experts and members of the Galveston Bay Council (GBC) and its subcommittees through a series of workshops with questions and discussion topics. For guidance, see the U. S. Environmental Protection Agency's (EPA) "Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans."

HARC established a work group of stakeholder experts to obtain input used in the development of a vulnerability assessment focused on coastal resilience. The group consisted of relevant representatives and subject matter experts from the GBC, subcommittees, and other 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 Comprehensive Conservation and Management Plan for GBEP. The work group 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

[1] https://oceanservice.noaa.gov/ecosystems/resilience/

**Table 1: Galveston Bay Estuary Resilience Assessment Work Group**

| ***Organization*** | ***Expertise*** |
|---|---|
| **USGS** | Water Resources |
| **EIH-UHCL** | Water Resources/Ecology |
| **TPWD** | Habitat Restoration |
| **GBF** | Restoration |
| **TAMU AgriLife Ext** | Habitat ecology |
| **H-GAC** | Water Quality |
| **TPWD** | Estuarine ecology |
| **TPWD** | Kills and Spills |
| **USFWS** | Estuarine ecology/restoration/conservation |
| **TAMUG** | Relative sea level rise |
| **TAMU** | Relative sea level rise & 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** | SLAMM, marine spatial planning |

Environmental Institute of Houston at the University of Houston Clear Lake (EIH-UHCL), Texas A&M University (TAMU), US 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, including water resources, habitat restoration, wetlands, social systems, and relative sea level rise. A complete list is included in Table 1.

An initial invitational facilitated work group meeting was held to provide an overview and purpose of the project and ask for stakeholder input from participants. The purpose of the initial meeting was to gain local perspectives and information and identify concerns or interests to the work group 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 Assessment, which involved identifying GBEP organizational goals susceptible to estuary stressors. The work group identified all the GBP priorities/goals as susceptible to estuary stressors (Table 2) (see Appendix A for the complete details on GBP Priorities). This initial brainstorming session focused on input and information on the Galveston Bay Estuary Resilience Assessment, providing participants an opportunity to identify, list, and provide feedback on the GBP priorities/goals, risk identification, and potential stressors.

| Table 2: GBP Priorities/Goals |
| --- |
| **Engage Communities** |
| **Ensure Safe and Aquatic Human Use: Increase public awareness of current public health risks/Reduce risk through watershed-based plans (WBPs)** |
| **Ensure Safe and Aquatic Human Use: Reduce NPS and 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** |

The work group 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 priorities/goals. The work group identified and defined eleven estuary stressors through this brainstorming session (Figure 1) that the work group thought were impactful when discussing coastal resilience. The following stressors are the ones that the group determined Galveston Bay is facing now and/or in the future. ***Changes to land use and the built environment (infrastructure)*** is linked to population increase, but distinct from it in order to focus on changes to the land. ***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 lead to 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.

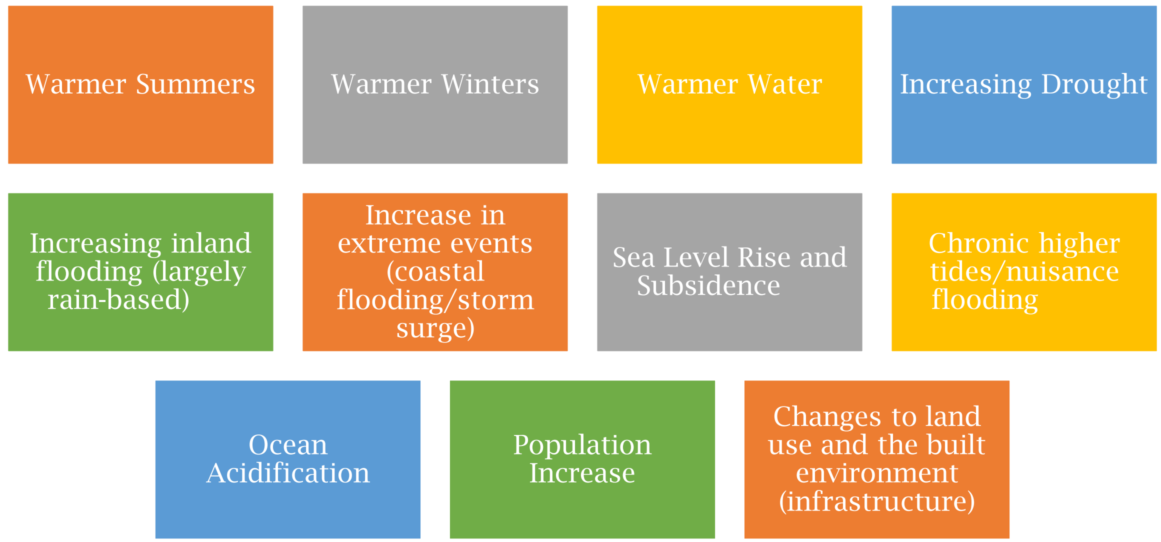



*Figure 1 The work group identified 11 estuary stressors facing Galveston Bay now and in the future*

For each of the stressors, risks from the stressor on meeting the GBP priority were identified. So, for example, stakeholders were asked to consider: For the GBP priority/goal of Ensure Safe and Aquatic Human Use: Reduce NPS and PS (including WWTF 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 work group 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 – comprised integrity of water bodies.

The next step for the work group was to take the stressors and risks developed during the initial work group meeting and follow-ups, and convene for a second work group meeting to develop the risk analysis, which included selecting risks and stressors identified in the initial workshop and characterizing each risk to make an initial determination of consequence (impact) and probability (likelihood) of each risk. Risks were ranked on a qualitative scale for consequence and probability. For example, for the GBP priority/goal of Ensure Safe and Aquatic Human Use: Reduce NPS and PS (including WWTF and sanitary sewer system) Pollution, and the stressor of Warmer Summers, the work group 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 and may not be attainable. The results from each work group meeting were then developed into a series of consequence/probability matrices. For each GBP priority/goal, the probabilities and consequences for each stressor/risk are 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: red and Example B: yellow). Hexagons provide further explanation of how consequences and probabilities were determined in the red example.

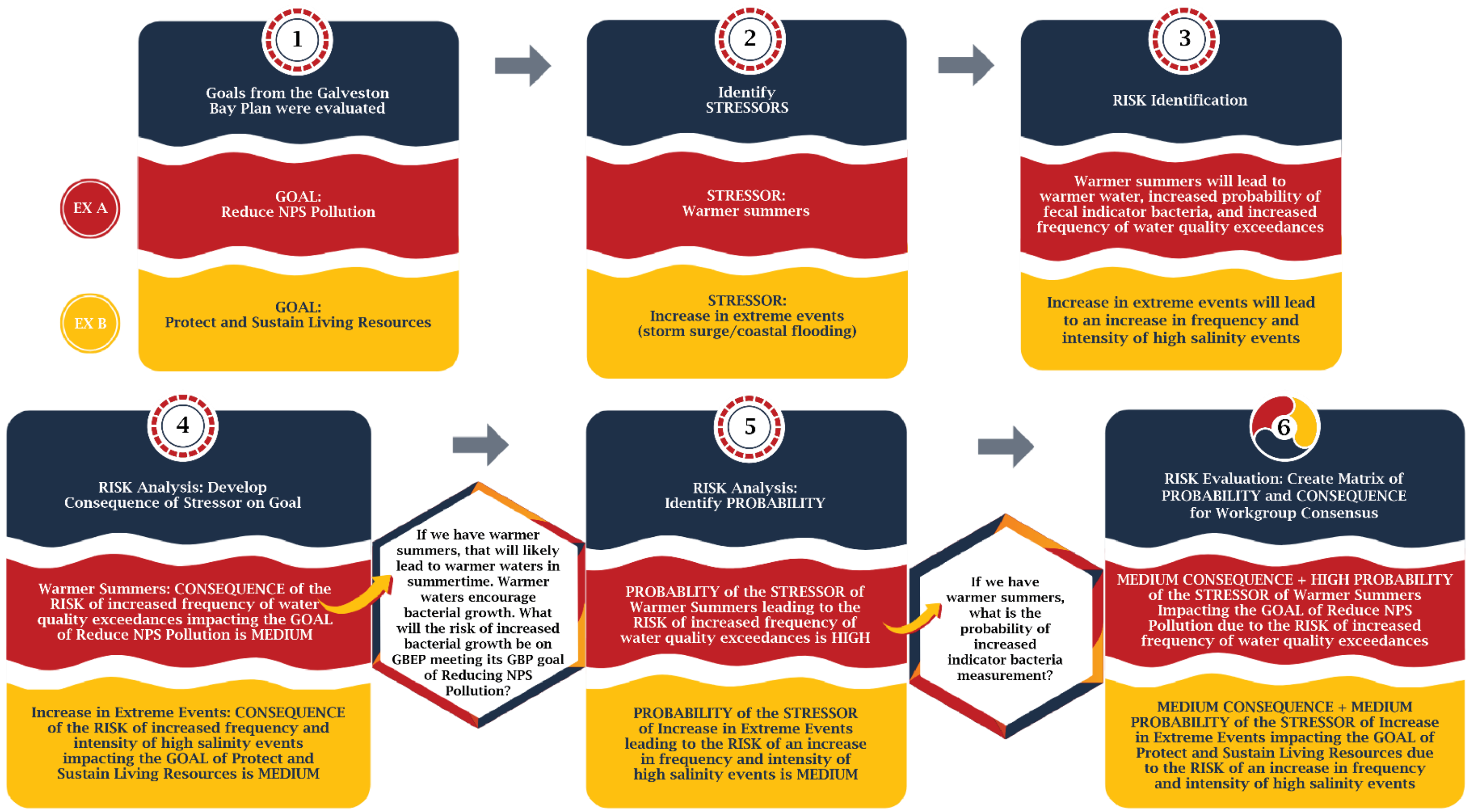



*Figure 2 Flow Diagram of two examples from Goal to Consequence/Probability Development*

A series of draft consequence/probability matrices for the risks identified during the second work group meeting were prepared and presented to the work group in a final work group meeting for the work group to review and provide input on the draft consequence/probability matrices. The resulting series of consequence/probability matrices were developed over 18 months through three expert stakeholder work group meetings and targeted one-on-one stakeholder follow-up discussions. Through 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 Assessment were generated by stakeholders in the expert work group to reflect the most likely impacts to Galveston Bay based on their years of research and experience working in the region. Figure 3 details the steps taken by the work group during the development of the Galveston Bay Estuary Resilience Assessment.

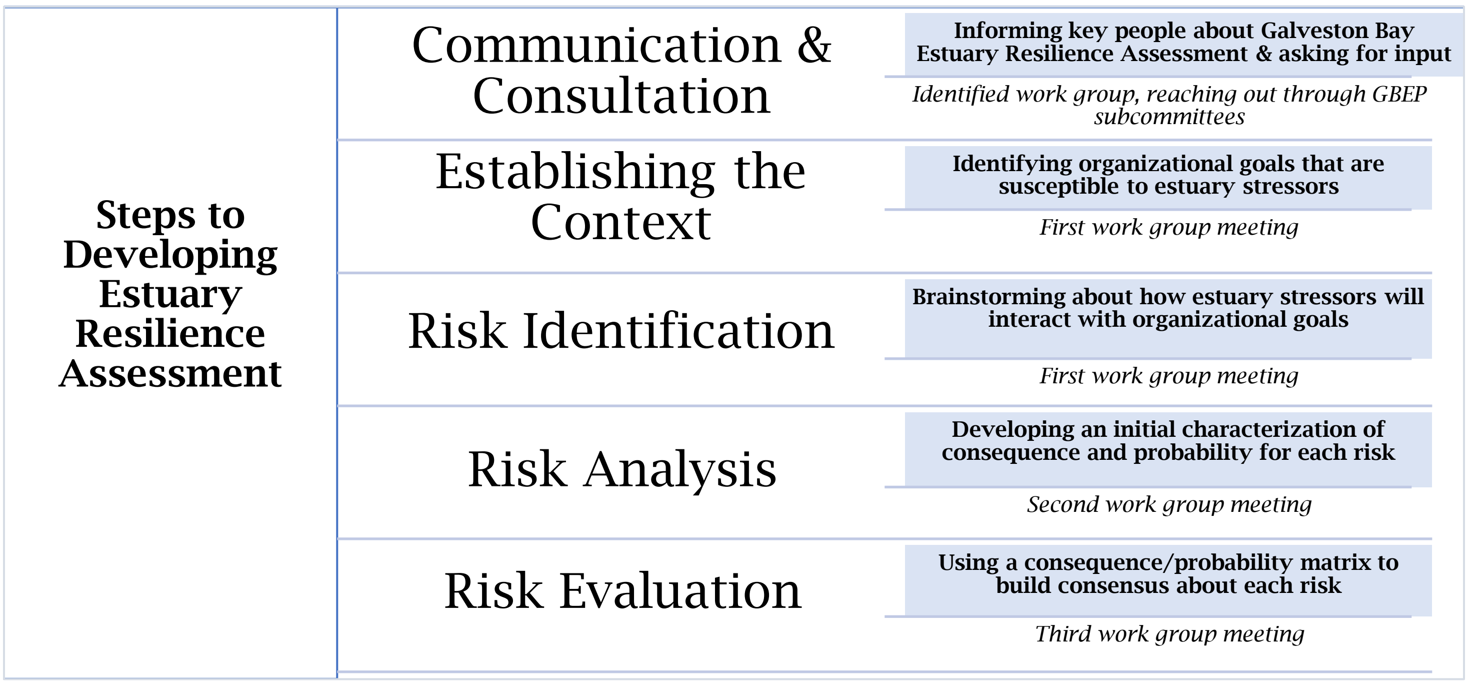



*Figure 3 Outline of Steps undertaken by the work group*

In order to develop the Galveston Bay Estuary Resilience Assessment, stakeholders in the expert work group progressed through the steps above for 15 GBP goals and 11 estuary stressors suggested by the work group as the most likely to impact Galveston Bay (Table 2 and Figure 1). The creation of the consequence/probability matrix required five components as outlined in Figure 3: Use of **priorities/goals** from each of the GBP priorities (Table 2).

1. Identification of estuary **stressors** that Galveston Bay will be facing now and in the future (identified by the work group stakeholders) (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 Priority/Goal** (Figure 4). 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 work group identified a stressor of Land Use Change. One of the risks the work group identified for the stressor of Land Use Change was Increased Impervious Surfaces. The work group 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 4, for all stressors associated with Nuisance Flooding, Increasing Extreme Event Flooding, and Relative Sea Level Rise, the work group 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 5 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 planning decisions. The matrices could be used as part of risk evaluation (assessing risks to determine which ones an organization will move forward with in the action planning process), finding and selecting adaptation actions and, possibly, developing a risk-based adaptation 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 priority/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 4: 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**<br>2. Population Increase\| **Increased resource demands**<br>3. Relative Sea Level Rise\| **Wetland loss**<br>4. Warmer Summers\| **Heat stress**<br>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**<br>2. Warmer Summers\|Warmer Waters\| **Warmer waters lead to increased bacteria**<br>3. Warmer Water\| **Heat Stress** |
| Medium | | 1. Increasing Drought\| **Increase in tree loss**<br>2. Warmer Winters\| **Increase in invasive species** | 1. Increasing Extreme Event Flooding\| **Stakeholders may not be able to deal with more events/damages**<br>2. Increasing Drought\| **Decrease in water quality**<br>3. Relative Sea Level Rise\| **Increased storm surge** |
| Low | | | 1. Increasing Inland Flooding\| **Wider spread of waterborne pathogens**<br>2. Ocean Acification\| **Loss of oyster reef habitat** |

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

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

## GBP Priority/Goal: Ensure Safe and Aquatic Human Use: Reduce NPS and PS (including WWTF and sanitary sewer system) pollution

| Likelihood (Probability of Occurrence) | Low | Medium | High |
|---|---|---|---|
| **High** | 1. Increasing Extreme Event Flooding\| **WWTF will go offline more often**<br>2. Increasing Extreme Event Flooding\| **Frequency of sanitary sewers infiltration events will increase**<br>3. Increasing Inland Flooding\| **Increased runoff from events will lead to pollutant load increase**<br>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**<br>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**<br>2. Increasing Extreme Event Flooding\| **New sources of pollution**<br>3. Increasing Drought\| **Increased water usage**<br>4. Increasing Inland Flooding\| **Could increase erosion of streambeds**<br>5. Population Increase\| **Increased population leads to increase in sources of NPS pollutants**<br>6. Relative Sea Level Rise\| **High water tables will drown coastal septic systems causing them to fail**<br>7. Relative Sea Level Rise\| **Contaminated sites may flood**<br>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**<br>2. Increasing Drought\| **Increasing bacteria load**<br>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**<br>2. Warmer Summers\| **Increased evapotranspiration** | 1. Warmer Waters\| **Increased bacterial growth, Increasing bacteria load exceedances**<br>2. Warmer Winters\| **Eliminates freeze events**<br>3. Warmer Winters\| **Lead to warmer water, increased likelihood of fecal indicator bacteria and water quality exceedances** | |
| | **Consequence** | | |

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

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

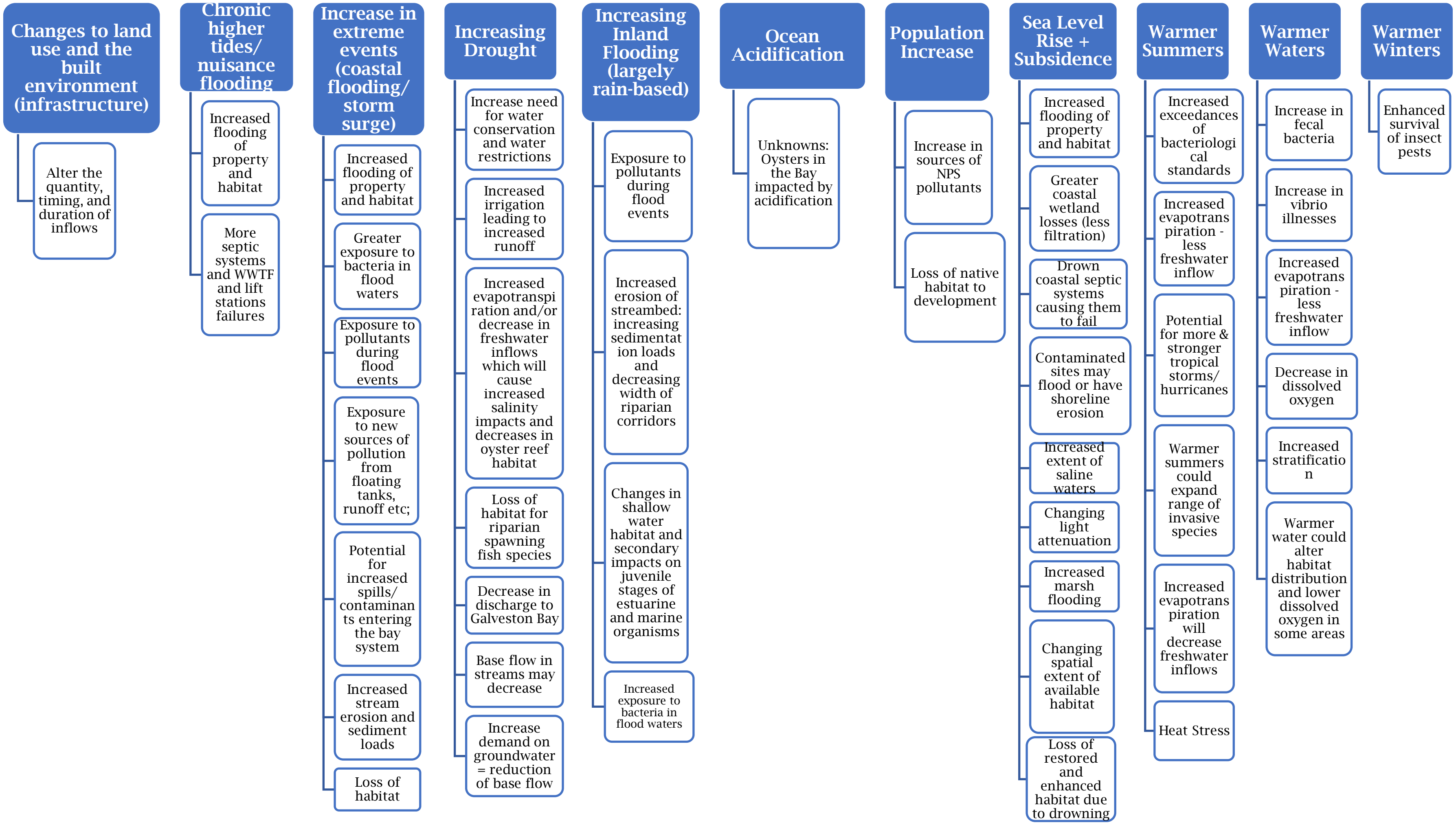
| Likelihood (Probability of Occurrence) | Low | Medium | High |
|---|---|---|---|
| **High** | | 1. Increasing Extreme Event Flooding\| **Changes periodicity of freshwater inflows** | 1. Increasing Drought\| **Increasing demand on water resources; decrease in discharge to Galveston Bay**<br>2. Increasing Drought\| **Base flow in streams may decrease**<br>3. Increasing Drought\| **Increase in demand on groundwater = further reduction of base flow**<br>4. Warmer Summers\| **Increased evapotranspiration will decrease freshwater inflows** |
| **Medium** | | 1. Increasing Extreme Event Flooding\| **Changes periodicity of freshwater inflows**<br>2. Relative Sea Level Rise\| **Loss of wetlands could impact quality of freshwater inflows**<br>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**<br>2. Increasing Extreme Event Flooding\| **Accumulated impacts from other stressors**<br>3. Relative Sea Level Rise\| **Less availability of groundwater = more demand on surface water, decreased base flow**<br>4. Warmer Summers\| **Harmful algal blooms are more likely to develop in warm, salty water**<br>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** | |

**Consequence**

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

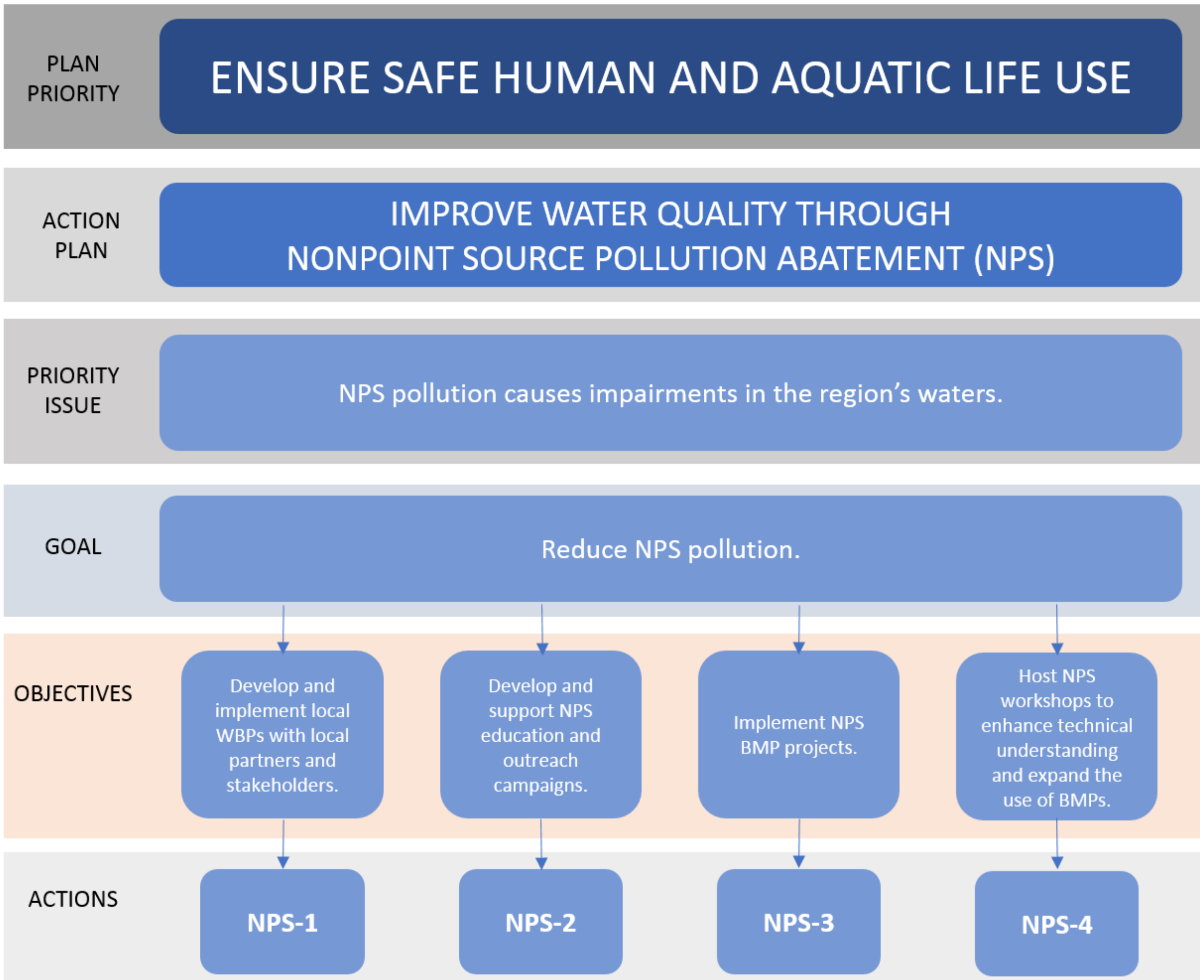
| Likelihood (Probability of Occurrence) | Consequence: Low | Consequence: Medium | Consequence: High |
|---|---|---|---|
| **High** | 1. Warmer Winters\| **Proliferation of mangroves in Galveston Bay is likely if deep freezes occur less often** | 1. Increasing Drought\| **Sessile organism stress** |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

Figure 5 Overall High Consequence and High Probability Risks

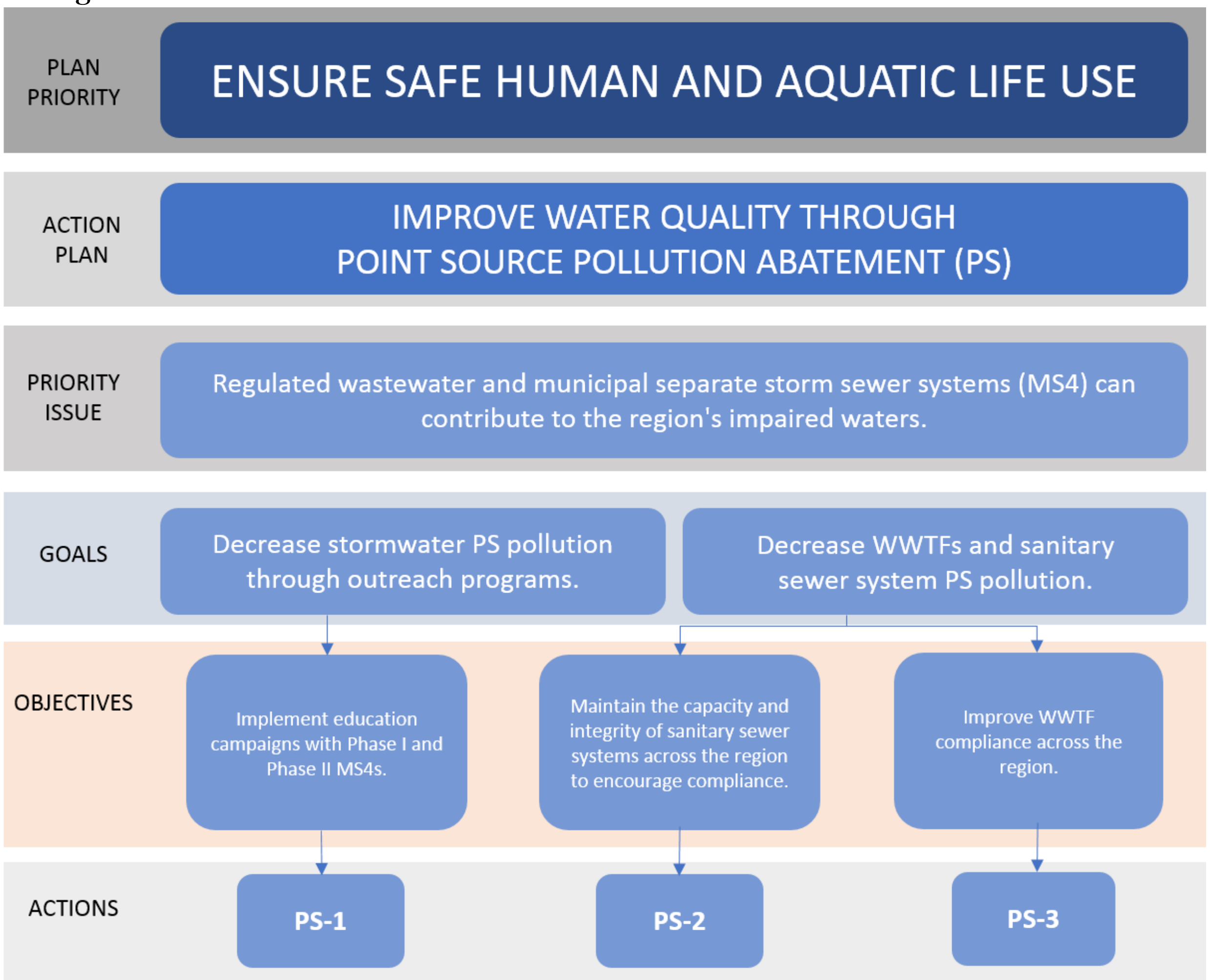


*Appendix A: Galveston Bay Plan - Plan Priorities and Action Plans (Figures from the Galveston Bay Plan, 2nd edition, **https://gbep.texas.gov/galveston-bay-plan/** )*

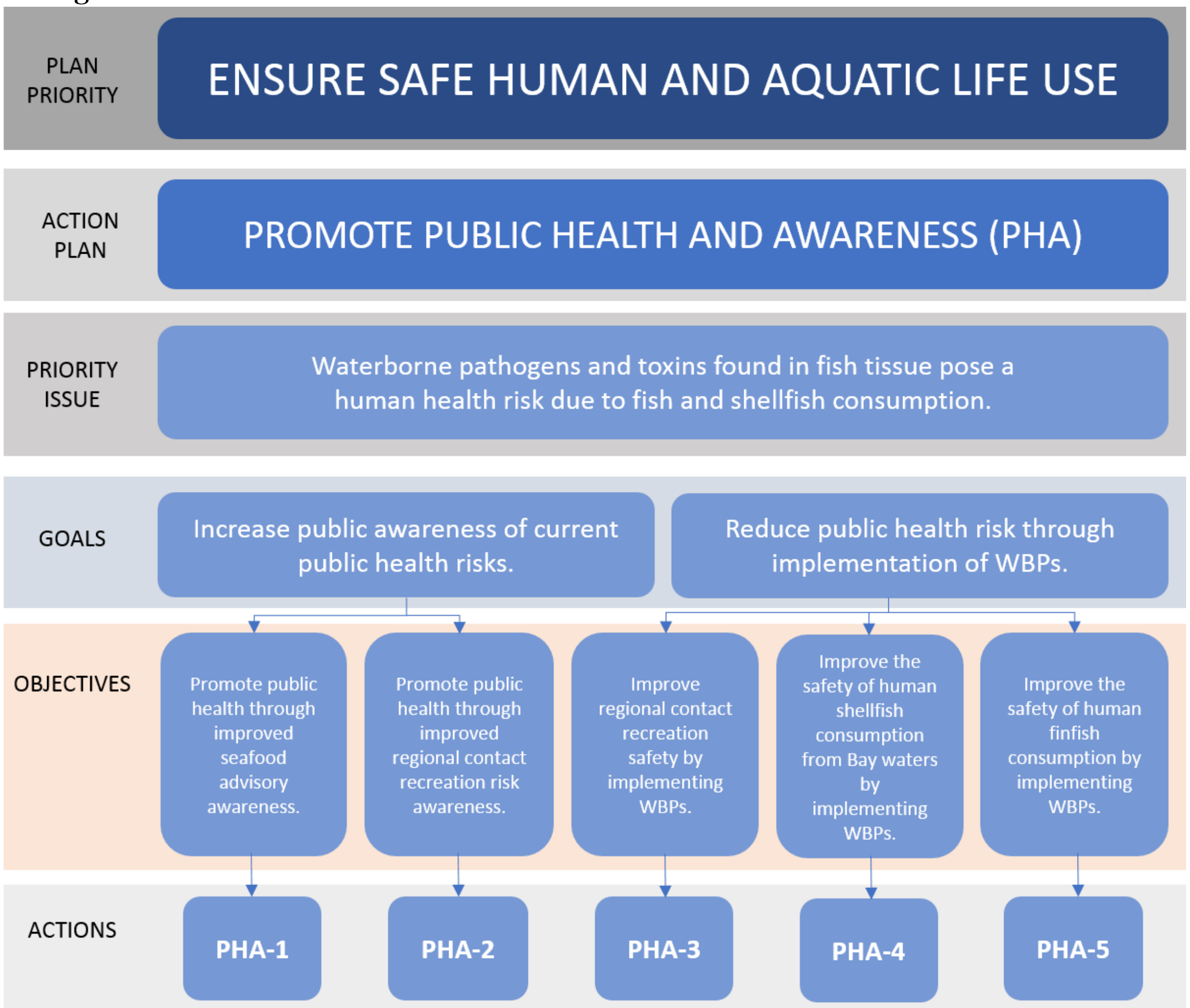
GBP Figure 12. Nonpoint Source Action Plan



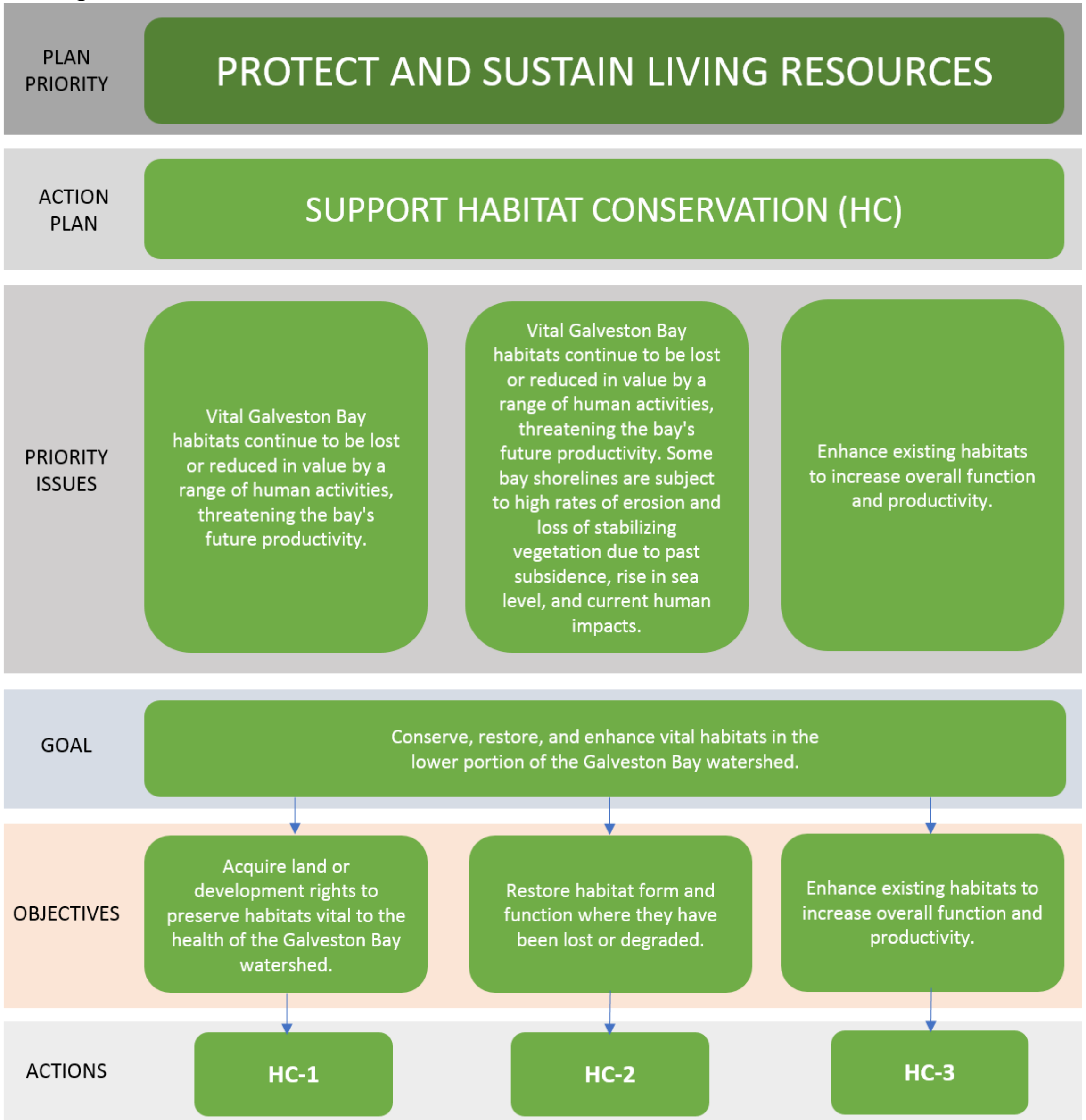
GBP Figure 15. Point Source Action Plan



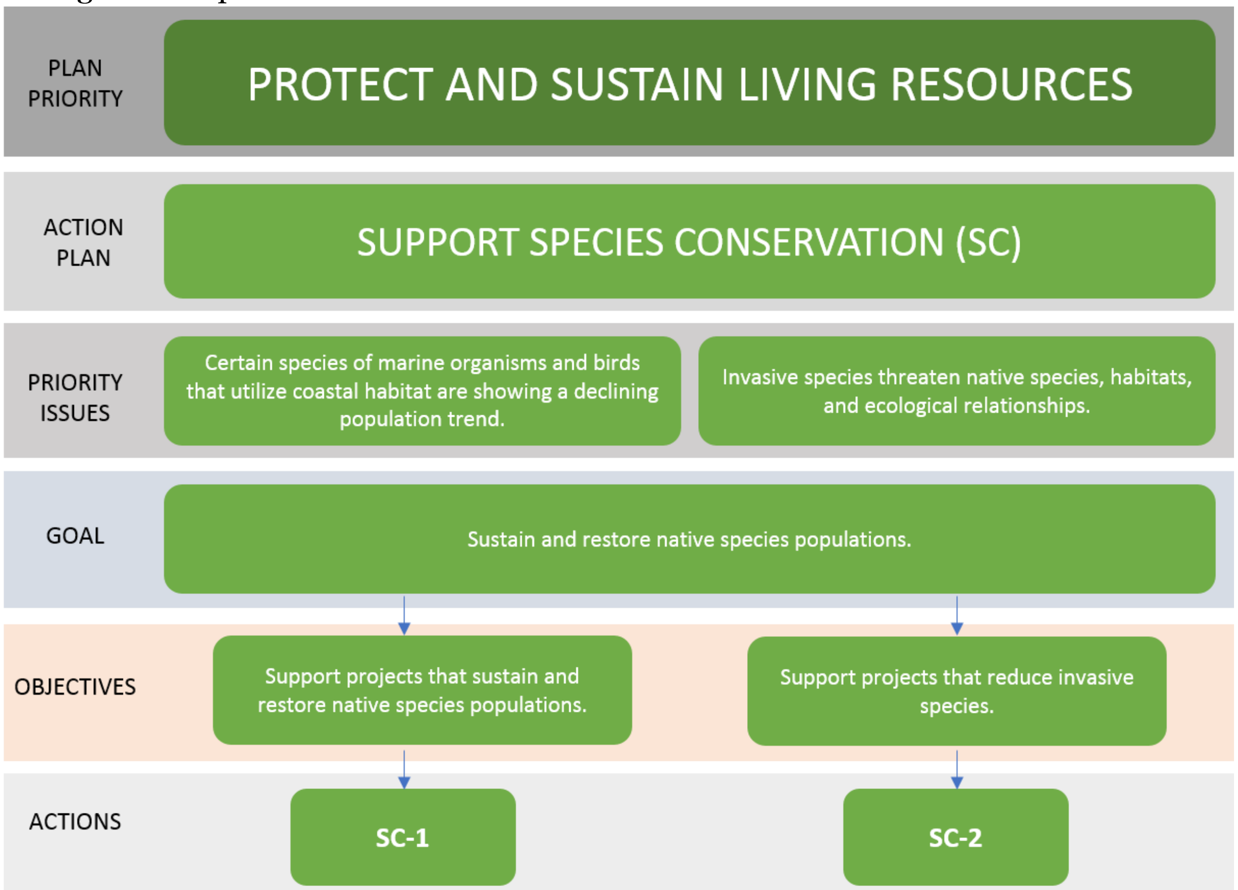
GBP Figure 17. Public Health Awareness Action Plan



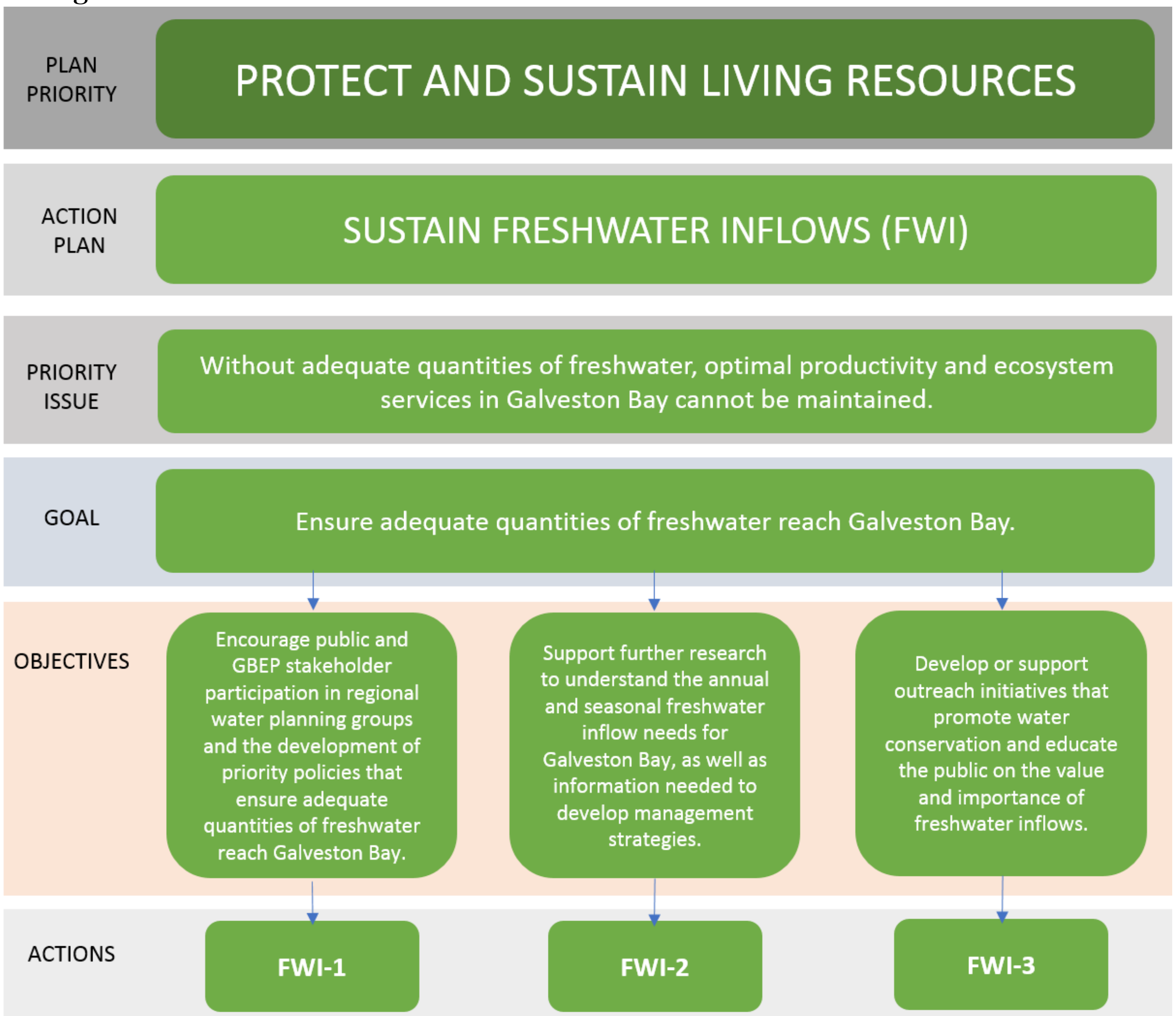
GBP Figure 21. Habitat Conservation Action Plan



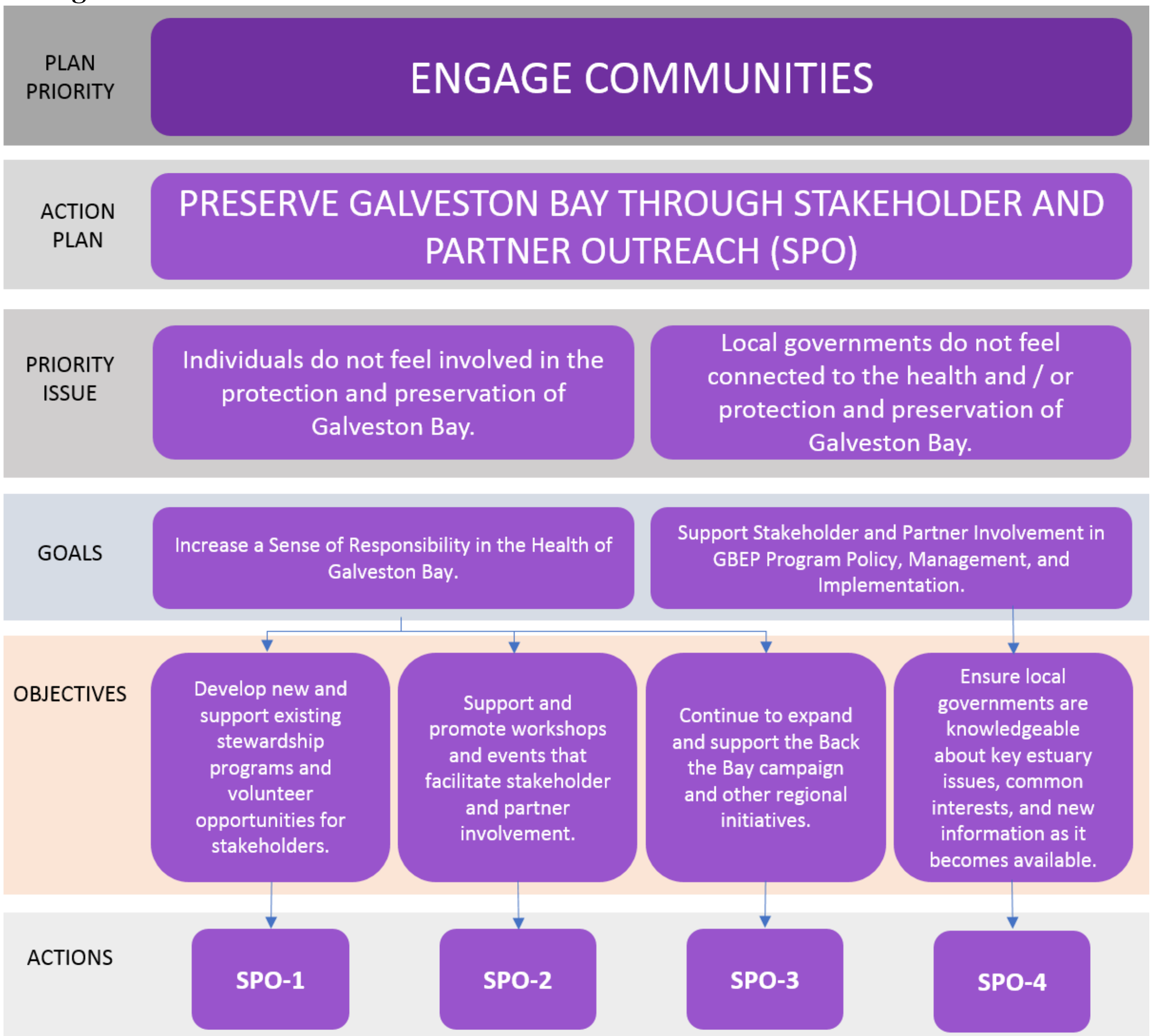
GBP Figure 23. Species Conservation Action Plan



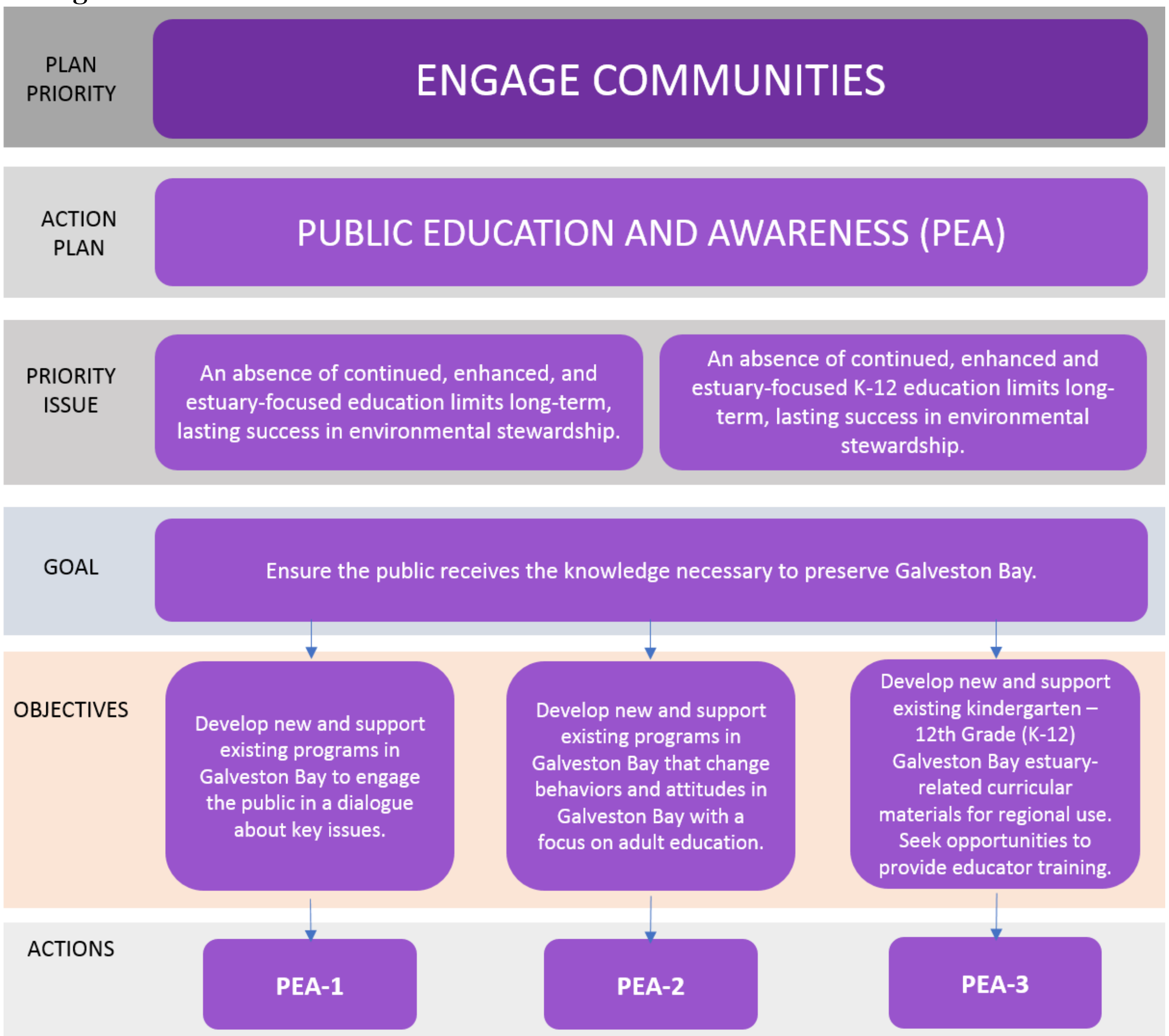
GBP Figure 25. Freshwater Inflows Action Plan



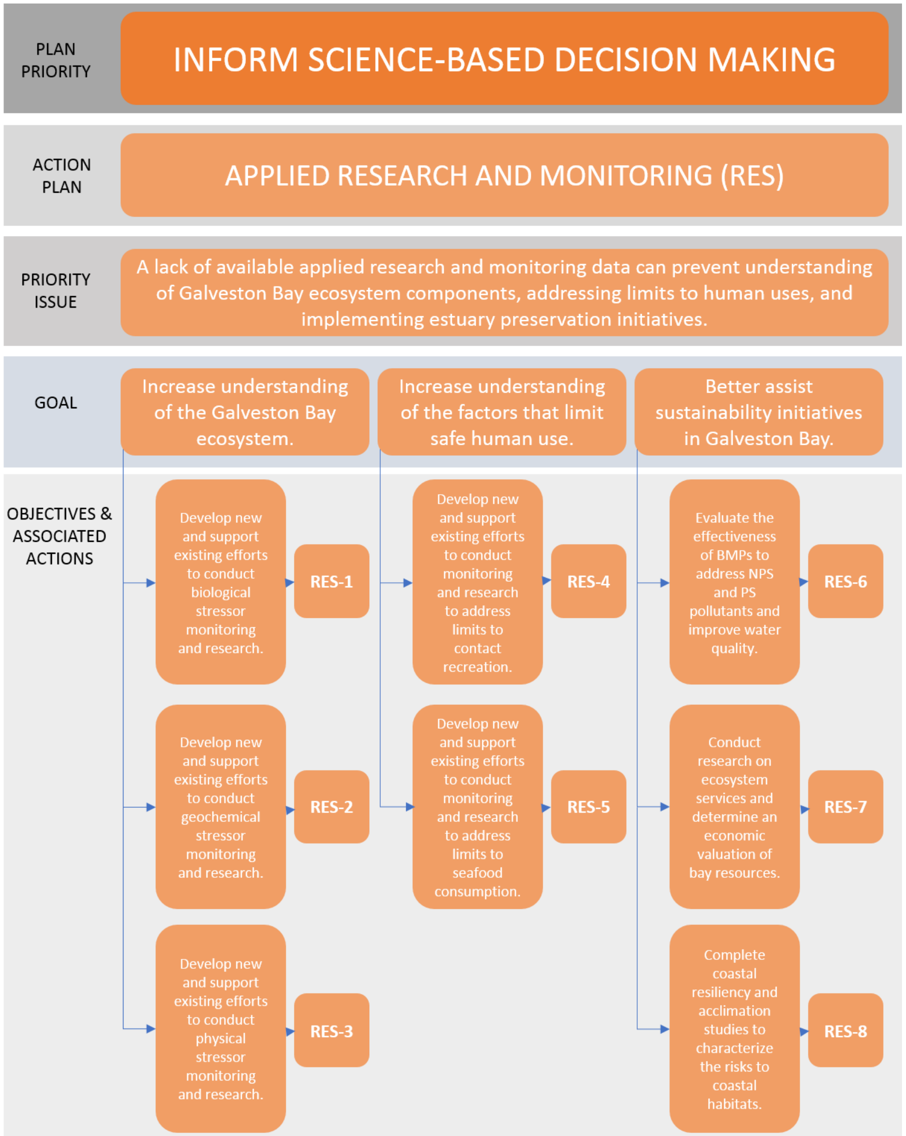
GBP Figure 27. Stakeholder and Partner Outreach Action Plan



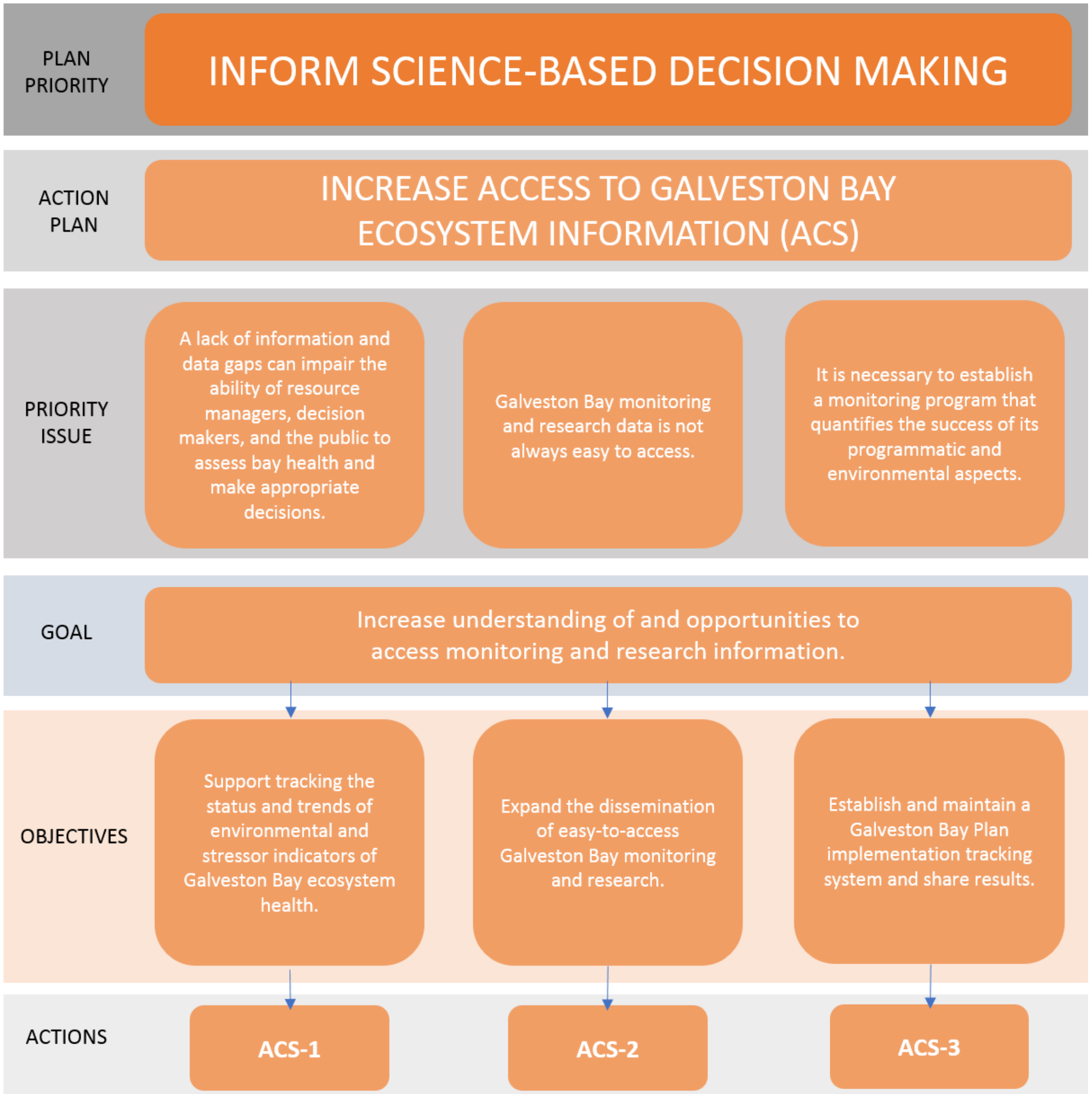
GBP Figure 29. Public Education and Awareness Action Plan



GBP Figure 31. Applied Research and Monitoring Action Plan



GBP Figure 33. Increase Access Action Plan



## *Appendix B: Consequence / Probability Matrix organized by Stressor and by Consequence / Probability for All Categories and Stressors*

These are the IDs for the GBEP Plan Goals and Stressor used in the CP Matrices

| GBP Priority | GBP Goal ID |
|---|---|
| Engage Communities | ECG |
| Ensure Safe and Aquatic Human Use: Increase public awareness of current public health risks/Reduce risk through WBPs | SAGWBP |
| Ensure Safe and Aquatic Human 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 habitats 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 + subsidence | SL |
| Warmer Summers | WS |
| Warmer Waters | WH |
| Warmer Winters | WW |

*Consequence / Probability Matrix by Stressor*

*Consequence / Probability Matrix by GB Plan Goal. See PowerPoint document for full accessible version. HARC (Ed.) 2022. Galveston Bay Estuary Resilience Assessment Report, Appendix C: Accessible Version of Consequence/Probability Matrices for Estuary Resilience. Texas Commission on Environmental Quality, Houston, Texas.*

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**<br>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**<br>2. ECG\| **Increase in vibrio illnesses**<br>3. SAGWNPS\| **Using more water for irrigation leading to increased runoff**<br>4. SAGWNPS\| **Warmer summers will lead to warmer water, increased likelihood of fecal indicator bacteria, and increased frequency of water quality exceedances**<br>5. ISG\| **Warmer waters lead to increased bacteria** | 1. ECG\| **Warmer waters = increased bacteria**<br>2. SAGWBP\| **Increased exceedances of bacteriological standards**<br>3. ISG\| **Increased evapotranspiration - less freshwater inflow, compromised water quality**<br>4. ISG\| **Potential for more & stronger tropical storms/hurricanes**<br>5. PSGCRE\| **Warmer summers could expand range of invasive species.**<br>6. PSGFI\| **Increased evapotranspiration will decrease freshwater inflows** |
| Medium | | 1. ISG\| **Essential food sources may die off**<br>2. ISG\| **How warmer summers impact oyster reefs**<br>3. PSGFI\| **Increased evapotranspiration will increase salinity in upstream reaches**<br>4. PSGNS\| **Heat stress to native populations and metabolic costs/mortality; changes to food webs**<br>5. PSGNS\| **Increased salinity (from increased evaporation and decreased freshwater inflow) can impact the distribution, abundance, and productivity of native species**<br>6. PSGNS\| **Life cycle stages (e.g., spawning) is influenced by environmental cues (temperature)**<br>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)**<br>2. ISG\| **Heat stress to native populations**<br>3. ISG\| **Changes in communities to more tropical composition**<br>4. PSGFI\| **Harmful algal blooms are more likely to develop in warm, salty water.**<br>5. PSGNS\| **Increased water temperatures would increase oyster predation and parasites**<br>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) | Low | Medium | High |
|---|---|---|---|
| **High** | 1. ISG\| **Potential for prolonged time period of bacterial/pathogen presence**<br>2. PSGCRE\| **Increase plant productivity, vertical accretion, and carbon sequestration. This should accelerate as mangroves become more prominent**<br>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**<br>2. SAGWBP\| **Increased exceedances of bacteriological standards.**<br>3. SAGWBP\| **Criteria for discharging may not be met**<br>4. SAGWNPS\| **Extended growing season leading to increased irrigation and runoff**<br>5. ISG\| **Potential for prolonged hurricane season** | 1. PSGCRE\| **Warm winters will enhance survival of insect pests.**<br>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**<br>2. ISG\| **Increased evapotranspiration - less freshwater inflow, less water availability**<br>3. PSGFI\| **Increased evapotranspiration will increase salinity in upstream reaches**<br>4. PSGNS\| **Warmer winters could expand range of invasive species; more temperate native species will move north**<br>5. PSGNS\| **Increased salinity (from increased evaporation and decreased freshwater inflow) can impact the distribution, abundance, and productivity of native species**<br>6. PSGNS\| **Oyster reef loss to dermo and drilling predators** | 1. PSGFI\| **Increased evapotranspiration will decrease freshwater inflows**<br>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.**<br>2. SAGWNPS\| **Warmer winters will lead to warmer water, increased likelihood of fecal indicator bacteria, and increased frequency of water quality exceedances.**<br>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** |
| | **Low** | **Medium** | **High** |
| | **Consequence** | | |

## Stressor: Warmer Waters

| Likelihood (Probability of Occurrence) \ Consequence | Low | Medium | High |
|---|---|---|---|
| **High** | 1. PSGCRE\| **Increased water temperatures could cause changes in phytoplankton community composition** | 1. ECG\| **Increase in vibrio illnesses**<br>2. SAGWBP\| **Increased bacterial growth, increasing bacteria load exceedances.**<br>3. ISG\| **Warmer waters lead to increased bacteria & potentially other pathogens**<br>4. PSGCRE\| **Increase in oyster predation and parasites** | 1. ECG\| **Heat Stress**<br>2. ECG\| **Warmer waters lead to increased bacteria**<br>3. SAGWBP\| **Increase in vibrio illnesses (increased communication on public health risks)**<br>4. ISG\| **Increased evapotranspiration - less freshwater inflow; compromised water quality**<br>5. PSGCRE\| **Decrease in dissolved oxygen**<br>6. PSGCRE\| **Increased stratification**<br>7. PSGNS\| **Warmer water could alter habitat distribution and lower dissolved oxygen in some area**<br>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)**<br>2. ISG\| **Reduction in nutrient loading and productivity of estuary** | 1. ISG\| **Changes in communities to more tropical composition**<br>2. PSGFI\| **Increased evapotranspiration will increase salinity in upstream reaches**<br>3. PSGNS\| **Oyster reef loss to dermo and oyster drilling predators**<br>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?**<br>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**<br>2. SAGWNPS\| **Increased bacterial growth, increasing bacteria load exceedances.**<br>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) | Low | Medium | High |
|---|---|---|---|
| **High** | 1. PSGCRE\| **changes to sediment loads**<br>2. PSGCRE\| **loss of seasonal wetlands** | 1. SAGWBP\| **Pollutant concentrations increase (less dilution)**<br>2. SAGWNPS\| **Pollutant concentrations increase**<br>3. SAGWNPS\| **Increased soil shrinkage will cause pipes to shift and crack leading to greater inflow and infiltration (I&I).**<br>4. ISG\| **Less inflow - decimation of upper bay assemblages - Rangia, Vallisneria and oysters due to increased parasitism**<br>5. ISG\| **Prolonged reduced freshwater input has long-term effects**<br>6. ISG\| **Increased salinity in brackish habitats + salinization of freshwater habitats --> loss of submerged aquatic veg**<br>7. ISG\| **Increased chances of red & brown tides**<br>8. PSGCRE\| **loss of ephemeral species and ephemeral habitats**<br>9. PSGCRE\| **Loss of tree and vegetative cover**<br>10. PSGNS\| **Sessile organism stress** | 1. SAGWBP\| **Increased Water conservation/ restrictions**<br>2. SAGWNPS\| **Increased irrigation = increased runoff**<br>3. PSGCRE\| **Increased evapotranspiration and/or decrease in freshwater inflows = increased salinity and decreases in oyster reef habitat**<br>4. PSGCRE\| **loss of habitat for riparian spawning fish species**<br>5. PSGFI\| **Increasing demand on water resources; decrease in discharge to Galveston Bay**<br>6. PSGFI\| **Base flow in streams may decrease**<br>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**<br>2. SAGWNPS\| **Increasing bacteria load (less dilution)**<br>3. PSGCRE\| **Area of suitable habitat decreases and limited to upper portion of estuaries.** | 1. ECG\| **Decrease in water quality - less for dilution**<br>2. PSGNS\| **Species may not tolerate new drought regimes**<br>3. PSGNS\| **Increasing marine and invasive species including predators, parasites, and diseases**<br>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**<br>2. PSGCRE\| **less water for restoration and enhancement** | 1. PSGNS\| **Increase in stranding events (e.g. marine mammals) and inundation of freshwater habitats.**<br>2. PSGNS\| **Adverse effect for secretive marsh birds like rails in salt marshes if transition habitats not available.**<br>3. PSGNS\| **Shifting vegetation community composition** | |
| | **Low** | **Medium** | **High** |
| | **Consequence** | | |

## 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**<br>2. PSGCRE\| **Coastal barriers reduce tidal exchange and ultimately alter salinity and circulation patterns that influence habitats and the species inhabiting them**<br>3. PSGCRE\| **Loss of native habitat due to development**<br>4. PSGCRE\| **Reservoir operations can shift the timing and amount of peak inflows** |
| **Low** | | 1. SAGWBP\| **Increased runoff**<br>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**<br>2. ISG\| **Changes in inflow regime which affects oyster and other species**<br>3. PSGCRE\| **movement of invasive species (+/-)** | 1. SAGWBP\| **Bacteria in flood waters**<br>2. SAGWBP\| **Exposure to pollutants during flood**<br>3. SAGWNPS\| **Could increase erosion of streambeds, increasing sedimentation and decreasing width of riparian corridors**<br>4. PSGCRE\| **Increased stream erosion and sediment loads**<br>5. PSGNS\| **Changes in shallow water habitat and secondary impacts on juvenile stages of estuarine and marine organisms**<br>6. ISG\| **Correlation with increase in lesions on bottlenose dolphins** |
| **Medium** | | 1. ISG\| **Unknowns: Impacts on estuarine wetland**<br>2. ISG\| **Unknowns: how are superfund sites impacted by increased flooding?**<br>3. PSGCRE\| **loss of habitat**<br>4. PSGCRE\| **increase in frequency and intensity of decreased salinity events**<br>5. PSGCRE\| **impacts for riparian fish spawning**<br>6. PSGFI\| **Changes periodicity of freshwater inflows**<br>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**<br>2. SAGWNPS\| **Potential for increased overtopping and "leaking systems" releasing more pollutants**<br>3. PSGCRE\| **low light due to increased sediment load** | 1. PSGCRE\| **changes to nutrient supply**<br>2. PSGFI\| **Changes seasonality of freshwater inflows**<br>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) | Low | Medium | High |
|---|---|---|---|
| **High** | 1. SAGWNPS\| **WWTF will go offline more often during intense events**<br>2. SAGWNPS\| **Frequency of sanitary sewers infiltration events will increase (increased inundation of septic systems)** | 1. ISG\| **Reduction of positive impacts of freshwater inflow**<br>2. PSGCRE\| **movement of invasive species**<br>3. PSGFI\| **Changes periodicity of freshwater inflows** | 1. ECG\| **Increased flooding of property and habitat**<br>2. SAGWBP\| **Bacteria in flood waters**<br>3. SAGWBP\| **Exposure to pollutants during flood events**<br>4. SAGWNPS\| **Increase in extent in tidal flooding could lead to new sources of pollution from floating tanks, runoff etc;**<br>5. ISG\| **Potential for increased spills/contaminants entering the bay system**<br>6. PSGCRE\| **Increased stream erosion and sediment loads**<br>7. PSGCRE\| **loss of habitat** |
| **Medium** | | 1. PSGCRE\| **increase in frequency and intensity of high salinity events**<br>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.**<br>2. ISG\| **Unknowns: how do storms impact freshwater wetlands?**<br>3. PSGFI\| **Accumulated impacts from other stressors (e.g., pollution)**<br>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**<br>2. PSGNS\| **Potential adverse effect for secretive marsh birds like rails in salt marshes if transition habitats are not available** | |
| | **Low** | **Medium** | **High** |
| | **Consequence** | | |

Stressor: Sea Level Rise + Subsidence

| Likelihood (Probability of Occurrence) | Consequence: Low | Consequence: Medium | Consequence: High |
|---|---|---|---|
| **High** | | 1. ECG\| **Wetland loss**<br>2. ISG\| **Reduction of positive impacts of freshwater inflow due to increased intrusion of saltwater.**<br>3. ISG\| **Increase in bacteria levels from failing septic systems?**<br>4. PSGCRE\| **changing spatial extent of available habitat** | 1. ECG\| **Increased flooding of property and habitat**<br>2. SAGWBP\| **Greater coastal wetland losses could occur (less filtration)**<br>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**<br>4. SAGWNPS\| **Contaminated sites may flood or have shoreline erosion**<br>5. SAGWNPS\| **Greater coastal wetland losses (less filtration)**<br>6. PSGCRE\| **Increased extent of saline waters**<br>7. PSGCRE\| **Changing light attenuation**<br>8. PSGNS\| **Increased marsh flooding**<br>9. PSGNS\| **changing spatial extent of available habitat**<br>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**<br>2. PSGCRE\| **habitat conversion to open water**<br>3. PSGFI\| **Loss of wetlands could impact quality of freshwater inflows**<br>4. PSGNS\| **Increased extent of saline waters** | 1. ECG\| **Increased storm surge**<br>2. SAGWNPS\| **Potential increase of saltwater intrusion into wastewater pipelines, increasing water load and overwhelming water treatment capacity**<br>3. PSGCRE\| **Increased marsh flooding**<br>4. PSGFI\| **Less availability of groundwater (due to subsidence and saltwater intrusion) = more demand on surface water, decreased base flow**<br>5. PSGNS\| **Changing light attenuation** |
| **Low** | | | |

Stressor: Chronic higher tides/nuisance flooding

| Likelihood (Probability of Occurrence) | Low | Medium | High |
|---|---|---|---|
| High | | 1. SAGWNPS\| **Increase in extent in tidal flooding could lead to new sources of pollution**<br>2. ISG\| **Unknowns: how do chronic higher tides impact restored wetlands**<br>3. PSGCRE\| **Loss of outer marsh habitat; uncertainty of ability of wetland to migrate inland**<br>4. PSGCRE\| **Habitat loss, conversion, and migration hold implications for native species**<br>5. PSGCRE\| **May create unfavorable habitat conditions more frequently** | 1. ECG\| **Increased flooding of property and habitat**<br>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** |
| | **Consequence** | | |

Stressor: Acidification

| Likelihood (Probability of Occurrence) \ Consequence | Low | Medium | High |
|---|---|---|---|
| **High** | | | 1. PSGCRE\| **Unknowns: Oysters in the Bay impacted by acidification** |
| **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**<br>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.**<br>3. ISG\| **Unknowns: does acidification in Galveston Bay impact oyster reefs?** | 1. ECG\| **Loss of oyster reef habitat**<br>2. 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**<br>2. SAGWNPS\| **WWTF capacity may become an issue in already dense areas where expansion may be difficult.**<br>3. ISG\| **Increased demand places more pressure on available supply.**<br>4. PSGCRE\| **Increased recreational fishing pressure and trampling** | 1. SAGWNPS\| **Increased population leads to increase in sources of NPS pollutants**<br>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**<br>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 exceedances 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. IS|ISG|LU|**Changes to land use and infrastructure alter the quantity, timing, and duration of inflows.**
19. IS|ISG|EE|**Potential for increased spills/contaminants entering the bay**
20. IS|ISG|WS|**Increased evapotranspiration - less inflow, compromised water quality**
21. 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**

**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|PL| **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**

**All Risks Grouped: High Consequence, Low Likelihood**

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

**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 exceedances.**
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 exceedances**
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/hurricanes**
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**

**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**

## 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 exceedances**
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 exceedances**
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 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**

## 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**
3. SA|SAGWNPS|IF|**Increased runoff from events will lead to short-term pollutant load increase**
4. SA|SAGWNPS|IF|**Potential for increased overtopping and "leaking systems“**
5. EC|ECG|PI|**More people to educate and promote water conservation.**
6. IS|ISG|WW|**Potential for prolonged time period of bacterial/pathogen presence**
7. PS|PSGCRE|ID|**Changes to sediment loads**
8. PS|PSGCRE|ID|**Loss of seasonal wetlands**
9. PS|PSGCRE|IF|**Low light due to increased sediment load**
10. PS|PSGCRE|WS|**Increased evapotranspiration which could lead to aquatic/subtidal species composition change**
11. PS|PSGCRE|WS|WW|**Increased plant productivity, vertical accretion, and carbon sequestration.**
12. PS|PSGCRE|WH|**Increased water temperatures could cause changes in phytoplankton community composition**
13. 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**