Climate Change Vulnerability Assessment

of the Charlotte Harbor National Estuary Program's

2013 Comprehensive Conservation & Management Plan

Approved May 31, 2018

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Executive Summary

The U.S. EPA has set a goal for all National Estuary Program CCMPs to be “climate ready” by 2020, in adapting their Comprehensive Conservation and Management Plans (CCMP) to address climate change risks. The goal of this vulnerability assessment was to identify and analyze potential climate change risks that may interfere with the Charlotte Harbor National Estuary Program’s ability to achieve existing CCMP quantifiable objectives.

After communication and consultation with stakeholders and management conference members, four primary climate stressors were determined to create 48 specific climate risks. These risks were evaluated for their likelihood and level of impact to CCMP quantifiable objectives based on the most recent climate change data. Five experts were surveyed in areas relating to climate science and coastal planning and asked to rate each risk on a qualitative scale (low, medium, high) for both likelihood of occurrence and level of impact to the specified objective. In addition, feedback was gathered from the general public who were participants in the 2018 CHNEP Conservation Lands Workshop. Risks that were consistently analyzed to pose high risk to CCMP quantifiable objectives were overloaded stormwater systems, septic failure, loss of coastal vegetation, and habitat loss or degradation.

For the CCMP priority area fish and wildlife habitat loss, 14 risks were identified, 9 of which were rated medium to high risk. Objective FW-1 (protect and restore native habitats) was found to have the greatest vulnerability to climate change impacts, with 6 risks rated medium to high, including shoreline erosion, changes to plant zonation, loss of coastal and shallow water habitat, and impacts to shellfish habitat. Other risks contributing to the vulnerability of objectives in this priority area were the effects of sea level rise and storminess on habitat shifts and the stress of habitat loss and disturbance events on native populations.

For priority area water quality degradation, overloaded stormwater systems were consistently found to pose a high risk to CCMP quantifiable objectives. Objective WQ-1 (maintain or improve water quality) had the highest number of medium and high risks, including overloaded stormwater systems, septic system failure, changes to fresh water flows, increased bacteria and algae growth, and nutrient loading from heavy precipitation events. Overloaded stormwater systems also posed high risk to quantifiable objectives WQ-2 (meet water quality criteria that are protective of living resources) and WQ-3 (reduce harmful algal blooms). Additional risks impacting this priority area were increased algae growth rates, loss of coastal vegetation, lower dissolved oxygen levels, and effects of sea level rise on oyster habitat.

For the priority area hydrologic alterations, 11 risks were analyzed. For objective HA-1 (maintain a more natural seasonal variation in freshwater flows), all four risks were found to pose medium to high risk, with the highest risk being the loss or degradation of wetlands and resultant impacts on drainage patterns. Degradation of wetlands was also rated as high risk for objective HA-2 (enhance historic watershed boundaries). Quantifiable objectives HA-3 (reduce negative effects of artificial structures) and HA-4 (improve linkages between stakeholder groups) has the fewest number of risks identified and are primarily related to interactions with human infrastructure and development.

Based on results of the risk analysis, CHNEP staff and management conference members will decide how to revise, eliminate, or add quantifiable objectives to the CCMP to reflect how quantifiable objectives need to be adapted to minimize risks. This will be done as part of the CHNEP CCMP update currently underway and targeted for completion in spring 2019.

Introduction

Charlotte Harbor National Estuary Program

The Charlotte Harbor National Estuary Program (CHNEP) is a partnership of citizens, elected officials, resource managers and commercial and recreational resource users who are working together to improve the water quality and ecological integrity of Charlotte Harbor's estuaries and watersheds. The National Estuary Program was established in 1987 by amendments to the Clean Water Act to protect and restore "estuaries of national significance" in the United States and is now a network of 28 estuary programs throughout the United States. The CHNEP was established in 1995 and is now one of 28 national estuary programs administered by the US Environmental Protection Agency.

The CHNEP is guided by a Comprehensive Conservation and Management Plan (CCMP), which identifies priority areas of concern within the study area and outlines actions needed to address them. The four priority problems of the 2013 CCMP are water quality degradation, hydrologic alterations, fish and wildlife habitat loss, and stewardship gaps. During the risk identification phase of this project, no risks were identified for the priority problem of stewardship gaps, and this priority area was not included in the risk analysis phase.

Vulnerability Assessment

The EPA Climate Ready Estuaries Program was initiated in 2008 with the goal of helping the 28 National Estuary Programs (NEPs) and other resource managers to address the impacts of climate change on coastal areas. Through this program, the EPA provides tools and resources for NEPs and partners to effectively adapt to changing conditions. One such tool, the EPA "Being Prepared for Climate Change Workbook", provides guidance for resource managers to conduct a risk-based climate change vulnerability assessment and provides decision-making tools for planning adaptation strategies for a changing climate in order to make a more climate resilient CCMP.

The purpose of conducting this vulnerability assessment is to apply the guidelines in the EPA "Being Prepared for Climate Change Workbook" to understand the risks and opportunities associated with climate change impacts in the CHNEP study area. As Southwest Florida continues to experience climate change, adaptation planning will be crucial to minimize adverse effects to coastal systems. In order to effectively adapt to changing conditions, the CHNEP must identify how climate change will impact its organizational goals and incorporate that knowledge into future management strategies. This vulnerability assessment will help the CHNEP to identify and adapt to

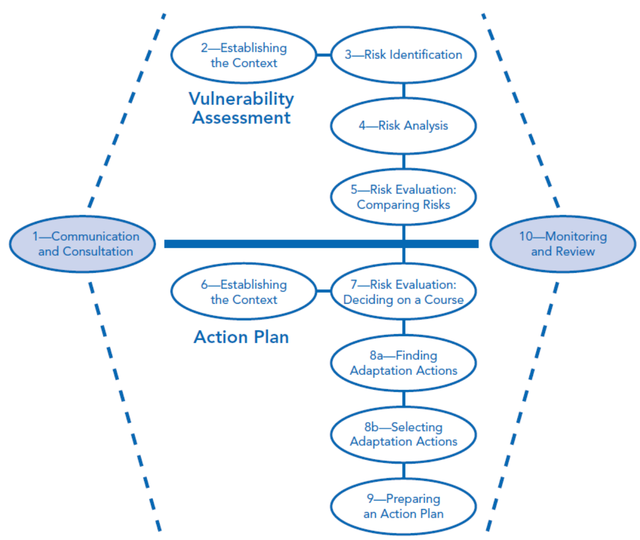


Figure 1: Steps for adaptation planning. This vulnerability assessment comprises steps 1-5 and will be used to inform steps 6-10 of action planning and implementation. From EPA "Being Prepared for Climate Change Workbook"

climate change risks and support a more climate resilient community.

The risks identified in this vulnerability assessment are not an exhaustive list of climate change impacts for the CHNEP study area. Rather, they represent those risks that threaten the achievement of specific CHNEP goals as outlined in the 2013 CCMP. By contextualizing climate impacts in terms of the risk posed to specific quantifiable objectives, the results of this assessment be used to inform CCMP actions and priorities in to the 2019 CCMP Update.

Climate Stressors

Ocean Acidification

The oceans act as a natural sink for atmospheric carbon dioxide by absorbing atmospheric CO_2 and removing it from the atmosphere. Higher concentrations of atmospheric carbon dioxide due to anthropogenic emissions have led to increased dissolved CO_2 concentrations in the oceans and the process of ocean acidification. While this reduces the levels of greenhouse gases in the atmosphere, when CO_2 dissolves in seawater reactions occur that reduce pH (increase acidity) and reduce the relative abundance of carbonate ions needed by calcifying organisms to form shells and skeletons (Doney 2009).

Since the industrial revolution, anthropogenic CO_2 emissions have contributed to higher concentrations of dissolved CO_2 and acidification of seawater. According to the IPCC Fifth Assessment Report, since 1750 about 40 percent of anthropogenic CO_2 emissions have persisted in the atmosphere. The rest have been absorbed by carbon sinks, including the ocean which has absorbed approximately 30 percent of anthropogenic CO_2 emissions between 1750 and 2011 (IPCC 2014).

Compared to open ocean conditions, acidification in coastal environments has greater variability due to the interactions affecting pH, such as composition of freshwater flows, coastal upwelling of CO_2 rich water, nutrient inputs and organic matter (IPCC 2014; Cai et al. 2011; Feely et al. 2008). One relevant concern for the CHNEP study area is the potential for eutrophication to enhance coastal acidification. Excessive nutrient runoff from rivers and streams can lead to eutrophication, reduced oxygen levels, and production of CO_2 as organic material is broken down (Cai et al. 2011). Eutrophic waters may have a reduced buffering capacity and experience greater acidification than open ocean habitats. A case study of eutrophication impacts in the Northern Gulf of Mexico predicts a decline in pH of .74 units by 2100 (Cai et al. 2011).

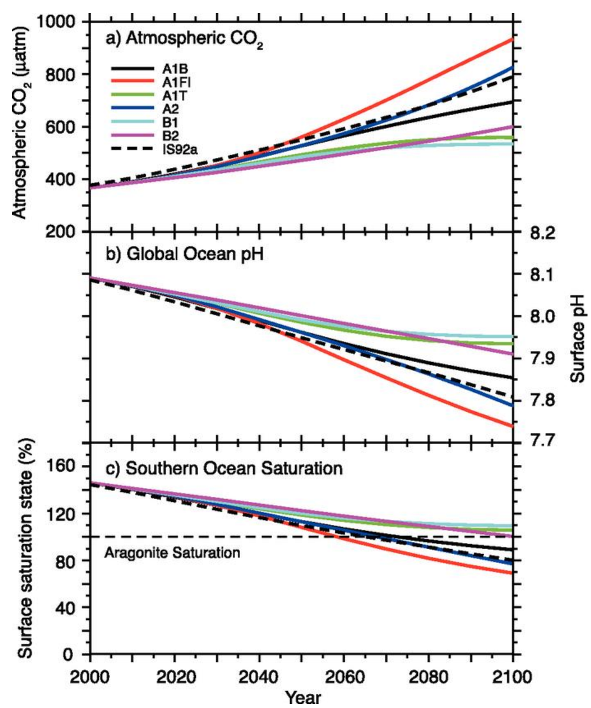


Figure 2: For the six IPCC Special Reports on Emissions Scenarios a) projected atmospheric CO_2 b) projected average sea surface pH and c) projected average aragonite (a form of calcium carbonate used by marine organisms) saturation state in the Southern Ocean. From IPCC 2007.

While eutrophication may exacerbate acidification, other coastal components may buffer acidification effects. An ongoing study in Tampa Bay is examining whether the presence of habitats such as stable seagrass beds may act to buffer acidification in coastal environments and mitigate the adverse effects on other organisms, such as shellfish (Yates 2016). These interactive factors increase the temporal and spatial variability of pH in coastal systems and create challenges for projecting future scenarios in the CHNEP study area.

Sea Level Rise

Florida's topography, porous karst geology, and large coastal population make Florida uniquely vulnerable to sea level rise. Data from the Fort Myers NOAA tide gauge show that sea level at that location has risen approximately 6 inches since recording started in 1966, with an average rate of 2.99 mm/year or approximately an inch a decade (NOAA 2017). Future scenarios based on data from the Fort Myers tide gauge indicate continued sea level rise, with projected rise of between 3.7 feet (intermediate) and 6 feet (intermediate-high) by 2100 (Figure 4, NOAA 2017).

Year	NOAA2017 Low	NOAA2017 Intermediate	NOAA2017 Int-High	NOAA2017 High
2000	0.00	0.00	0.00	0.00
2030	0.39	0.72	0.95	1.18
2050	0.72	1.38	1.90	2.49
2080	1.12	2.72	4.13	5.61
2100	1.31	3.77	6.00	8.37

Figure 3: Sea level rise scenarios for Fort Myers (values expressed in feet). Source: NOAA 2017

This rate of sea level rise is consistent with global trends. From 1901 to 2010, global mean sea level (GMSL) rose approximately 0.19m (IPCC 2014). There is broad consensus on future projections for sea level rise. The most recent NOAA estimates for GMSL (Sweet et al. 2017) have risen to correspond with rates of ice melt in Greenland and Antarctica and reflect observed instability of Antarctic ice sheets. Even with decreased emissions scenarios, sea level is expected to rise.

Sea level rise presents unique challenges to coastal infrastructure and exacerbates other climate change effects, such as storm surge. Impacts associated with sea level rise include erosion, flooding, saltwater intrusion, and habitat loss and migration.

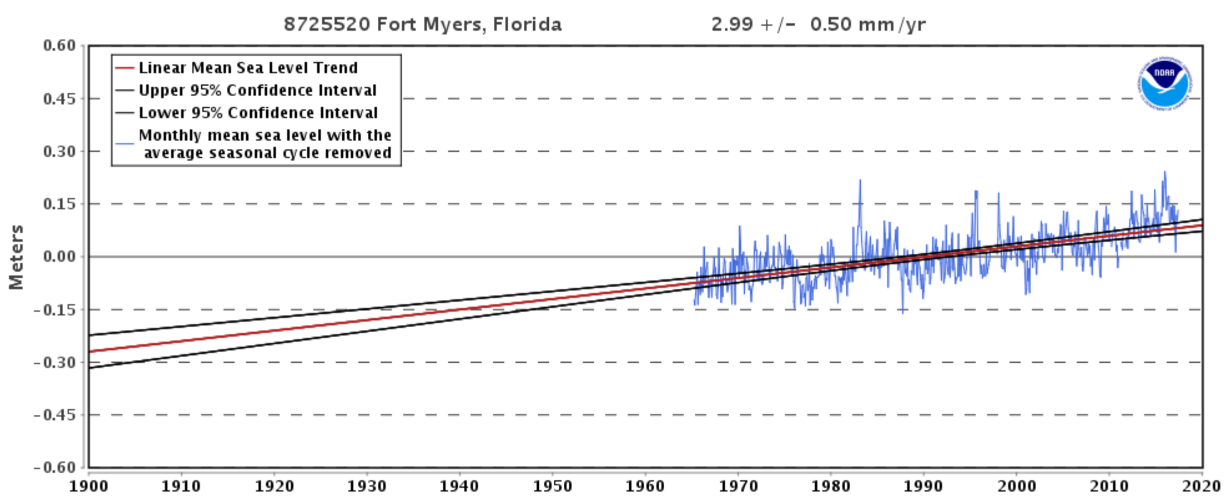


Figure 4: Mean sea level trend for Fort Myers tide gauge. Source: NOAA 2017

Precipitation Changes

Future rainfall patterns for Southwest Florida are uncertain. According to IPCC projections for a "middle-of-the-road" emissions scenario, the east coast of the US is predicted to experience a 7% increase in rainfall by the end of the 21st Century, while the Caribbean is predicted to experience a 14% decrease in rainfall over the same period (IPCC 2014). Rainfall in South Florida is generally expected to fall more in line with the Caribbean, though projections are subject to high degree uncertainty as well as seasonal and interannual variability (Misra et al. 2011).

Precipitation in Southwest Florida is influenced by a combination of local factors, such as sea breeze convection and land use changes, and large-scale processes, including the Atlantic Multi-decadal Oscillation (AMO), the El Nino Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO). These interactions and the high natural variability of rainfall patterns create challenges for downscaling regional and global climate models. The current warm phase of the AMO is associated with more hurricane activity and greater amounts of rainfall in Florida, while the cooler phase is generally marked by fewer hurricanes and less rainfall, which may exacerbate drought conditions and effects of future warming for Florida (Misra et al. 2011).

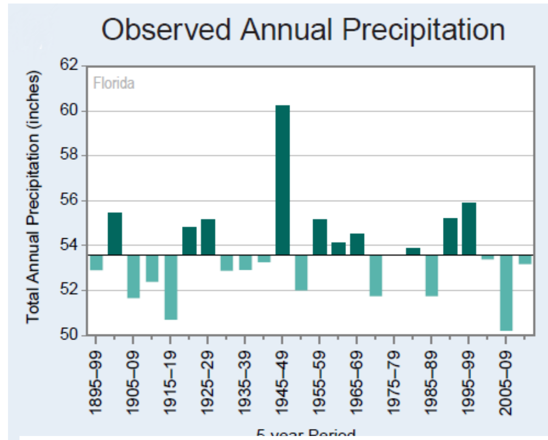


Figure 5: Observed annual precipitation in Florida. Source: Runkle 2017

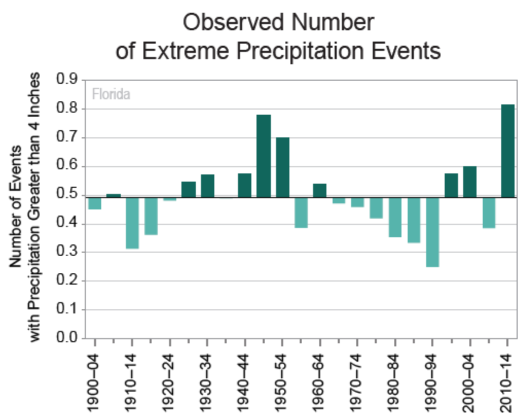


Figure 6: Observed number of extreme precipitation events (over 4 inches) in Florida. Source: Runklel 2017

Though average rainfall amounts are subject to greater uncertainty and may fall within the range of natural variability, extreme precipitation events are expected to increase throughout the Southeast United States, including Florida (Ingram 2013; Carter et al. 2014; Easterling et al. 2017; Runkle et al. 2017). Due to the atmosphere's increased capacity to hold moisture at warmer temperatures, extreme precipitation events are expected to increase in intensity by 6-7% for each degree Celsius increase in temperature (Easterling et al. 2017). With continued warming, intensity of extreme precipitation events and amount of hurricane rainfall is expected to increase for Florida (Easterling et al. 2017; Runkle et al. 2017).

Since the 1970s, there has been an increase in tropical cyclone activity in the North Atlantic (Kunkel et al. 2013; Kossin et al. 2017). This activity is the product of numerous influences, including volcanic eruptions, Saharan dust outbreaks, anthropogenic greenhouse gas emissions, aerosols, and natural oceanic and atmospheric circulations (Kossin et al. 2017). Compared to historical trends, the number of Category 4 and 5 hurricanes in the North Atlantic basin has increased since the 1970s though it is unclear whether this can be attributed to anthropogenic causes rather than natural variability (Carter et al., 2014; Kunkel et al. 2013; Misra et al. 2011).

Globally, tropical cyclone intensity is expected to increase with warmer temperatures, as is the amount of hurricane rainfall (Carter et al. 2014; IPCC 2014; Kossin et al. 2017). For the north Atlantic, the frequency of very intense (Category 4 and 5) storms is expected to increase (IPCC 2014; Kossin et al. 2017; Kunkel et al. 2013; Bender et al. 2010).

For decreased rainfall scenarios, impacts on water availability include saltwater intrusion, reduced fresh water flows, and habitat changes. During the AMO cool phase (likely by 2026) Florida would experience 2-3 decades of greater drought conditions and fewer tropical cyclones, further constraining water supply

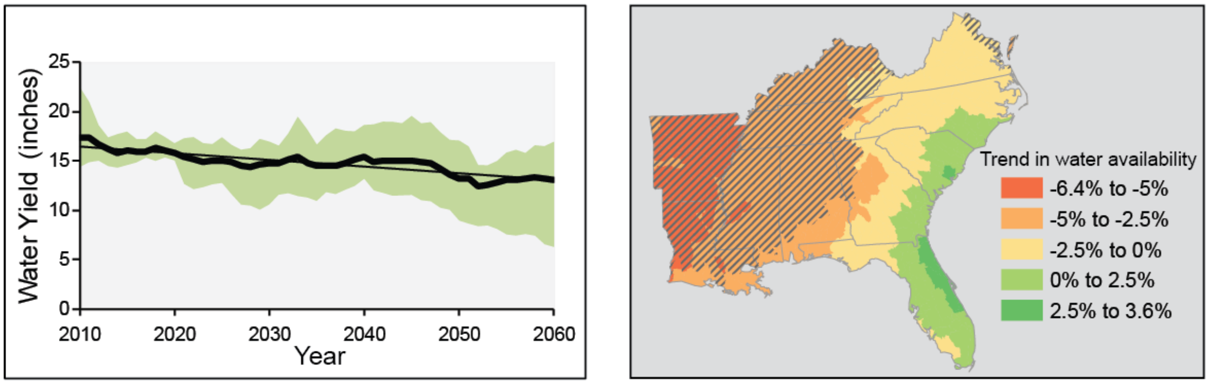


Figure 7: Projected trend in water availability for the Southeast due to climate change based on A1B and B2 emissions scenarios. Source: Carter et al. 2014

and exacerbating demand stresses from population growth and development (Misra et al. 2011).

Warmer Temperatures

Since the beginning of the 20th century, temperatures in Florida have increased approximately 1 degree F (Runkle et al. 2017). Though there has not been a significant increase in average daytime temperatures the number of very warm nights has increased significantly (Runkle et al. 2017).

Even under reduced emissions scenarios, average annual temperatures in Florida are projected to increase (Figure 9). In addition to warmer average temperatures, the number of days over 95 degrees F is expected to increase 40-50 days by 2050 as compared to 1971-2000 (Figure 8, Carter 2014).

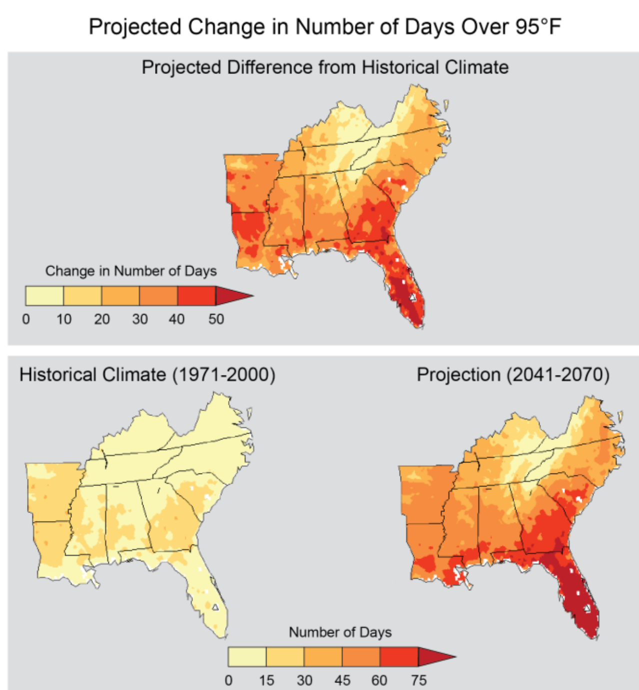


Figure 8: Projected change in days over 95. Source: Carter et al. 2014 National Climate Assessment Ch. 17

With warmer temperatures, evapotranspiration is expected to increase and have impacts on water availability (SFWMD 2009; Carter et al. 2014). Though there is a high degree of uncertainty in projections, IPCC figures suggest annual ET rates may increase by up to 15 percent by the end of the 21st century compared to 1980 to 1999 measurements (Bates 2009).

Increased evapotranspiration may increase rates of water loss from surface water storage systems, affect habitat quality, and increase likelihood of saltwater intrusion (Obeysekera et al. 2011; Carter et al. 2014; Florida Oceans and Coastal Council 2010).

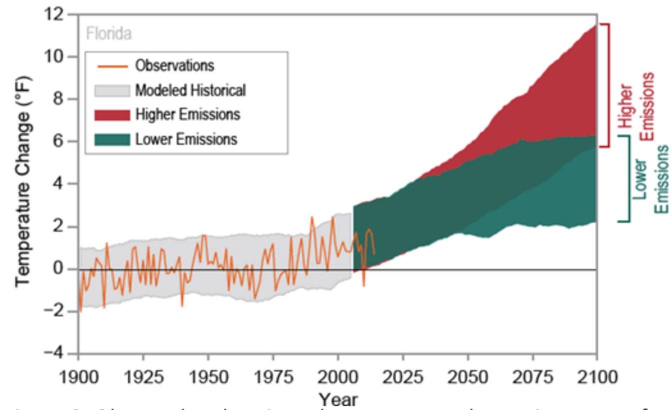


Figure 9: Observed and projected temperature change in near-surface air temperature for Florida. From Runkle et al. 2017

Results and Visualizations

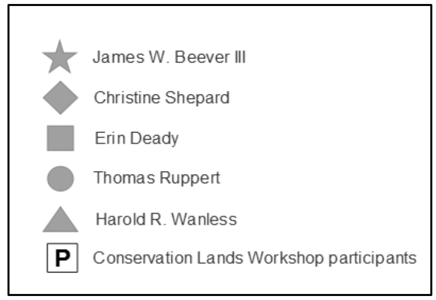
Five experts were surveyed in areas relating to climate science and coastal planning and asked to review the list of risks compiled and agree or disagree with the categorization of a risk, then rate the risk on a qualitative scale (low, medium, high) for both likelihood of occurrence and level of impact to the specified objective. These results were then compiled and reviewed by staff to create visualizations of the likelihood and impact for each risk identified. In addition to expert review, risks were analyzed by participants at the 2018 Conservation Lands Workshop through an interactive exercise. The following sections provide the results of the surveys and interactive exercise in text and in associated graphics.

Fish and Wildlife Habitat Loss

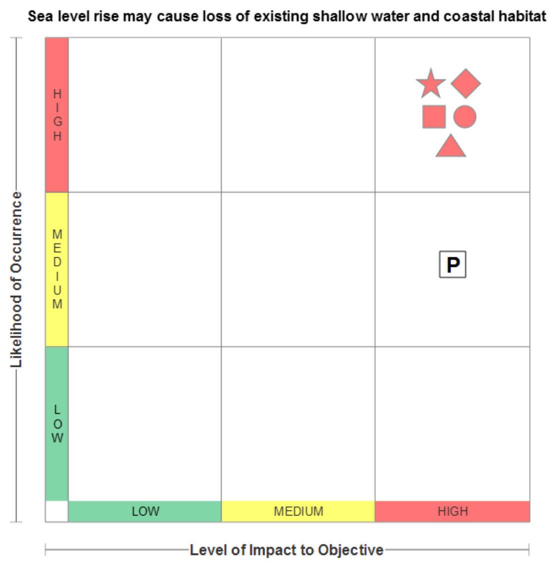
Objective FW-1: *Protect, enhance, and restore native habitats where physically feasible and within natural variability, including submerged aquatic vegetation, submerged and intertidal unvegetated bottoms, oyster, mangrove, salt marsh, freshwater wetland, native upland, and water column.*

Eight climate risks were evaluated for this objective and were primarily associated with sea level rise and increasing temperatures. Rising sea levels and the accompanying loss of existing shallow water and coastal habitat may have severe effects on the achievement of this objective, particularly if shorelines are not allowed to migrate naturally. Impacts to Objective FW-1 from sea level rise include direct loss of coastal habitat types if habitat migration is impeded, shifting salinity regimes and impacts on oyster and seagrass habitat availability, and exacerbated effects of storm surge. Habitat changes due to sea level rise may also result in mismatched or outdated protection areas and the need for reevaluation of priorities in order to ensure accurate and updated management areas that are consistent with anticipated habitat changes. Additional concerns raised for this objective include the impacts of drought and increased temperatures on native habitats and more dramatic storm surges that will be further exacerbated by rising sea levels. Increased runoff due to inadequate drainage systems and anticipated population growth in the Southwest Florida area may also lead to nutrient loading and contribute to hypoxic environments in coastal systems.

(1) Sea level rise may cause loss of existing shallow water and coastal habitat

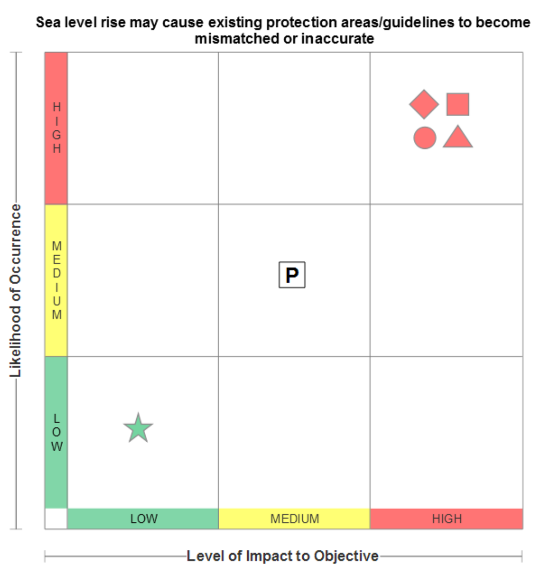


Coastal habitats will be significantly affected by a range climate stressors, including sea level rise, warmer temperatures, and changes in precipitation. In many cases, development and human responses to climate threats will exacerbate these climate impacts and increase vulnerability of coastal systems (Twilley, 2007; Peterson et al. 2008; Erwin 2009). Erosion, turbidity, and decreased light penetration associated with sea level rise will limit suitability of existing shallow water habitat and lead to habitat migration where natural shoreline exists (Beever et al. 2009; EPA CRE 2009). Increased flooding or inundation of coastal habitats will lead to significant shifts in community structure over time as suitable habitat and species ranges are "squeezed" between rising seas and impeding structures (e.g. seawalls, development, flood protection structures) (Twilley, 2007). Artificial structures such as sea walls, roads, and flood protection structures will impede habitat migration and result in habitat loss where sea level rise makes existing habitat unsuitable (Twilley, 2007).



(2) Sea level rise may cause existing protection areas or guidelines to become mismatched or inaccurate

Where habitat is lost or changed significantly, existing protection guidelines and management priorities may become inaccurate. Updated goals should include consideration of how habitat types may change in the future in order to meet current and future needs. The CHNEP's Habitat Resiliency to Climate Change Project (HRCC) is using in-depth spatial analysis to examine the projected effects of sea level rise data on future habitat conditions. The HRCC aims to understand existing and future habitat connectivity in order to provide informed resiliency solutions, such as migration corridors.

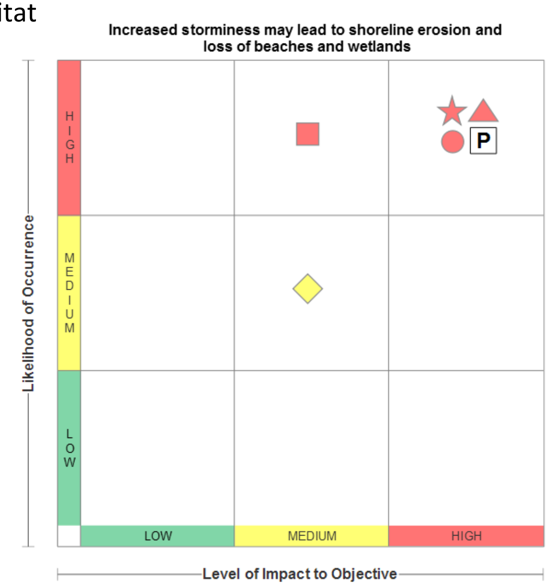


(3) Sea level rise may reduce light penetration and affect sea grass populations

Seagrasses play a variety of essential roles within the estuary and serve as an important indicator for water quality. They improve water quality by trapping suspended sediments and cycling nutrients, are an important food source for a variety of species and provide essential habitat for many species, and are classified as a Valued Ecosystem Component for the Caloosahatchee estuary (Chamberlain and Doering 1998; Mazotti et al. 2008). As sea levels rise, existing seagrass habitat will be shaded out with increasing depth. In addition to direct impacts on light penetration, sea level rise will contribute to erosion and increased turbidity, shifts in salinity regimes, and nutrient loading (Beever et al. 2009; Wanless, personal communication). In areas where shorelines are not impeded, seagrass beds will migrate landward, colonizing new areas as old ones are lost due to sea level rise (Beever et al. 2009; Ruppert, personal communication). Where shorelines are impeded by development, sea walls, and other artificial structures, seagrass habitat will be lost as sea levels rise.

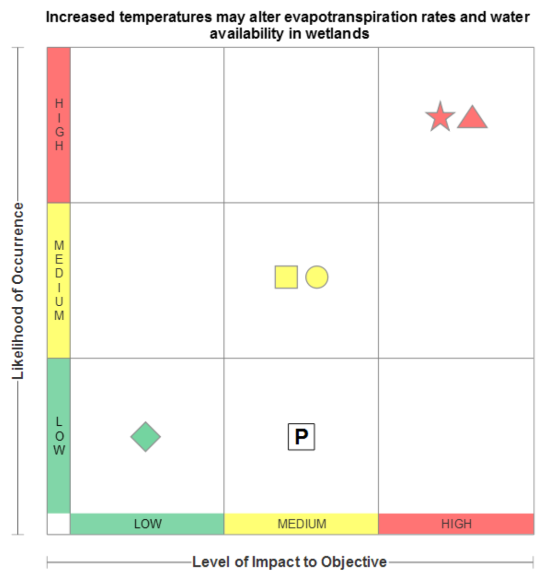
(4) Increased storminess may lead to shoreline erosion and loss of beaches and wetlands

Rates of shoreline erosion will be affected by factors including storm events, sea level rise, and wind and wave action, all of which will be impacted by climate change. Storminess is likely to increase shoreline erosion and will have a high impact on fish and wildlife habitat (Peterson et al. 2008; Osgood, 2008). Erosion will be exacerbated by sea level rise and loss of coastal vegetation and may call for beach renourishment or other management strategies. In the CHNEP study area, the effects of storms on beach erosion are already being observed, with shorter periods of time between renourishment events (Beever, personal communication) and the combined impacts of sea level rise and storm events will become severe by the end of the century (Wanless, personal communication). Shoreline hardening structures, such as sea walls may also contribute to increased erosion along natural shoreline. Wetlands will be lost where rate of sedimentation cannot keep up with erosion impacts of sea level rise and frequent flooding (Twilley, 2007).



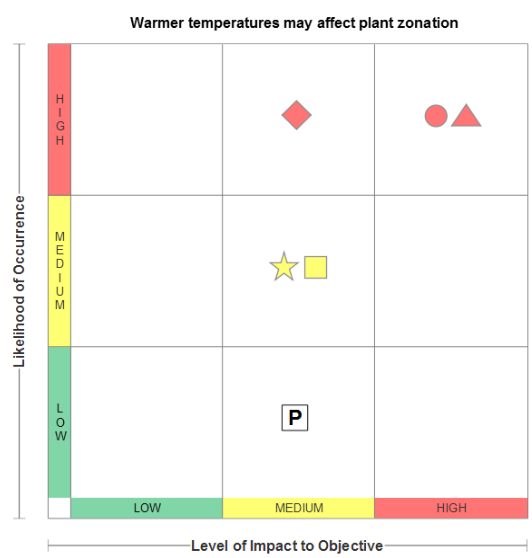
(5) Increased temperatures may alter evapotranspiration and water availability in wetlands

Risks associated with rising temperatures include impacts on water availability in wetland habitats, drought, and shifts in suitable plant habitat and species range. Both average temperatures and temperature extremes (days over 95) are expected to increase (Runkle et al. 2017; Vose 2017; Carter et al 2014) and will have impacts on hydrology and habitat quality. Increased air temperatures and changes in precipitation are predicted to alter historic hydrology of wetland habitats (Beever et al. 2009; EPA CRE 2009) and effects of longer, drier dry periods are already being observed in the CHNEP study area (Beever, personal communication). Altered surface water demands and potential development will also contribute to water availability in wetland habitat. Water demands, especially irrigation and agriculture, generally increase with rising temperatures (IPCC 2014) and evaptranspiration and water demand is expected to increase in south Florida (SFWMD 2009). Specific impacts will vary by community and may be unpredictable due to uncertainty in precipitation projections for the area (Ruppert, personal communication; Wanless, personal communication).



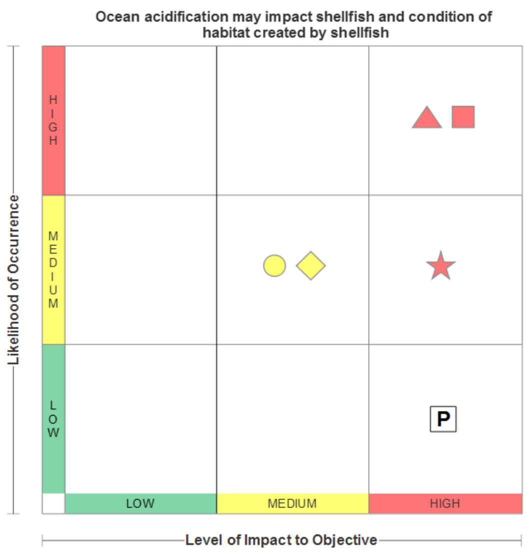
(6) Warmer temperatures may affect plant zonation

Plant zonation will be affected by multiple climate-related factors, including warmer temperatures, precipitation changes, and sea level rise. Warmer temperatures may alter species composition, shift favorable habitat ranges northward, and increase competition between native and non-native species (EPA CRE 2009). Longer, drier dry seasons and extended periods of low rainfall will also put stress on native populations and contribute to habitat changes. For species at the northern ends of their range, habitat migration may be infringed by development or increased competition from other species, leading to local extirpation (Beever et al. 2009).



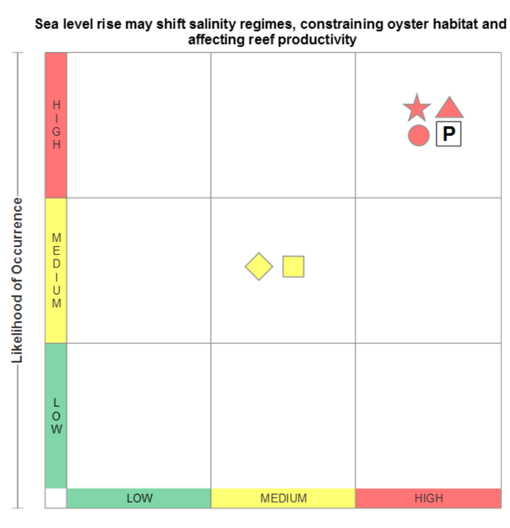
(7) Ocean acidification may impact shellfish and condition of habitat created by shellfish

Coastal acidification may have significant effects on submerged and intertidal habitats, particularly on shellfish communities. Higher concentrations of CO_2 in seawater reduce the calcium carbonate saturation state and relative availability of carbonate ions necessary for shell-forming organisms, including oysters. In laboratory settings, many calcifying species have demonstrated decreased growth rates under conditions of higher CO_2 (Fabry et al. 2008; Doney, 2009). Acidification in estuarine systems has also been shown to put stress on oyster larvae and negatively affect growth rates of larvae (Miller 2009). The effects of acidification in estuarine systems will be more variable than in open ocean habitat due to the natural heterogeneity of coastal systems, which are characterized by complex interactions of factors such as salinity, pH, nutrient levels and freshwater inflows (Miller et al. 2009). The combined effects of nutrient inputs, freshwater inflows, and eutrophication may make coastal systems particularly vulnerable to acidification (Feely et al. 2010; Cai et al. 2011). Conversely, stable seagrass communities may act to buffer acidification effects (Yates et al. 2016). Oyster communities in the CHNEP study area provide a number of ecosystem services including habitat creation, shoreline stabilization, and water quality improvements. The rate and extent of ocean acidification in the CHNEP study area are uncertain, with experts indicating the effects are already being observed and will increase in severity as the century progresses (Beever, personal communication).



(8) Sea level rise may shift salinity regimes, constraining oyster habitat and affecting reef productivity

Another concern for oyster communities in the CHNEP study area is the effect of changes in salinity in the estuary. Sea level rise, altered flow ways from coastal morphology changes, and freshwater inflows will all affect salinity levels and impact oyster habitat. Sea level rise pushing salinity regimes upstream may constrain oyster habitat due to morphology of rivers and streams (Beever, personal communication). Reduced salinity has been shown to increase energetic costs and reduce productivity for oyster communities (Tolley et al. 2010) and has been shown to slow development and increase mortality of larvae (Tolley et al. 2010; Volety 2001). Large releases of fresh water have been observed to negatively impact oyster communities in the Caloosahatchee estuary within the CHNEP study area (Volety 2001) and precipitation changes may increase high-volume rain events and the frequency of out-of-season releases. Conversely, longer dry periods and extended periods of low rainfall will allow saltwater to intrude farther

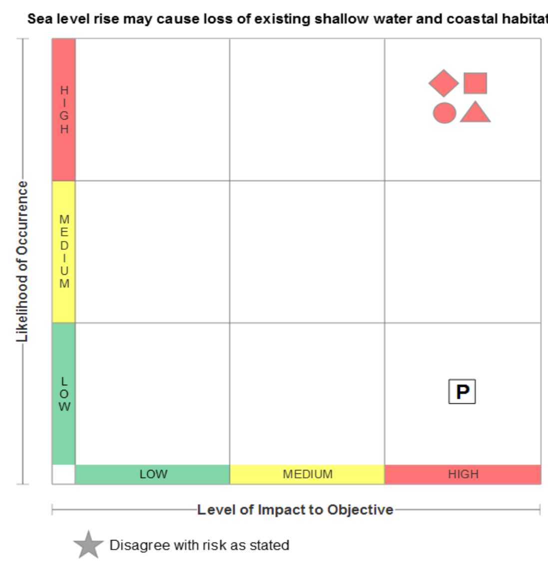


upstream and push tidal oyster populations farther upstream into more constrained river and stream morphology.

Objective FW-2: *By 2020, achieve a 100 percent increase in conservation, preservation, and stewardship lands within the boundaries of the CHNEP study area.*

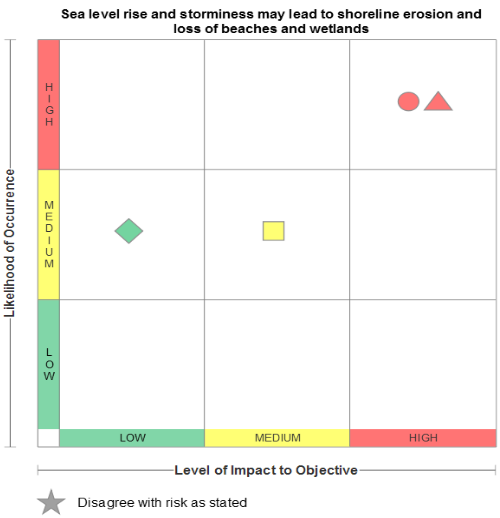
The risks associated with this objective are linked to the effects of sea level rise and storminess on the availability and acquisition of conservation lands. Additional risks to this objective, though not necessarily climate change related, include population growth and increased development that may inhibit natural habitat migration and exacerbate flooding and erosion impacts from storm events. Infrastructure costs may also limit resources available to carry out this objective. One potential adaptation strategy noted during risk analysis was the use of migration corridors to allow habitat to migrate naturally as sea levels continue to rise (Wanless, personal communication). The CHNEP is currently working with partners to analyze sea level data and future habitat changes. The Habitat Resiliency to Climate Change project will identify future habitat needs and potential for adaptation strategies, such as migration corridors.

(9) Sea level rise may cause loss of existing shallow water and coastal habitats



Although the rate of sea level rise from now until 2020 is not significant enough to affect land availability in the next two years (Beever, personal communication), sea level rise will contribute to the loss of existing shallow water and coastal habitats if these systems are not allowed to migrate naturally and will interact with stresses from land use changes and population growth in Southwest Florida.

(10) Sea level rise and storminess may lead to shoreline erosion and loss of beaches and wetlands



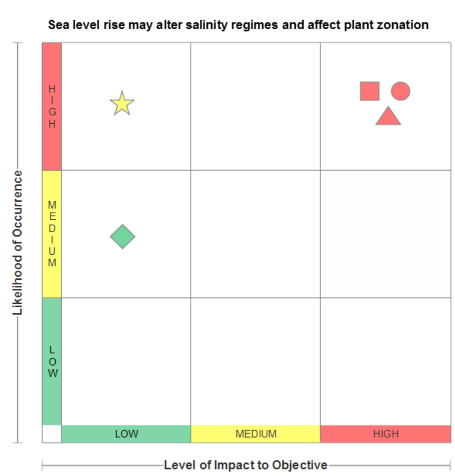
Rates of shoreline erosion will be affected by multiple factors, including storm events, sea level rise, and sedimentation. Southwest Florida is particularly susceptible to major storm events and increased intensity of storms, coupled with sea level rise, may lead to losses of existing beaches and wetlands where migration pathways conflict with human development (Ruppert, personal communication). As changing conditions alter coastal habitats, successful adaptation strategies will need to anticipate potential changes and set realistic goals that are consistent with those changes (Wanless, personal communication). As demand for flood and storm surge protection measures increases, erosion impacts will be exacerbated by the effects of shoreline hardening and artificial coastal structures.

Objective FW-3: *By 2020, achieve controllable levels of invasive exotic plants and exotic nuisance animals on publicly managed lands. Encourage and support the removal and management of invasive exotic plants and exotic nuisance animals on private lands.*

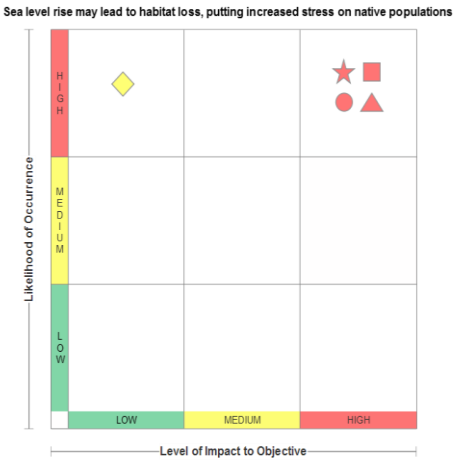
Impacts associated with sea level rise and warmer temperatures were found to pose the highest risk to this objective. Habitat changes due to sea level rise may put pressure on native populations and reduce the availability of suitable habitat types, particularly as species ranges shift in response to warmer temperatures. Shifting salinity regimes may also affect plant zonation and affect productivity of mangrove and oyster communities. Stresses to native communities may accelerate spread of and colonization by invasive species. Warmer average temperatures may contribute to the spread and establishment of new and existing exotic species, and more frequent extreme heat events may increase stress to native populations and allow for colonization by invasives.

(11) Sea level rise may alter salinity regimes and affect plant zonation

Multiple factors will interact to affect plant zonation. Altered salinity regimes will reduce productivity of low salinity mangrove communities and adversely affect species including wood storks, roseate spoonbills, and crocodiles (EPA CRE 2009, Beever et al 2009). As salinity gradients migrate with rising sea levels, existing freshwater wetlands may transition to tidal wetlands (Twilley, 2007, EPA CRE 2009). Where species ranges are constrained by development, local extirpation may occur (Beever et al. 2009). Changing conditions may favor invasive species that are more adapted to altered conditions. Changed species range may increase competition with natives and non-natives and have adverse effects on fish and wildlife populations (Osgood, 2008; Stys et al. 2017).

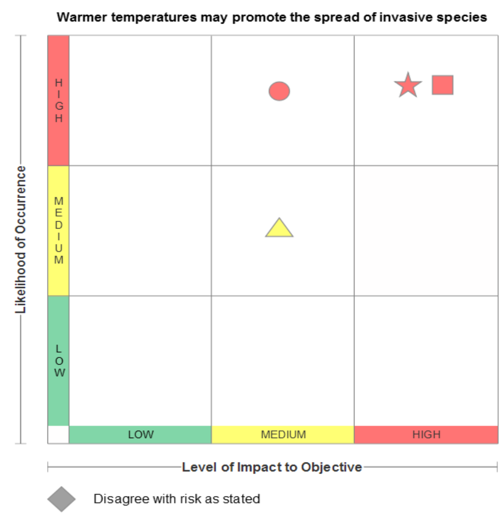


(12) Sea level rise may lead to habitat loss, putting increased stress on native populations



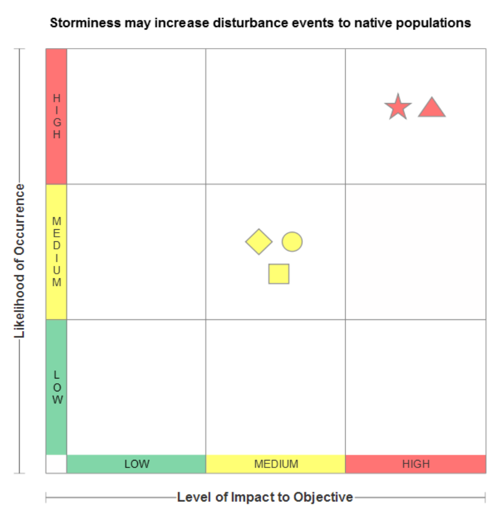
Changes to historical habitat will be one of the most dramatic and significant effects of climate change, with cascading effects for water quality, fish and wildlife populations, and hydrologic systems. Multiple factors will contribute to habitat loss, including sea level rise and warmer temperatures. As historical habitat is lost, native species may face increased competition from invaders that are better adapted to changing conditions (Beever et al. 2009; EPA CRE 2009). Where potential habitat migration is limited, native species may become extirpated (Beever et al. 2009).

(13) Warmer temperatures may promote the spread of invasive species



Warmer temperatures may promote spread of invasive species and put stress on native populations that are not well-equipped for changing conditions. As species ranges shift northward, native species may face increased competition from invasive species that are better suited to shifting conditions (Twilley, 2007). Disturbance events, such as drought and intense storms, may put additional stress on native populations and increase colonization opportunities for invasives (Beever et al. 2009; EPA CRE 2009).

(14) Storminess may increase disturbance events to native populations



In addition to gradual habitat shifts and competition from invasive species, native populations may undergo stress from increased disturbance events, including droughts, high volume rain events, and more intense storms. Though the impacts of invasive species will likely involve a gradual shift in species composition, frequent disturbance events associated with a changing climate may promote more rapid colonization of native habitat by invasive species (Beever et al. 2009; EPA CRE 2009). Extreme variation in freshwater flows may have impacts on fish phenology and habitat range (Osgood, 2008; Beever et al. 2009).

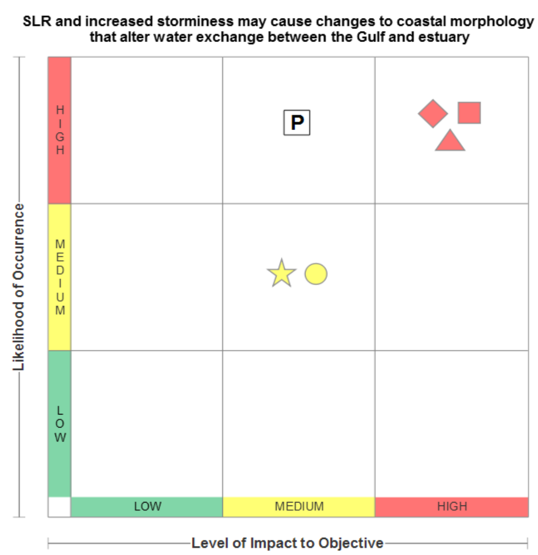
Water Quality Degradation

Objective WQ-1: *Maintain or improve water quality from year 2000 levels. By 2018, bring all impaired water bodies into a watershed management program such as reasonable assurance or basin management action plan. By 2015, remove at least two water bodies from the impaired list by improving water quality.*

This objective is vulnerable to all four of the primary climate stressors identified and is particularly vulnerable to interactions of multiple stressors. Population growth, development, and changing water resource demands will interact with changing conditions to impact water quality. Climate impacts may increase vulnerability of already stressed human infrastructure systems, such as stormwater overload and septic system failure, both of which were found to pose a high risk to this objective. The interaction of climate stressors with human systems may also be an opportunity for public engagement on issues of community resiliency. While Conservation Lands Workshop participants rated overloaded stormwater systems as high likelihood and high level of impact, septic system failure was not viewed by workshop participants as high likelihood or high impact.

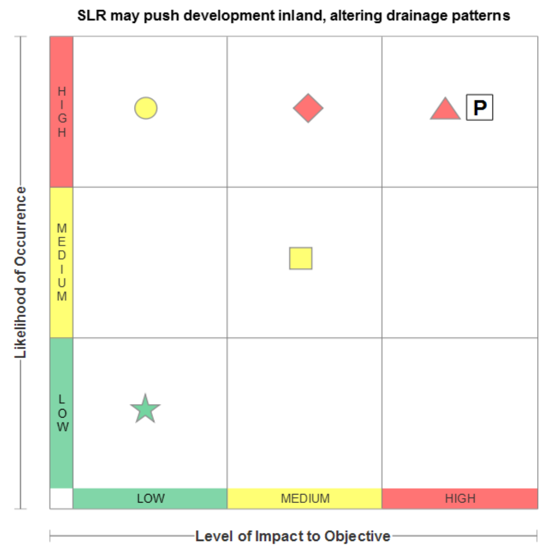
(15) Sea level rise and increased storminess may cause changes to coastal morphology and alter water exchange between Gulf and estuary

Coastal barrier island systems within the CHNEP study area may become more dynamic as a result of sea level rise and more intense storm events. These naturally dynamic systems respond to storm surge, winds, and other coastal influences. However, human alterations to coastal systems coupled with expected increase in storm surge and sea level rise may result in more dramatic changes to coastal morphology and require additional management (Burkett et al. 2005; FOCC 2010). Changes to these coastal systems, such as overwash, erosion, and the opening or closing of new or existing passes (Beever, personal communication), will affect the water exchange between the Gulf and estuaries, affecting water quality and the estuarine ecosystem. Considerations for this risk include the role of critical thresholds in adaptation planning and how to anticipate future changes. Human alterations to coastal systems, such as berms and protection measures for infrastructure may increase erosion effects and exacerbate the adverse effects of storm surge and should be considered in planning strategies for such systems (Burkett et al. 2005).



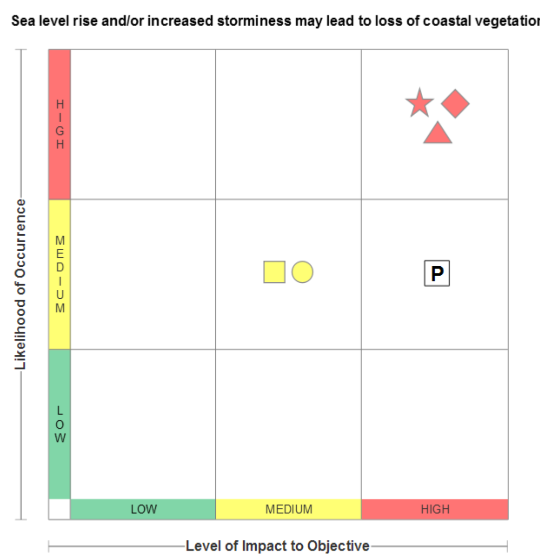
(16) Sea level rise may push development inland, altering drainage patterns

Indirect effects of sea level rise and storm events will impact water quality. As sea levels rise, measures taken to protect coastal infrastructure, such as shoreline hardening and movement of development to match shifting shorelines may alter drainage patterns and contribute to increased contaminants in waterways (Peterson et al. 2008). In the long run, rising seas may also claim previously developed or polluted sites that will affect newly inundated shallow marine environments (Wanless, personal communication). Precipitation changes, increased evapotranspiration, and changes in land use and water demands will affect the pattern and quantity of freshwater flowing downstream into the estuary system (Bates, 2008; SFWMD 2009; Carter et al. 2014). Sea level rise and resultant shifts in habitat, such as wetland quality and distribution, also have the potential to impact drainage patterns and water quality (EPA CRE 2009; Beever et al. 2009; Erwin 2009).

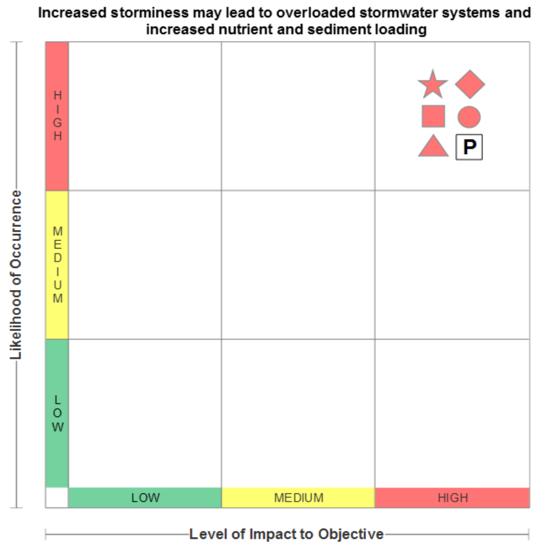


(17) Sea level rise and storminess may lead to loss of coastal vegetation

Sea level rise and increased storminess may accelerate the loss of coastal vegetation and have impacts on nutrient and sediment loading into coastal systems. Though natural systems are adapted to recover from periodic disturbance events, increased frequency of these disturbances may inhibit the ability of these communities to recover between events (Burkett et al. 2005). Natural migration of habitat landward will be impeded in some communities by human development and will result in habitat loss (Ruppert, personal communication). Mangrove communities in South Florida have demonstrated progressive deterioration from storm to storm (Wanless, personal communication). Increased demand for coastal armament as a result of storm surge and sea level rise may contribute to loss of coastal vegetation and increase in nutrient-rich runoff (Peterson et al. 2008).

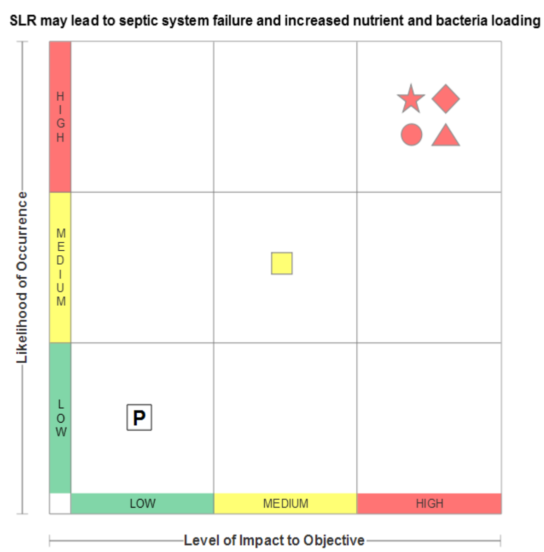


(18) Increased storminess may lead to overloaded stormwater systems and increased nutrient and sediment loading



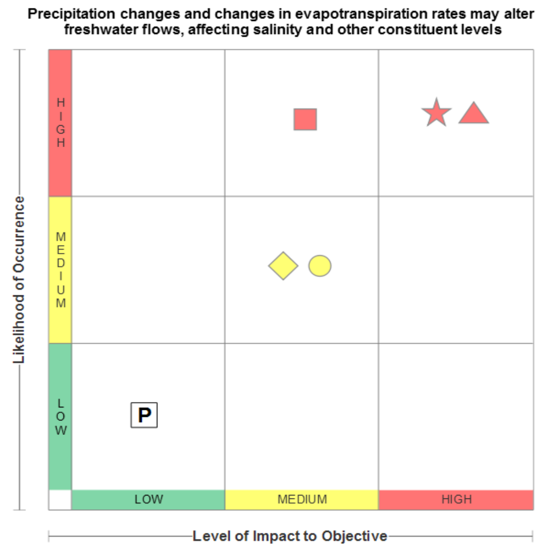
Stormwater systems that have been designed for current conditions will not be adequate to address future needs. Intensity of extreme rainfall events is expected to increase (Runkle, 2017; Carter et al. 2014). The effects of heavy precipitation events will exacerbate issues from land use and population growth (SFWMD 2009; Obeysekera et al. 2011). Increased storminess and high volume rain events will lead to overloaded stormwater systems and increased nutrient and sediment loading. The effects of inadequate stormwater systems are already being observed in Florida (SFWMD 2009; Wanless, personal communication). This risk illustrates the interactions of climate stressors with human infrastructure and coastal development and was consistently rated to be high likelihood and high impact.

(19) SLR may lead to septic system failure and increased nutrient and bacteria loading



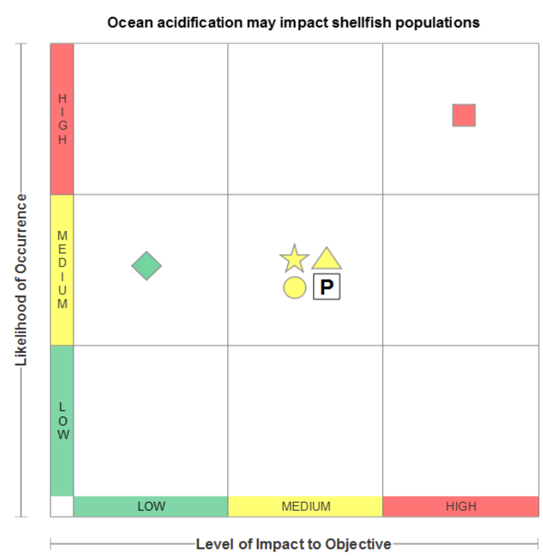
Another source of nutrient and bacteria loading in waterways will be septic failure caused by rising sea levels. Barrier island and coastal communities will be particularly susceptible to septic failure as sea levels continue to rise (Beever, personal communication), and septic failure is already a major issue in South Florida (Wanless, personal communication). While initial risk analysis indicated septic failure would be high risk, Conservation Lands Workshop participants assigned this risk a low likelihood and low level of impact, possibly highlighting opportunities for future public engagement and discussion of community resiliency as it relates to interactions with human systems.

(20) Precipitation changes and changes in evapotranspiration rates may alter fresh water flows, affecting salinity and other constituent levels



Seasonal and annual variations in rainfall patterns will affect the quality and quantity of freshwater inflows (Peterson et al. 2008). High volume rain events resulting in extreme freshwater flows will increase flushing of pollutants (Wanless, personal communication), alter salinity levels, and increase nutrient and sediment loads. Conversely, droughts and extended periods of low freshwater flow allow for saltwater to intrude farther upstream into tidal creeks, limiting suitable habitat for fish and other organisms (Chamberlain and Doering 1998; Tolley, 2010; Osgood, 2008). Where riverine systems are impeded by artificial structures, such as the Franklin Lock structure in the Caloosahatchee, low freshwater flows can result in habitat compression for species that depend on lower salinity levels (Tolley, 2010). Expert results indicated this would present a medium-high risk for the objective while workshop participants indicated low likelihood and low level of impact, highlighting another potential opportunity for community outreach.

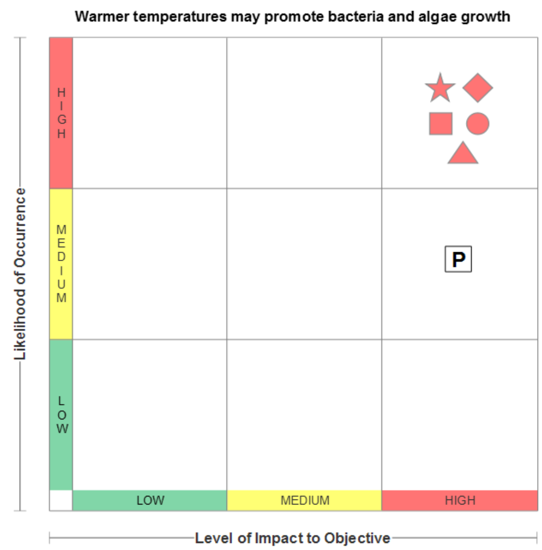
(21) Ocean acidification may impact shellfish populations



When atmospheric CO_2 dissolves in seawater, it reacts to form carbonic acid, increasing the acidity of the water and reducing the relative abundance of the carbonate ions necessary for calcifying organisms to produce shells (Doney, 2009). Shellfish such as oysters act as ecosystem engineers by creating habitat for other species, filtering water, and providing protection from storm events. The rate of ocean acidification on the coasts is more variable than the rate in open ocean due to the interactions of various factors, such as composition of freshwater inflows, nutrient levels leading to eutrophication, and upwelling (Cai et al. 2011; Feely, 2009; Miller, 2009). Along the Northern Gulf Coast, pH is expected to drop by .74 units by 2100, which could have significant impact on calcifying organisms and the quality of habitat supported by those organisms (Cai et al. 2011). In the CHNEP study area, the rate and extent of acidification is still uncertain, with experts indicating the effects are already being observed and will increase in severity as the century progresses (Beever, personal communication).

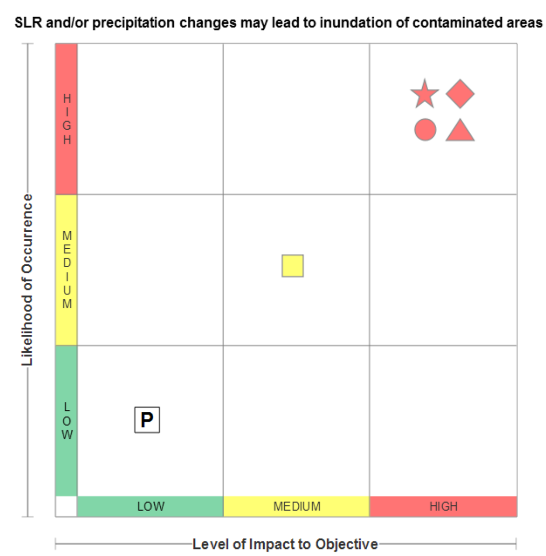
(22) Warmer temperatures may promote bacteria and algae growth

Warmer water temperatures may increase algae growth rates, resulting in algae blooms which can block sunlight and reduce oxygen availability. Some species of algae can also produce harmful toxins that adversely affect the health of humans and wildlife species. Warmer temperatures may favor harmful algae species by providing a competitive advantage over non-harmful species, increasing the likelihood of harmful algae blooms (HABs) and reduced water quality (EPA 2013). Longer dry periods and concentrated, high volume rain events may result in flushing of accumulated nutrients into water bodies, increasing the concentrations of nutrient levels in water bodies and promoting algal growth rates. Effects of HABs and warmed flood discharges are already being observed (Wanless, personal communication; Beever, personal communication).



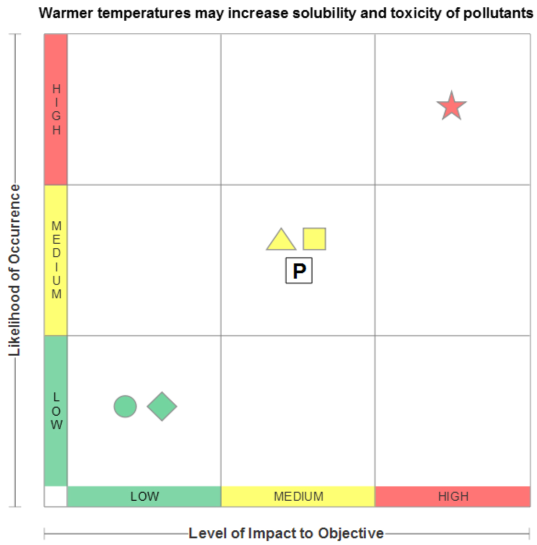
(23) Sea level rise and precipitation changes may lead to inundation of contaminated areas

Sea level rise, storm surge, and changes in precipitation patterns will increase likelihood of flooding in coastal and inland areas, including potentially contaminated areas such as landfills and corrective action sites (Peterson et al. 2008; EPA 2016). In inland communities, extreme rainfall events and increased flooding could increase the likelihood of contaminants entering water bodies (EPA 2016). The effects of flooding in contaminated areas are already being observed in South Florida, where heavily contaminated areas are more prevalent (Wanless, personal communication). While expert responses suggested this would be a high impact and high likelihood risk, workshop participants found the opposite (low likelihood and low level of impact to objective), making this risk one of the few highly divergent risks between initial risk analysis and workshop feedback. One explanation could be that workshop participants interpreted contaminated areas more narrowly as strictly Superfund and Brownfield sites that are not a significant issue in the CHNEP study area.



(24) Warmer temperatures may increase solubility and toxicity of pollutants

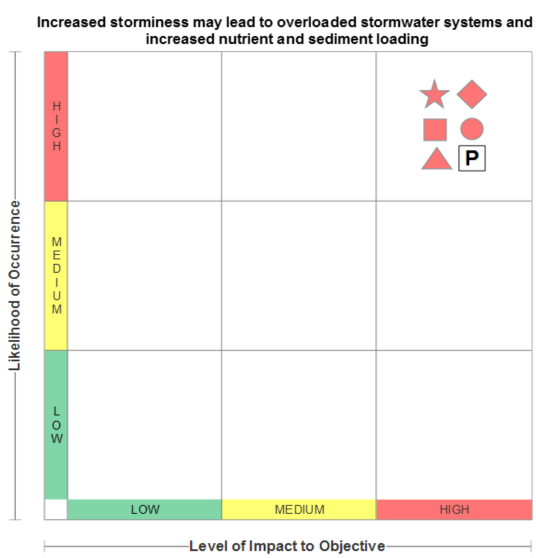
Warmer water temperatures will increase the toxicity of certain pollutants, including household chemicals, heavy metals, and pesticides (Lovett 2010). Warmer waters could also and enhance eutrophication by contributing to algal growth rates (EPA 2013) and reducing dissolved oxygen levels (Baron et al. 2008). Storm surge, flooding, and more frequent heavy rainfall events will contribute to large flushes of contaminants, the effects of which will be exacerbated by warmer water temperatures (Wanless, personal communication). High volume rain events followed by long dry periods may result in the flushing of large amounts of accumulated pollutants into water bodies and increased concentrations of pollutants in subsequent dry periods (Baron et al. 2008).



Objective WQ-2: *By 2020, develop and meet water quality criteria that are protective of living resources for dissolved oxygen, nutrients, chlorophyll a, turbidity, salinity, and other constituents.*

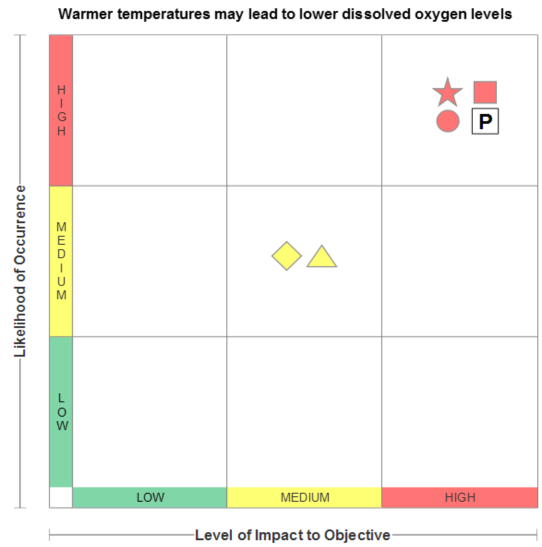
Four risks were identified for this objective and overloaded stormwater systems were found to pose high-risk. Similar to WQ-1, this objective will be impacted by interactions between climate stressors and human development and population growth. Risks that were rated high likelihood and high level of impact by a majority of participants include overloaded stormwater systems and loss of coastal vegetative buffer.

(25) Increased storminess may lead to overloaded stormwater systems and increased nutrient and sediment loading



The effects of inadequate stormwater systems are already being observed in Florida (Wanless, personal communication). More frequent heavy rainfall events will increase the likelihood of overloaded stormwater systems and increase runoff into water bodies. Climate effects on stormwater systems will aggravate challenges from development and population growth (SFWMD 2009). Changing conditions may also lead to overloading of sewage treatment plants that are not designed to meet the effects of hurricanes and sea level rise (SFWMD 2009; Wanless, personal communication). This risk was high likelihood and high level of impact by all experts surveyed and Conservation Lands Workshop participants.

(26) Warmer temperatures may lead to lower dissolved oxygen levels



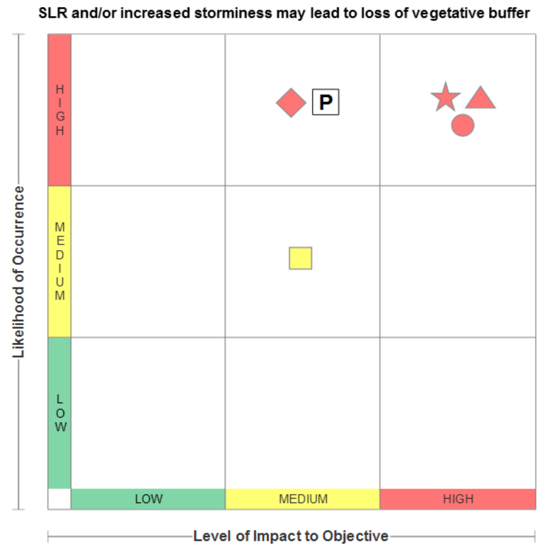
Dissolved oxygen levels decrease with warmer temperatures, limiting the growth and productivity of many aquatic organisms, including fish, invertebrates, and plankton (Beever, 2009). Warmer temperatures may also contribute indirectly to hypoxic conditions by promoting algae growth and increasing the likelihood of eutrophication (Boesch, 2007). Similarly, increased nutrient loading due to changes in precipitation patterns (e.g. higher river inflows) may also contribute to lower levels of dissolved oxygen by promoting algae growth and increasing likelihood of eutrophication (Boesch, 2007).

(27) Changes in precipitation and ET rates may alter fresh water flows, affecting salinity and other constituent levels

Changing precipitation patterns will affect both the quantity and the composition of fresh water flows. During periods of low rainfall, salinity regimes may intrude upstream and compress habitat for organisms in tidal creeks. Altered water flows may affect frequency of freshwater releases and pulse events, affecting salinity criteria for aquatic organisms including submerged aquatic vegetation, oysters, and zooplankton (Tolley et al. 2010, FGCU 2006, Chamberlain and Doering, 1998, Mazzotti 2008). Evapotranspiration is expected to increase with warmer temperatures (Bates, 2008; SFWMD 2009) and may affect water levels and supply systems. Under decreased rainfall scenarios, increased evapotranspiration will contribute to more frequent drying, loss of peat, and oxidation of organic soils and possible increase in mercury and sulfate release (Aumen et al. 2013).

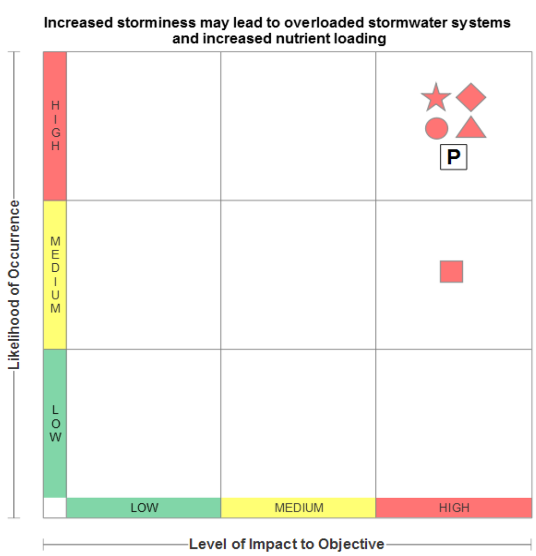
(28) SLR/storminess may lead to loss of vegetative buffer

Sea level rise and more intense storm events may accelerate the loss of coastal vegetation and have impacts on nutrient and sediment loading into coastal systems (Peterson et al. 2008; Beever et al. 2009). The greatest loss of vegetation will occur where landward migration is impeded by artificial structures, such as seawalls and bulkheads (Beever, personal communication). Mangrove communities in South Florida have demonstrated progressive deterioration from storm to storm (Wanless, personal communication). Increased demand for coastal armament and flood protection structures as a result of storm surge and sea level rise may contribute to loss of coastal vegetation and increase in nutrient-rich runoff.



Objective WQ-3**:** *By 2025, reduce severity, extent, duration, and frequency of harmful algal blooms (HABs), including macroalgae, phytoplankton and periphyton, through the identification and reduction of anthropogenic influences.*

Harmful algae blooms pose a significant threat to water quality in the CHNEP study area. These blooms can pose risks to wildlife and human health. Inadequate stormwater systems, warmer temperatures, and loss of coastal vegetation pose high risk to this objective. Additional concerns raised for this objective were the effects of Lake Okeechobee water releases and other major watershed nutrient discharges.



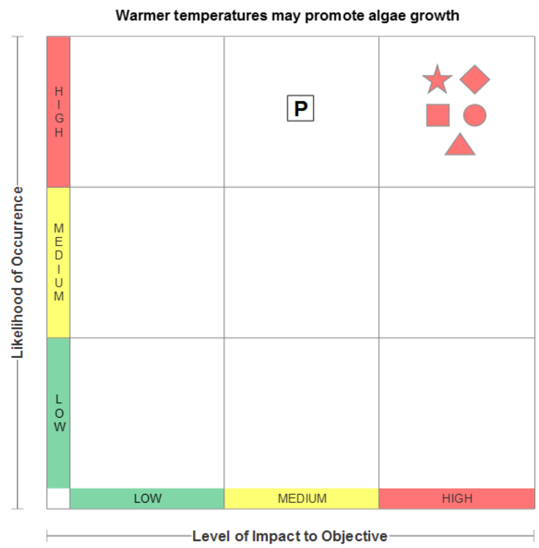
(29) Increased storminess may lead to overloaded stormwater systems and increased nutrient loading

Sources of nutrient runoff include fertilizers from residential and commercial lawns, animal waste, agricultural operations, and litter and oil on roads. An increase in heavy rain events can result in flushing of these nutrients into water bodies in a short period of time. Extended periods of low rainfall and lower water levels may increase concentrations of nutrients in water bodies (Peterson et al. 2008). Excessive nutrient levels may promote algal blooms.

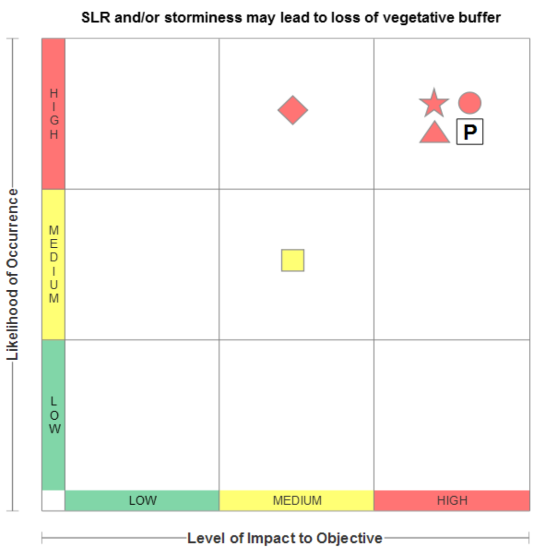
See previous risks: (18) and (25)

(30) Warmer temperatures may promote algae growth

Warmer water temperatures provide a competitive advantage to harmful algae species relative to non-harmful species (EPA 2013), increasing the likelihood of HABs. Warmer temperatures also result in increased thermal stratification in the water column, which can favor harmful algae, such as cyanobacteria and dinoflagellates, which can move to the surface and outcompete other algae species for nutrients and sunlight (EPA 2013). Periods of low rainfall may result in increased nutrient concentrations in water bodies, contributing to HABs.



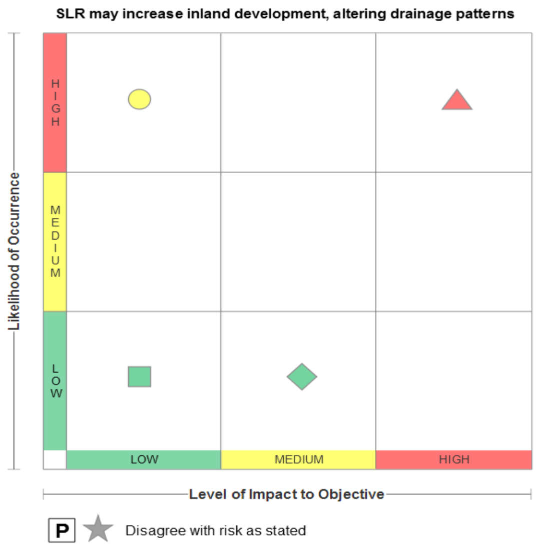
(31) SLR/storminess may lead to loss of vegetative buffer



Coastal vegetation provides valuable nutrient cycling and water filtration services that improve water quality. Loss of vegetation due to sea level rise and intense storm events may increase the amount of nutrients entering water bodies and contribute to algae blooms. Loss or migration of coastal vegetation may also alter drainage patterns, affecting quantity and quality of runoff.

See previous risks: (17) and (28)

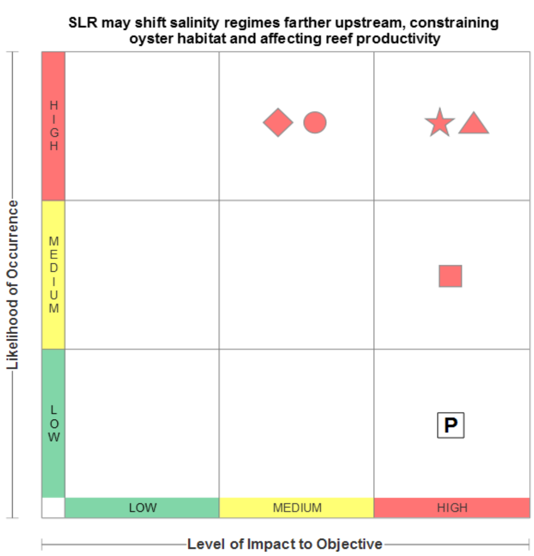
(32) SLR may increase inland development, altering drainage patterns



Changes in precipitation, temperature, and sea level rise may influence development patterns and land use (Peterson et al. 2008). Increased nuisance flooding and storm surge impacts will contribute to shoreline infrastructure and potential future development plans. Many different factors influence development patterns, and the rate of sea level rise by 2025 (timeframe of current objective) is not expected to be significant enough to drastically alter development patterns and this risk was found not to be high-risk or relevant to the objective stated by most risk analysis participants.

Objective WQ-4**:** By 2025, meet shellfish harvesting standards year round for the Myakka River conditionally restricted area and the conditionally approved areas of Lemon Bay, Gasparilla Sound, Myakka River, and Pine Island Sound.

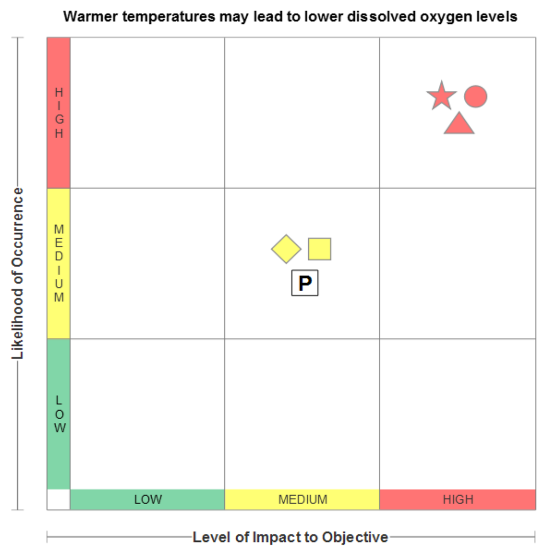
(33) SLR may shift salinity regimes farther upstream, constraining oyster habitat and affecting reef productivity



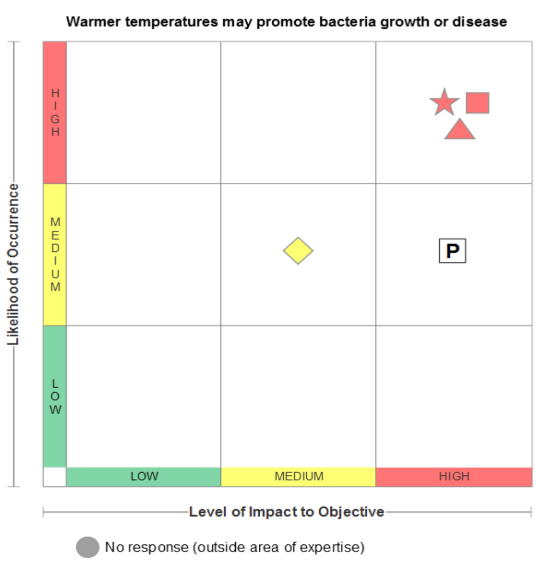
Oysters provide a range of environmental and economic benefits and have been identified as a Valued Ecosystem Component in the Caloosahatchee estuary (Chamberlain and Doering 1998). Oyster reefs provide essential food and habitat for a diverse range of species and have high recreational and commercial value. Reefs prevent coastal erosion and provide shoreline protection from wind and wave action. Oysters improve water clarity and quality by filtering particulates, nutrients, and sediments. Sea level rise or reduced freshwater inflow from rivers can result in increased saltwater intrusion in the estuary and shift optimal salinity regimes upstream. As salinity moves upstream, oyster habitat will be constrained due to the morphology of rivers and streams (Beever, personal communication).

(34) Warmer temperatures may lead to lower dissolved oxygen levels

Warmer water temperatures reduce the levels of dissolved oxygen available for marine organisms to breathe and survive. Other factors affecting DO levels include nutrient levels, freshwater flows, and sedimentation. Human impacts such as nutrient loading can affect the levels of dissolved oxygen in waterways by contributing to algae blooms that deplete oxygen levels during decomposition (Boesch, 2007, EPA 2013). High freshwater flows may increase fresh and salt water stratification and limit movement of oxygen from the surface to deeper in the water column. Increased turbidity can reduce light penetration and limit the productivity of photosynthetic organisms.



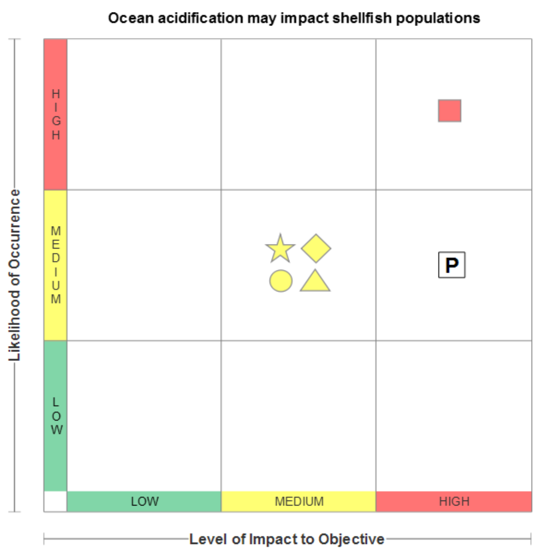
(35) Warmer temperatures may promote bacteria growth or disease



Because they feed by filtering water, shellfish can concentrate materials such as bacteria in their bodies. Sources of bacteria include wastewater overflows, septic system failures, pet waste, and stormwater runoff, particularly after heavy rain events. Both warmer water temperatures and higher salinities increase the susceptibility of oysters to the parasite *P. marinus* (Volety, 2014). Natural variability of flows between wet summer months (warmer temperatures and low salinity) and drier winter months (cooler temperatures and higher salinity) help prevent disease, but variation in flows, such as increased freshwater in winter or extended dry periods in summer may increase prevalence of disease among shellfish populations (Volety, 2014).

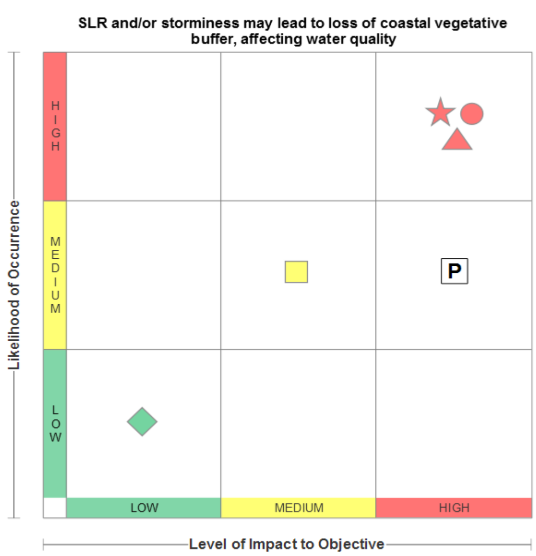
(36) Ocean acidification may impact shellfish populations

Higher concentrations of CO_2 in seawater reduce the calcium carbonate saturation state and relative availability of carbonate ions necessary for shell-forming organisms, including oysters (Doney 2009). In laboratory settings, many calcifying species have demonstrated decreased growth rates under conditions of higher CO_2 (Fabry et al. 2008; Doney 2009). Acidification in estuarine systems has also been shown to put stress on oyster larvae and negatively affect growth rates of larvae (Miller 2009). The effects of acidification in estuarine systems will be more variable than in open ocean habitat due to the natural heterogeneity of coastal systems, which are characterized by complex interactions of factors such as salinity, pH, nutrient levels and freshwater inflows (Miller et al. 2009). The combined effects of nutrient inputs, freshwater inflows, and eutrophication may make coastal systems particularly vulnerable to acidification (Feely et al. 2010; Cai et al. 2011). A case study of the Northern Gulf of Mexico found that pH was expected to drop by .74 by the end of the century, in part due to the impacts of eutrophication from nutrient-rich river inflows (Cai et al. 2011).



Oyster communities in the CHNEP study area provide a number of ecosystem services including habitat creation, shoreline stabilization, and water quality improvements. The rate and extent of ocean acidification in the CHNEP study area are still uncertain, with experts indicating the effects are already being observed and will increase in severity as the century progresses (Beever, personal communication).

(37) SLR/storminess may lead to loss of vegetative buffer, affecting water quality



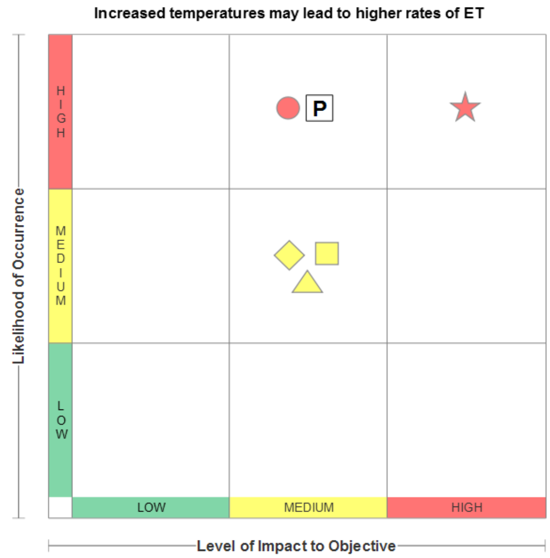
Coastal vegetation provides valuable nutrient cycling and water filtration services that improve water quality. Sea level rise and more intense storm events may accelerate the loss of coastal vegetation and have impacts on nutrient and sediment loading into coastal systems. Loss of vegetation may increase the amount of nutrients entering water bodies and contribute to algae blooms. The greatest loss of vegetation will occur where landward migration is impeded by artificial structures, such as seawalls and bulkheads (Beever, personal communication). Mangrove communities in South Florida have demonstrated progressive deterioration from storm to storm (Wanless, personal communication). Loss or migration of coastal vegetation may also alter drainage patterns, affecting quantity and quality of runoff.

See previous risks: (17) (28) and (31)

Hydrologic Alterations

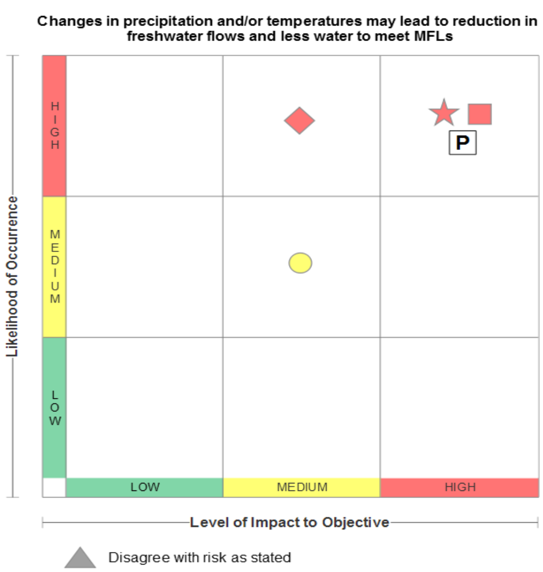
Objective HA-1: By 2020, identify, establish and maintain a more natural seasonal variation (annual hydrograph) in freshwater flows for Caloosahatchee River; Peace River and its tributaries; Myakka River, with special attention to Flatford Swamp and Tatum Sawgrass; Estero Bay and its tributaries.

(38) Increased temperatures may lead to higher rates of ET



Potential evaporation is expected to increase with warmer temperatures and may impact water availability, saltwater intrusion in aquifers, and surface water storage (Bates, 2008; SFWMD 2009; FOCC 2010; Carter et al. 2014). In south Florida, warmer temperatures are expected to increase evapotranspiration, though projections are uncertain (SFWMD 2009; Obeysekera 2011). IPCC projections indicate a possible increase in evapotranspiration up to 15 percent at the end of the 21st century compared to measurements from 1980 to 1999 (Bates, 2008). Increased evapotranspiration may lead to more severe droughts and may accelerate surface water loss. For decreased rainfall scenarios, ET will exceed rainfall and

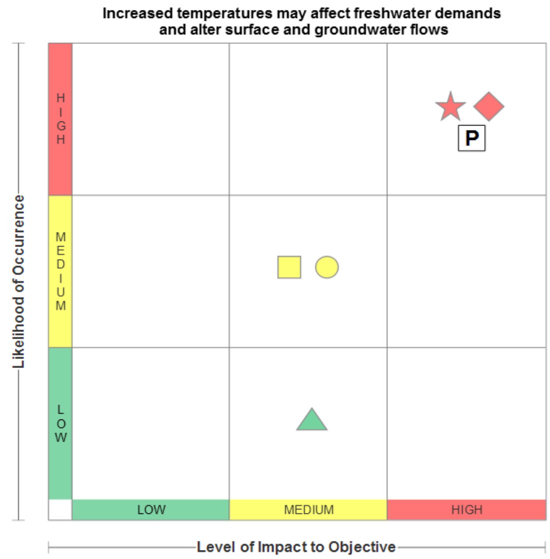
(39) Precipitation changes may lead to reduction in freshwater flows and less water to meet MFLs



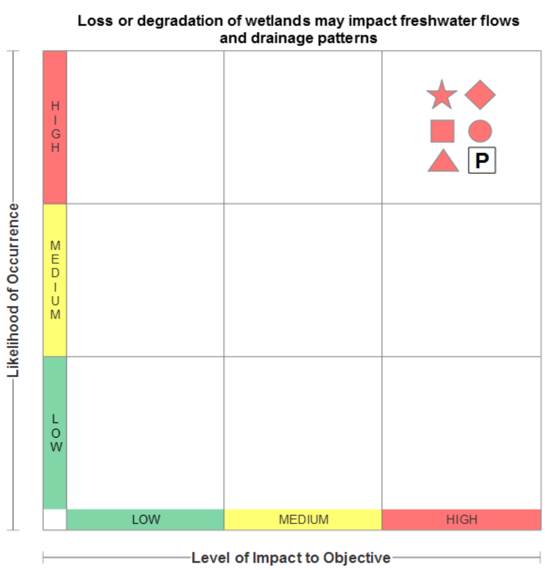
Changes in freshwater flows will depend largely on changes in timing and volume of precipitation, for which projections are uncertain. Decreased precipitation and increased temperatures may lead to increased freshwater demands and reduced freshwater flows. For decreased rainfall scenarios, depressed groundwater levels and sea level rise will increase the likelihood of saltwater intrusion (FOCC 2010). Competing water demands may reduce freshwater releases during dry season, allowing for greater saltwater intrusion upstream and affecting living resources. Conversely, increased frequency and intensity of extreme precipitation events may contribute to influxes of freshwater flows, nutrient and sediment loading, and reduced salinity.

(40) Increased temperatures may affect freshwater demands and alter surface and groundwater flows

Saltwater intrusion, increased evapotranspiration, and loss of wetlands could all impact our ability to maintain and restore more natural hydrology. Though precipitation projections are uncertain, reduced water availability is expected due to higher temperatures and evapotranspiration (Carter et al. 2014). The Cape Coral-Fort Myers area is one of the fastest growing metropolitan areas in the United States (Carter et al. 2014) and continued coastal development has the potential to amplify climate impacts in Southwest Florida (FOCC 2010). Changing water demands associated with population growth, human migration, and land use patterns will be exacerbated by higher temperatures and impacts on water availability (SFWMD 2009; Obeysekera 2011; FOCC 2010). Warmer temperatures and associated increases in evapotranspiration may compromise the performance of stormwater treatment areas (SFWMD 2009; FOCC 2010). Water use demands, particularly for agriculture and irrigation, are expected to increase with warmer temperatures and increased population (Carter et al. 2014; SFWMD 2009).



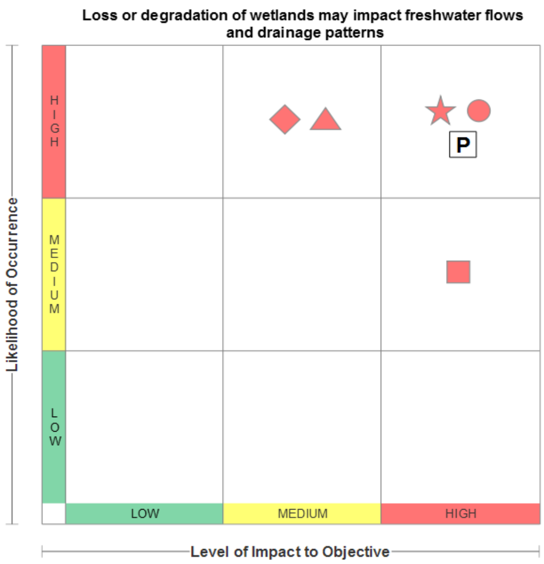
(41) Loss or degradation of wetlands may impact freshwater flows and drainage patterns



Wetlands provide valuable ecosystem services, including water storage and filtration and shoreline stabilization. Climate impacts will interact with population growth, human migration, and land use changes to impact wetland habitats and affect freshwater flows and watershed boundaries (Erwin 2009). Wetland locations, quality, and types will be affected by multiple interacting factors, including sea level rise, temperatures changes, subsidence, drought, storms, and land use (Burkett et al. 2005; Twilley, 2007; Erwin 2009). Though there may be no correlation between sea level rise and wetland changes over time, changes may occur once a threshold is reached (Burkett et al. 2005). Increased evapotranspiration and increased water demand with warmer temperatures will affect water availability and drainage patterns (SFWMD 2009; Obeysekera et al. 2011). More frequent or longer droughts may lead to dramatic shifts in community structure as saltwater intrudes into freshwater habitats and inland wetlands dry up (SFWMD 2009; Twilley, 2007; Carter et al. 2014).

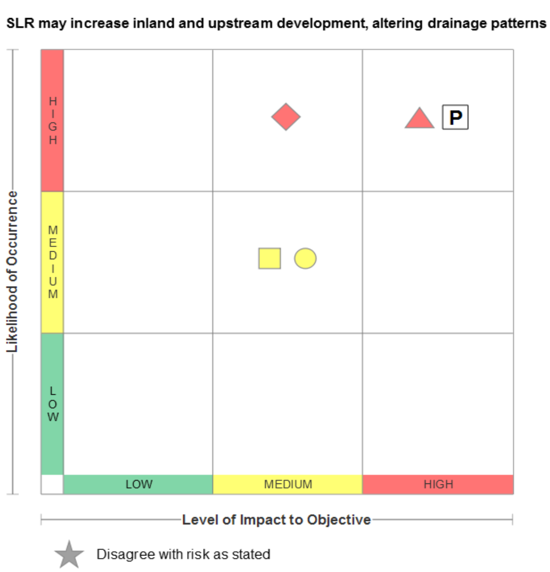
Objective HA-2: By 2020, restore, enhance and improve where practical historic watershed boundaries and natural hydrology for watersheds within the CHNEP study area, with special attention to Outstanding Florida Waters and Class I water bodies.

(42) Loss or degradation of wetlands may impact freshwater flows and drainage patterns



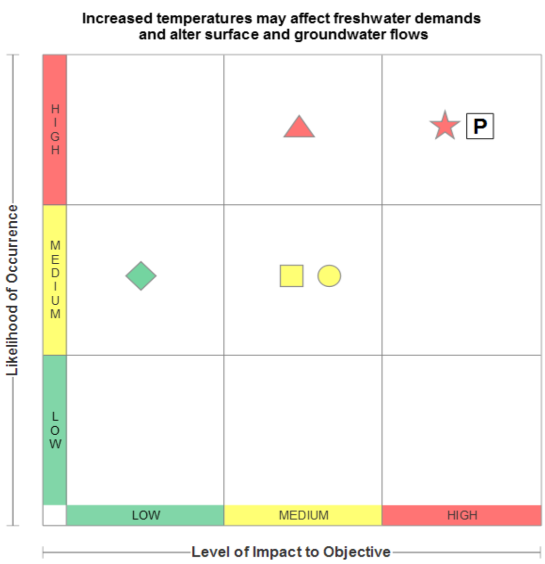
In addition to providing essential food and habitat for wildlife species, wetlands provide natural water storage and filtration and help lessen storm surge impacts by stabilizing shorelines (Twilley, 2007). Wetlands are particularly susceptible to climate change impacts that alter hydrological regimes (Erwin 2009). Impacts such as altered freshwater flows, warmer temperatures, sea level rise, and drought may compromise the capacity of wetland systems to provide valuable ecosystem services (Twilley, 2007; Erwin, 2009; Beever et al. 2009). More frequent inundation of coastal wetlands will increase vulnerability of coastal systems to storm surge (FOCC 2010) Changing climatic conditions will interact with existing pressures from development, population growth, and land use changes to stress wetland habitats.

(43) SLR may push development inland, altering drainage patterns



As sea levels rise, increased coastal armament and shifting development have the potential to impact drainage patterns. Precipitation changes, increased evapotranspiration, and changes in land use and water demands will affect the pattern and quantity of freshwater flowing downstream into the estuary system (Bates, 2008; SFWMD 2009). Sea level rise and resultant shifts in habitat, such as wetland quality and distribution, also have the potential to impact drainage patterns and water quality (EPA CRE 2009; Beever et al. 2009; Erwin 2009). In the CHNEP study area, land use changes and drainage ditches have led to loss or degradation of salt marsh habitat, and coastal development continues to impact wetland losses despite mitigation efforts (Beever et al. 2009; CHNEP 2013).

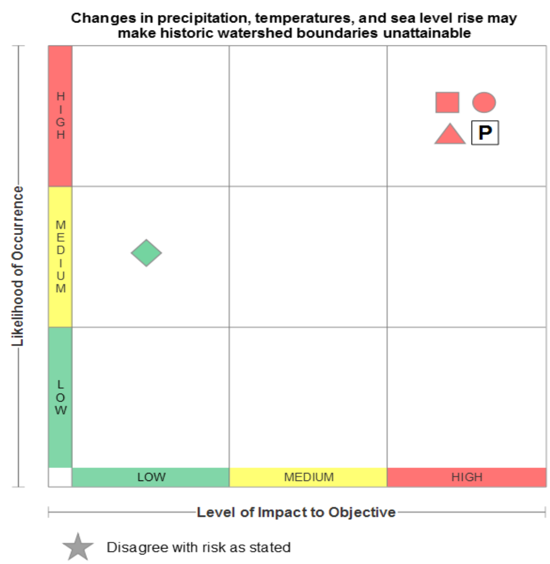
(44) Increased temperatures may affect freshwater demands and alter surface and groundwater flows



Water management challenges associated with population growth, development, and land use changes will be exacerbated by a changing climate. Warmer temperatures and increased evapotranspiration will lead to more rapid depletion of surface water storage systems and decreased water supply (SFWMD 2009). Water use demands, particularly for agriculture and irrigation, are expected to increase with warmer temperatures (Bates, 2008; SFWMD 2009). Warmer temperatures and associated increases in evapotranspiration may also compromise the performance of stormwater treatment areas (SFWMD 2009). Decreased rainfall could increase frequency or severity of drought (Obeysekera et al. 2011). Sea level rise may result in increased saltwater intrusion and reduced fresh water supply (SFWMD 2009; Obeysekera er al. 2011).

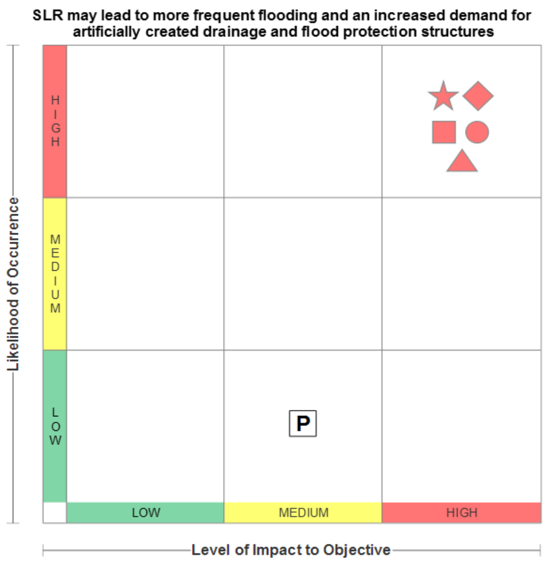
(45) Changes in precipitation, temperature, and sea level rise may make historic watershed boundaries unattainable

Climate stressors will amplify adverse effects of development and population growth on water resources in Florida (SFWMD 2009; Obeysekera 2011; EPA CRE 2009) and may contribute to more rapid or dramatic changes to watershed boundaries and historical hydrological regimes. Though the primary causes of historic hydrological alterations are dramatic land conversions and development and not related to climate change (Beever, personal communication), these impacts will be further exacerbated by changing conditions. Adaptive management will be essential in setting and achieving feasible hydrological restoration goals (Wanless, personal communication).



Objective HA-3: By 2020, enhance and improve to more natural hydrologic conditions water bodies affected by artificially created structures throughout the CHNEP study area. Reduce negative hydrologic effects of artificially created structures such as weirs, causeways, dams, clay settling areas and new reservoirs.

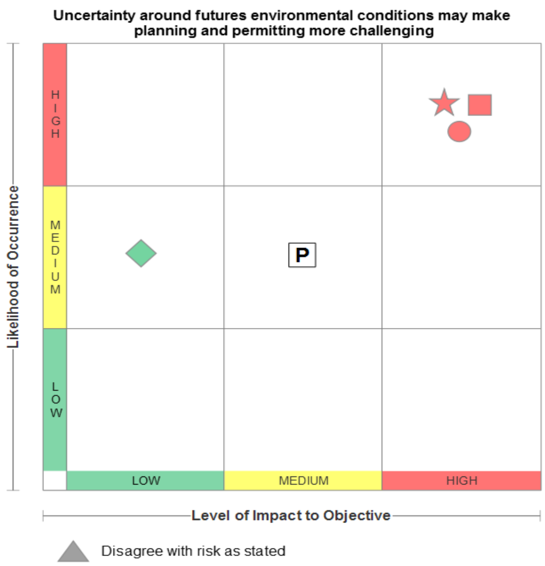
(46) SLR may lead to more frequent flooding and an increased demand for artificially created drainage and flood protection structures



Water-control structures are used to regulate the quantity and timing of freshwater flows and can have adverse effects on living resources. These structures are used to store or divert water during dry seasons or to release excess water and prevent flooding. Sea level rise, heavy rainfall events, and storm surge may contribute to flooding concerns and increase the demand for artificial structures. These measures will not solve the problem of sea level rise in the long run but may alter the natural hydrologic conditions of water bodies affected by artificial structures (FOCC 2010; Beever, personal communication). Potential impacts include altered drainage patterns and variations in seasonal flows of freshwater with impacts to wildlife and habitat quality.

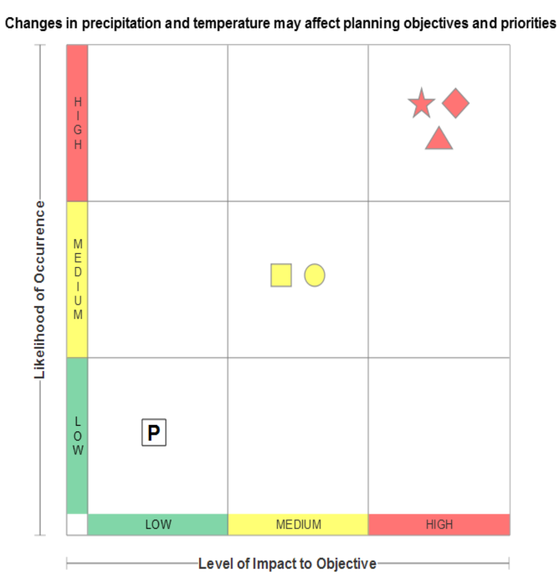
Objective HA-4: By 2020, for each watershed, identify and recommend additional reforms to improve linkages between local, water management district, state and federal government development permitting and capital programs affecting water storage, flood control and water quality. By 2025, implement the additional reforms.

(47) Increased uncertainty around future environmental conditions may make permitting more challenging



Although changing conditions create greater challenges in water management and potential uncertainty in future conditions, there is greater uncertainty when climate change impacts are not considered (Beever, personal communication). Though there is still uncertainty for the rate and degree of future changes, there is broad consensus about many anticipated effects (sea level rise, storm intensity, ocean acidification) in Florida that allow for effective planning (Wanless, personal communication).

(48) Changes in precipitation, temperature, and sea level rise may affect planning objectives and priorities.



Changing conditions will create new challenges for water management in Florida and are already affecting priorities for managers. Sea level rise and storm surge will be of particular concern in the short-term for coastal communities (FOCC 2010). Identifying needs and future planning objectives will be critical for successful adaptation strategies. A survey of 131 local land use plans found that along the Atlantic coast of the U.S., around 60% of land below elevation of 1 meter is developed and less than 10% of land below 1 meter has been allocated for conservation (Titus et al. 2009). As urban growth continues, this development may prevent inland migration of wetland communities as well as increase the vulnerability of coastal infrastructure (FOCC 2010). Failure to incorporate changing conditions into planning priorities may compromise the ability of communities to adapt and recover from impacts.

Summary and Conclusion

Of the 48 climate risks analyzed, risks that were consistently found to have high likelihood of occurrence and high impact to CCMP quantifiable objectives were overloaded stormwater systems, septic failure, loss of coastal vegetation, and habitat loss or degradation.

14 risks were identified for the priority area fish and wildlife habitat loss. Changes to historical habitat were evaluated to pose the highest risk to this priority area. Objective FW-1 was found to have the greatest vulnerability, with 6 medium-high risks, including loss of coastal and shallow water habitat, shoreline erosion, changes to plant zonation, and alteration of shellfish habitat. For objective FW-2, highest risks were related to the effects of sea level rise and storminess on habitat loss and migration. For objective FW-2, high-medium risks include habitat loss for native populations and increased disturbance events to native populations.

For priority area water quality degradation, overloaded stormwater systems were consistently found to pose a high risk to quantifiable objectives. Other high likelihood, high impact risks include failed septic systems, warmer temperatures promoting bacteria and algae growth, heavy rainfall leading to loss of vegetation and increased nutrient runoff, and effects of sea level rise on oyster productivity. Multiple risks for this priority area were related to the interactions of multiple stressors with human activity. Climate impacts may increase vulnerability of already stressed human infrastructure systems, such as stormwater overload and septic system failure (both high-risk to WQ-1). Objective WQ-1 had the highest number of high-medium risks evaluated including: overloaded stormwater systems, septic system failure, changes to fresh water flows, increased bacteria and algae growth, and nutrient loading from heavy precipitation events. Main concerns for objective WQ-2 are overloaded stormwater systems (high risk), lower dissolved oxygen levels, and loss of vegetative buffer. For objective WQ-3, the highest risks were overloaded stormwater systems, increased algae growth due to warmer temperatures, and loss of coastal vegetation. For WQ-4, medium-high risks include effects of sea level rise on oyster habitat, warmer temperatures promoting bacteria growth and disease in shellfish, and lower dissolved oxygen levels.

For the priority area hydrologic alterations, 11 risks were analyzed for four quantifiable objectives. For objective HA-1, all four risks analyzed were found to be high-medium risk, with the highest risk being the loss or degradation of wetlands and resultant impacts on drainage patterns. Degradation of wetland was also rated as high risk for quantifiable objective HA-2. Quantifiable objectives HA-3 and HA-4 have the fewest number of risks identified and are primarily related to interactions with human infrastructure and development.

The management conference members acknowledged during the review process that there are identified risks that are beyond the control of the CHNEP, and, as a result, the associated goals may be unobtainable

The final step in the vulnerability assessment process is to present the results of the risk analysis for management conference review. Based on results of the risk analysis, CHNEP staff and management conference members will decide how to revise, eliminate, or add quantifiable objectives to the CCMP to reflect how the quantifiable objectives need to be adapted to minimize risks. This will be done as part of the CHNEP CCMP update currently underway and targeted for completion in spring 2019.

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Appendix: Background and Methodology

Communication and Consultation

The first step in conducting this vulnerability assessment was to identify key stakeholders and establish a plan for stakeholder involvement throughout future project steps. To accomplish this step, this vulnerability assessment project was introduced to the four CHNEP management conference committees – Policy Committee, Management Committee, Technical Advisory Committee, and Citizens Advisory Committee – in the winter of 2016. Each management conference committee was made aware of the purpose of the vulnerability assessment and was asked to provide input as to individuals who should be involved in the assessment process, and CHNEP staff identified additional individuals that might be able to provide subject area expertise. Staff reached out to the individuals identified to provide information about the vulnerability assessment and to schedule a stakeholder meeting for interested parties.

A public stakeholder meeting was then held on February 3, 2017. The goal of the meeting was to share science-based projections of climate change identified during literature review and to receive input on associated vulnerabilities to the CCMP quantifiable objectives.

During the meeting, participants were provided with an overview of climate change projections and a list of significant potential effects that may occur in Southwest Florida as a result of climate change (excerpted from Beever et al. 2010). After group discussions regarding risks associated with each quantitative objective, a survey was given at the end of the meeting to all participants to gauge the perceived vulnerability of each of the CHNEP CCMP quantitative objectives and to gather additional information.

Establishing the Context for the Vulnerability Assessment

The purpose of this step was to review climate change impacts to the CHNEP study area and identify organizational goals presented in the CCMP that are vulnerable to climate change.

The expected magnitude and extent of climate change drivers in the Southeast United States were taken from the projections in Third National Climate Assessment (Carter et al. 2014). Three key points were highlighted in the Southeast Regional Assessment:

1. Sea level rise poses widespread and continuing threats to both natural and built environments and to the regional economy.
2. Increasing temperatures and the associated increase in frequency, intensity, and duration of extreme heat events will affect public health, natural and built environments, energy, agriculture, and forestry.
3. Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and affect the region's economy and unique ecosystems.

A literature review was conducted by staff to identify projected climate change stressors within the CHNEP study area. Based on the literature review, four primary climate change stressors were identified for the CHNEP study area:

1) Increased temperatures
2) Change in precipitation patterns
3) Sea level rise
4) Ocean acidification

A summary of relevant projections was compiled to inform the risk identification and risk analysis. An initial summary of projections was presented at the February 3 stakeholder meeting and has since been updated to include the new NOAA sea level rise projections released in 2017 (Sweet et al.). The regional sea level rise projections used are based on the Fort Myers tide gauge and are the projections used to inform the National Climate Assessment.

As part of the February stakeholder meeting, each of the CCMP quantifiable objectives was evaluated to determine if and how each of the four primary climate change stressors may affect the ability of the CHNEP to meet its organizational objectives in the future. Participants were presented with a summary of projections and asked to rate the level of vulnerability of each quantifiable objective to each of the four primary climate stressors. The results of the stakeholder survey are summarized below. [GRAPHIC]

WQ1	High	FW1	High	HA1	Moderate	SG1	Not Vulnerable
WQ2	High	FW2	Moderate	HA2	Moderate	SG2	Not Vulnerable
WQ3	High	FW3	High	HA3	High	SG3	Not Vulnerable
WQ4	Moderate			HA4	Low/Moderate	SG4	Not Vulnerable

Risk identification

The next step in the vulnerability assessment was to identify climate change risks that may impact the ability of the CHNEP to meet its CCMP goals.

This was accomplished through the February 2017 stakeholder meeting where members were presented with a list of potential climate change effects and asked to brainstorm how these impacts may affect the ability of the CHNEP to accomplish quantifiable objectives in the four priority areas of water quality degradation, fish and wildlife habitat loss, hydrologic alterations, and stewardship gaps. The results of this stakeholder meeting were reviewed and augmented by additional staff research to compile a list of climate risks, each associated with a specific organizational objective. Each risk was formatted to relate from one of the primary climate change stressors (increased temperatures, sea level rise, precipitation changes, and ocean acidification) to an impact on a specific organizational objective, outlining a pathway of how that climate impact could impact the organization's ability to reach its objective.

The results of the risk identification were consistent with the survey results of relative vulnerability by objective. No risks were identified for the four Stewardship Gap quantifiable objectives, and these were viewed by a majority of participants not to be vulnerable. Many climate change impacts identified were found to affect multiple CCMP quantifiable objectives. The results of the risk identification are summarized below.

Protect, enhance, and restore native habitats	• SLR may cause loss of existing shallow water and coastal habitats • SLR may cause existing protection areas/guidelines to become mismatched or inaccurate • SLR may shift salinity regimes farther upstream, constraining oyster habitat and affecting reef productivity • SLR may reduce less light penetration and affect seagrass populations • Warmer temperatures may affect plant zonation • Increased temperatures may alter evapotranspiration rates and water availability in wetlands • increased storminess may increase shoreline erosion and lead to loss of beaches and wetlands • ocean acidification may impact shellfish and condition of habitat created by shellfish
By 2020, achieve a 100 percent increase in conservation, preservation, and stewardship lands	• SLR may cause loss of existing shallow water and coastal habitats • SLR may increase inland development and limit new lands available for conservation • SLR and increased storminess may increase shoreline erosion and loss of beaches and wetlands
By 2020, achieve controllable levels of invasive exotic plants and exotic nuisance animals	• SLR may push salinity regimes farther upstream, affecting plant zonation • SLR may lead to habitat loss, putting increased stress on native populations • Warmer temperatures may promote the spread of invasive species • Increased storminess may increase disturbance events to native populations
Maintain or improve water quality from year 2000 levels	• SLR/storminess may cause changes to coastal morphology that alter water exchange between Gulf and estuaries • SLR/storminess may lead to loss of coastal vegetation • SLR may increase inland development, altering drainage patterns • SLR may lead to septic system failure and increased bacteria loads • Precipitation changes and changing ET rates may affect freshwater flows, affecting salinity and other constituent levels • Warmer temperatures may increase solubility and toxicity of pollutants • Warmer temperatures may promote bacteria and algae growth • Increased storminess may lead to overloaded stormwater systems and increased nutrient and sediment loading • SLR/storminess may lead to inundation of contaminated areas • Ocean acidification may impact shellfish populations

By 2020, develop and meet water quality criteria for dissolved oxygen, nutrients, chlorophyll *a*, turbidity, salinity, and other constituents	• SLR/storminess may lead to shoreline hardening and loss of vegetative buffer • Warmer temperatures may lead to lower dissolved oxygen levels • Precipitation changes and changing ET rates may affect freshwater flows, affecting salinity and other constituent levels • Increased storminess may lead to overloaded stormwater systems and increased nutrient and sediment loading
By 2025, reduce severity, extent, duration, and frequency of HABs	• SLR/storminess may lead to loss of vegetative buffer • SLR may increase inland development, altering drainage patterns (e.g. volume and distribution of runoff, extent of stormwater discharge area) • Warmer temperatures may promote algae growth • Increased storminess may lead to overloaded stormwater systems and increased nutrient loading
By 2025, meet shellfish harvesting standards year round	• SLR may shift salinity regimes farther upstream, constraining oyster habitat and affecting reef productivity • Ocean acidification may impact shellfish populations • Warmer temperatures may lead to lower dissolved oxygen levels • Warmer temperatures may promote bacteria growth or disease • SLR/storminess may lead to loss of vegetative buffer, affecting water quality
By 2020, identify, establish, and maintain a more natural seasonal variation in freshwater flows	• Increased temperatures may lead to higher rates of ET • Precipitation changes may lead to reduction in freshwater flows and less water to meet MFLs • Increased temperatures may affect freshwater demands and alter surface and groundwater flows • Loss or degradation of wetlands may impact freshwater flows and drainage patterns
By 2020, restore, enhance, and improve practical historic watershed boundaries and natural hydrology for watersheds	• Loss or degradation of wetlands may impact freshwater flows and drainage patterns • SLR may push development inland, altering drainage patterns • Increased temperatures may affect freshwater demands and alter surface and groundwater flows • Changes in precipitation, temperature, and sea level rise may make historic watershed boundaries unattainable
By 2020, enhance and improve to more natural hydrologic conditions water bodies affected by artificially created structures	• SLR may lead to more frequent flooding and an increased demand for artificially created drainage and flood protection structures
By 2020, for each watershed, identify and recommend additional reforms to improve linkages between development permitting and capital programs affecting water storage, flood control, and water quality	• Changes in precipitation and temperature may affect planning objectives and priorities. • Increased uncertainty around future environmental conditions may make permitting more challenging

Risk analysis

Fourth, the vulnerability assessment process involved determining an initial characterization of likelihood and level of impact for each risk based on expert review. These risks were then analyzed based on the most recent climate change data for the study area in order to determine the likelihood and level of impact of each risk. Five experts were surveyed in areas relating to climate science and coastal planning and asked to review the list of risks compiled and agree or disagree with the categorization of a risk, then rate the risk on a qualitative scale (low, medium, high) for both likelihood of occurrence and level of impact to the specified objective. These results were then compiled and reviewed by staff to create visualizations of the likelihood and impact for each risk identified. In addition to expert review, risks were analyzed by participants at the 2018 Conservation Lands Workshop through an interactive exercise.

Conservation Lands Workshop

On March 2, 2018, the CHNEP hosted a Conservation Lands Workshop that brought over eighty private citizens, land managers, water resource managers, hydrology modelers, and other environmental professionals together to gather their risk analysis input. During the workshop, participants were presented with one or more CCMP quantifiable objectives and a list of potential climate change risks and asked to work with their group members to determine a likelihood and impact rating for each risk. The results of this workshop are shown on each risk analysis matrix. In some cases, large discrepancies exist between expert consensus and the determinations made by participants in the workshop. These variations in response could help to identify opportunities for public education and engagement around climate resiliency. For quantifiable objectives FW-2 and FW-3, the Conservation Lands Workshop activity was not completed using the correct list of risks, and responses were not included on visualization matrices.

Risk evaluation

The final step in the vulnerability assessment process is to present the results of the risk analysis for management conference review. Based on results of the risk analysis, CHNEP staff and management conference members will decide how to revise, eliminate, or add quantifiable objectives to the CCMP to reflect how quantifiable objectives need to be adapted to minimize risks. This will be done as part of the CHNEP CCMP update currently underway and targeted for completion in spring 2019.