Embracing Our Future

SARASOTA BAY ESTUARY PROGRAM
CLIMATE VULNERABILITY ASSESSMENT

October 2017

SARASOTA BAY
ESTUARY PROGRAM
Restoring Our Bays

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CONTENTS

CITATION

SBEP and Shafer Consulting, LLC. 2017. Embracing Our Future: Sarasota Bay Estuary Program Climate Vulnerability Assessment. Prepared for the Sarasota Bay Estuary Program (SBEP) and United States Environmental Protection Agency. 48 pp.

ACKNOWLEDGEMENTS

This project was funded through a U.S. Environmental Protection Agency (US EPA) Climate Ready Estuaries Grant to the Sarasota Bay Estuary Program (SBEP) in Sarasota, Florida. The project was managed by Darcy Young of SBEP and Felicia Burks of the U.S. Environmental Protection Agency, Region IV. Development of this Vulnerability Analysis was guided by the US EPA's Being Prepared for Climate Change; A Workbook for Developing Risk-Based Adaptation Plans (EPA 2014). SBEP thanks its partner agencies, its Technical and Citizens Advisory Committees, the Science and Environment Council of Southwest Florida, and the many subject experts and citizens who participated in the vulnerability assessment process.

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photo credit: David Shafer

I. EXECUTIVE SUMMARY

Sarasota Bay is an economic engine valued at $11.8 billion (Hindsley 2012). A healthy Sarasota Bay generates employment, coastal property value, tax revenue, and tourism. The Sarasota Bay Estuary Program (SBEP) was established in 1989 to develop a plan to coordinate the restoration of Sarasota Bay among various federal, state, and local partners. As part of the National Estuary Program (NEP), SBEP was tasked with implementing parts of the Clean Water Act under the Environmental Protection Agency (EPA). Restoration partners, including EPA, Florida Department of Environmental Protection (FDEP), Southwest Florida Water Management District (SWFWMD), Sarasota County, Manatee County, City of Sarasota, City of Bradenton, and Town of Longboat Key entered into an Interlocal Agreement in 2004, pledging to work together and with SBEP toward a healthy and well-managed Sarasota Bay.

SBEP completed this Climate Vulnerability Assessment with funding from the EPA Climate Ready Estuaries Program to ensure that SBEP can continue to successfully work toward its goals of water quality improvement, habitat restoration, and citizen involvement in the face of climate change. SBEP staff, local experts, and citizen stakeholders collaborated to identify specific threats from four climate change stressors (sea level rise, warming air and water temperatures, changes in precipitation, and ocean acidification) and to evaluate how these threats might affect efforts by SBEP and its partners to achieve Program goals in the SBEP Comprehensive Conservation and Management Plan (SBEP CCMP 2014). Threats to CCMP implementation were ranked according to their relative likelihood of occurrence and consequence to SBEP goals, as analyzed by experts and concurred by SBEP staff and partners and by community stakeholders.

This Assessment identified 54 threats across six CCMP Action Plans (SBEP CCMP 2014). Twenty-four threats were deemed to be high likelihood and high consequence. The process of stakeholder and expert engagement also highlighted priority research questions related to climate change vulnerability. Questions were incorporated into a summary of research and technical needs that will be used by SBEP staff to inform resource allocation for research in future work plans.

In 2018, SBEP will incorporate the highest likelihood-highest consequence threats into an Adaptation Plan for SBEP's CCMP. The 2019 revision of SBEP's CCMP will incorporate key elements from the Adaptation Plan by prioritizing actions to reduce the probability of negative climate change impacts on water quality enhancement, habitat restoration, and citizen involvement in Sarasota Bay.

II. INTRODUCTION

Florida is one of the most at-risk states in the United States for potential impacts from climate change, with over 1,200 miles of coastline and nearly 4,500 square miles of estuaries and bays. Florida is part of the Atlantic Coastal Plain with a maximum elevation of less than 400 feet (Florida Oceans and Coastal Council 2009), making it prone to impacts from flooding and sea level rise. Increasing greenhouse gas (GHG) emissions continue to cause changes in precipitation, sea level, air and water temperatures, and ocean acidification in the Southwest Florida Region (Easterling et al. 2017), which put communities, habitats, and wildlife at risk.

During preparation of this Vulnerability Assessment, SBEP gathered stakeholder and expert input regarding potential threats from four climate stressors: sea level rise, changes in precipitation, warming air and water temperatures, and ocean acidification.

Through workshops and brainstorming sessions, stakeholders and experts identified vulnerabilities of CCMP Goals to one or more of the four climate stressors. Following EPA recommended methodology for identifying and assessing climate risks (EPA 2014), vulnerability was defined as a threat that would impact achieving a CCMP goal. Identified threats were assessed in terms of how likely they were to occur and how severe their impact might be on CCMP Goals. This Vulnerability Assessment outlines SBEP CCMP Goals, existing conditions of the Sarasota Bay Region, status of climate stressors, and a risk analysis of likely threats.

Comprehensive Conservation and Management Plan Goals

The creation of the Sarasota Bay Estuary Program (SBEP) in 1989 gave the region the means to restore and comprehensively manage the Bay. SBEP is part of the National Estuary Program network, which was established under 1987 Clean Water Act Amendments to improve the quality of Estuaries of National Significance. Each Estuary Program in the network is a unique voluntary program that operates through partnerships with the Environmental Protection Agency and other public and private sector organizations. SBEP operates collaboratively with its major partners and other organizations involved in watershed management. As part of the initial management process, SBEP created a Comprehensive Conservation Management Plan (CCMP), which is updated every five years.

The EPA has set a target for all local Estuary Program CCMPs to be "climate ready" by 2020. To integrate climate impacts into the upcoming 2019 SBEP CCMP revision, this Climate Change Vulnerability Assessment focused on six goals from the 2014 SBEP CCMP that were deemed to be vulnerable to potential climate change threats within the next 30 years:

1. Improve water transparency.
2. Manage the quantity and improve the quality of stormwater runoff to Sarasota Bay.
3. Restore shoreline and wetland habitats and eliminate further losses
4. Restore and sustain fish and other living resources in Sarasota Bay.
5. Provide increased levels of managed access to Sarasota Bay and its resources.
6. Engage, educate, and encourage environmental stewardship of Sarasota Bay and its resources.

photo credit: David Shafer

III. SARASOTA BAY

Sarasota Bay is a 56-mile-long coastal lagoon on the southwest coast of Florida. Its watershed spans from Anna Maria Sound in the north to the Venice Inlet in the south (Figure 1). The region lies entirely within the Southern Gulf Coastal Lowlands and covers about 455 square miles. The watershed is highly developed and consists of agricultural, residential, commercial, and light industrial land uses (Table 1).

Greater Sarasota Bay is comprised of one large bay segment, Big Sarasota Bay, and several smaller embayments, including Palma Sola Bay in the north and Roberts Bay, Little Sarasota Bay, and Blackburn Bay in the south (Figure 1). Numerous tidal creeks flow into these embayments, ranging in size from the largest (Phillippi Creek, with a drainage area of 36,417 acres) to the smallest (Palma Sola Creek, with a drainage area of 900 acres).

Each embayment is unique, differing in overall size, shape, water depth, shoreline features, habitat, and sediment characteristics. As a result, each embayment differs in water circulation, freshwater inputs, nutrient loads, and other variables.

Figure 1. Sarasota Bay Estuary Program segments and their watersheds. Source: SBEP CCMP 2014.

Natural Resources

Sarasota Bay area ecosystems support a diverse assemblage of plants, fish, and other wildlife. This interconnected web of habitats is as biologically productive as some of the world's most celebrated rain forests. The estuary's oyster and hardbottom reefs, seagrass beds, salt marshes, wetlands, and tidal creeks support more than 1,400 different species (SBEP 1990). About 22% of fish sampled in Sarasota Bay are important commercial and recreational species, including Spotted Seatrout, Snook, Sheepshead, Red Drum, Grouper, Snapper, and Mackerel (MacDonald et al. 2015).

In addition to providing vital forage and shelter needs, the Sarasota Bay area's mosaic of ecosystems contribute to water quality, nutrient cycling, and a variety of other ecosystem services. For example, 13,468 acres of seagrass (SWFWMD 2016) and oyster reefs in the bay play a vital role in filtering and removing aquatic pollutants. Seagrasses, mangroves, and other shoreline vegetation help stabilize banks, protect against storm surge, and serve as true carbon sinks — meaning that the carbon they absorb remains stored in soils even after the seagrasses and mangroves die and decay (Fourqurean et al. 2012). Globally, oceans and bays are responsible for absorbing nearly one third of all carbon emissions (Le Quere 2012) and over 90% of all excess global warming heat (IPCC 2014). They also produce about 70% of atmospheric oxygen (Walker 1980).

Ensuring that local systems are healthy and protected will assure the large-scale benefits of these systems.

History and Land Use

Sarasota Bay and surrounding waterways from Tampa Bay to Gasparilla Sound were historically separated by barrier islands, sandbars, mangrove islands, and oyster bars. In 1890, the U.S. Army Corps of Engineers began a series of dredging projects to connect waterways and allow navigable passage through what is now known as the Gulf Intracoastal Waterway. Shallow areas were made deeper and dredge spoils were used to widen existing islands or create smaller islets (Antonini 2002).

Most parts of Sarasota Bay are relatively shallow, with an average depth of 6.5 feet. The central part of the bay is 8–10 feet deep with a maximum depth in Longboat Pass of 27 feet (SBEP 1990). Four passes, Venice Inlet, Big Sarasota Pass, New Pass and Longboat Pass, connect bay waters to the Gulf of Mexico, promoting circulation and tidal mixing.

Historically, the Sarasota Bay watershed consisted of pine flatwoods and other upland habitats, wetlands, and marshes. Over time, urbanization, agriculture, and other land use changes (SWFWMD 2011), combined with the construction of various drainage and flood control projects, resulted in significant habitat loss and changes in hydrology. For example, since development, 26% of Sarasota's mangroves and 92% of its salt marshes have been lost (Antonini 2002). These changes negatively impact water quality, habitat, and fish and wildlife.

IV. CLIMATE STRESSORS

There are four main climate stressors predicted to affect the goals of SBEP's Comprehensive Conservation and Management Plan: sea level rise, changes in precipitation, warmer air and water temperatures, and ocean acidification. The following sections outline baseline and predicted future conditions for each stressor to provide foundational context for risk analysis.

Sea Level Rise

Florida's coastline has varied dramatically due to changes in sea level through geologic time (Figure 2). The Florida peninsula is composed of karst limestone layered over bedrock. The karst layer is composed of skeletal fragments of marine organisms, like corals and mollusks, originally deposited when sea levels were higher than today. Because limestone is highly porous and susceptible to dissolution in weakly acidic groundwater, it stores water — and can be shaped by both freshwater and saltwater over time.

The Sarasota Bay area lies within the Gulf Coastal Lowlands and contains many low-lying barrier islands. It is relatively flat, ranging in elevation from 0 to 40 feet (Figure 3). Porous geology and low elevation render the region highly susceptible to sea level rise. Since 1900, global mean sea level has risen about 7–8 inches, with about 3 inches of rise since 1993 (Paris 2012, Sweet et al. 2017). The closest marine tidal gauge to Sarasota Bay is in St. Petersburg, Florida. According to that gauge sea level increased an average of 2.71 mm per year between 1947–2017 (NOAA 2017a) (Figure 4).

For this Vulnerability Assessment, SBEP used sea level measurements from the St. Petersburg, Florida tide gauge and projection scenarios for sea level rise from the National Oceanic and Atmospheric Administration (NOAA 2017a).

NOAA 2017 sea level rise projection scenarios have also been adopted by Tampa Bay's Climate Science Advisory Panel (Tampa Bay Climate Science Advisory Panel 2015) and the City of Sarasota, Florida (City of Sarasota 2017). According to NOAA's 2017 intermediate and intermediate high projections, sea level may rise 1.44 feet to 1.97 feet, respectively, by 2050 and 3.9 feet to 6.17 feet by 2100 (Figure 5).

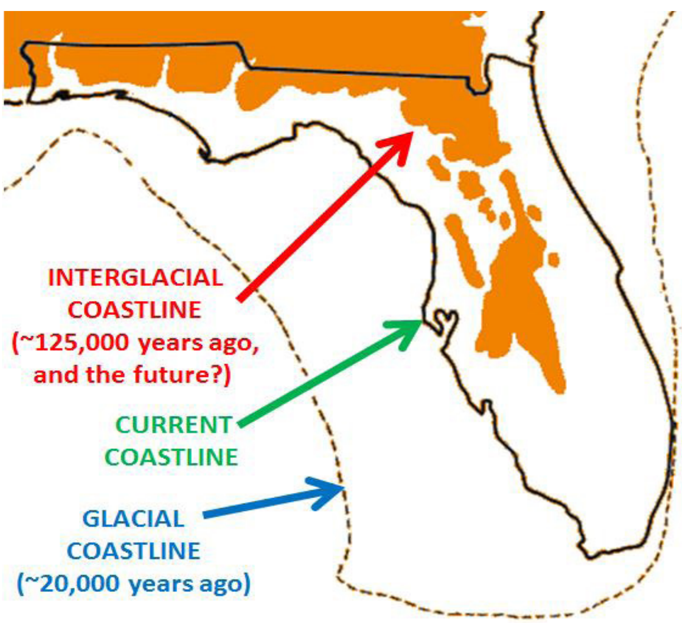


Figure 2. Historic Coastline of Florida. Source: Florida Geological Survey as cited in McNoldy 2014.

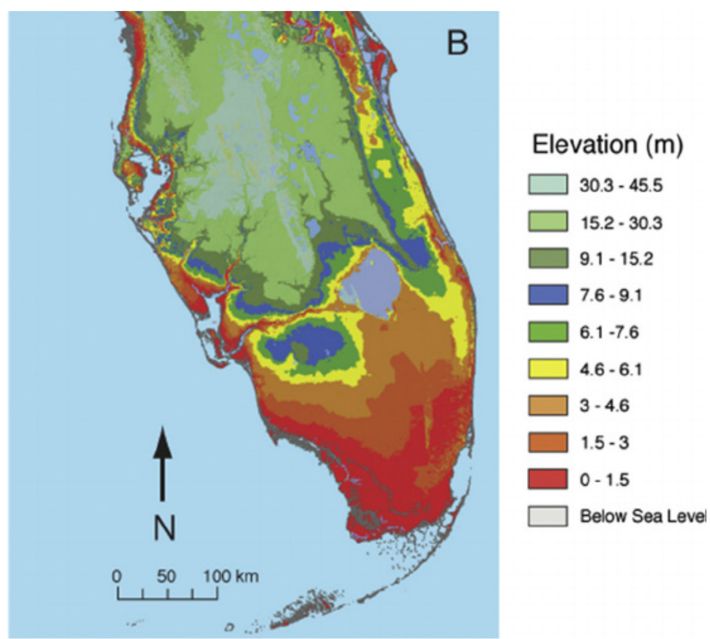


Figure 3. Florida Topography. Source: Glaser et al. 2015.

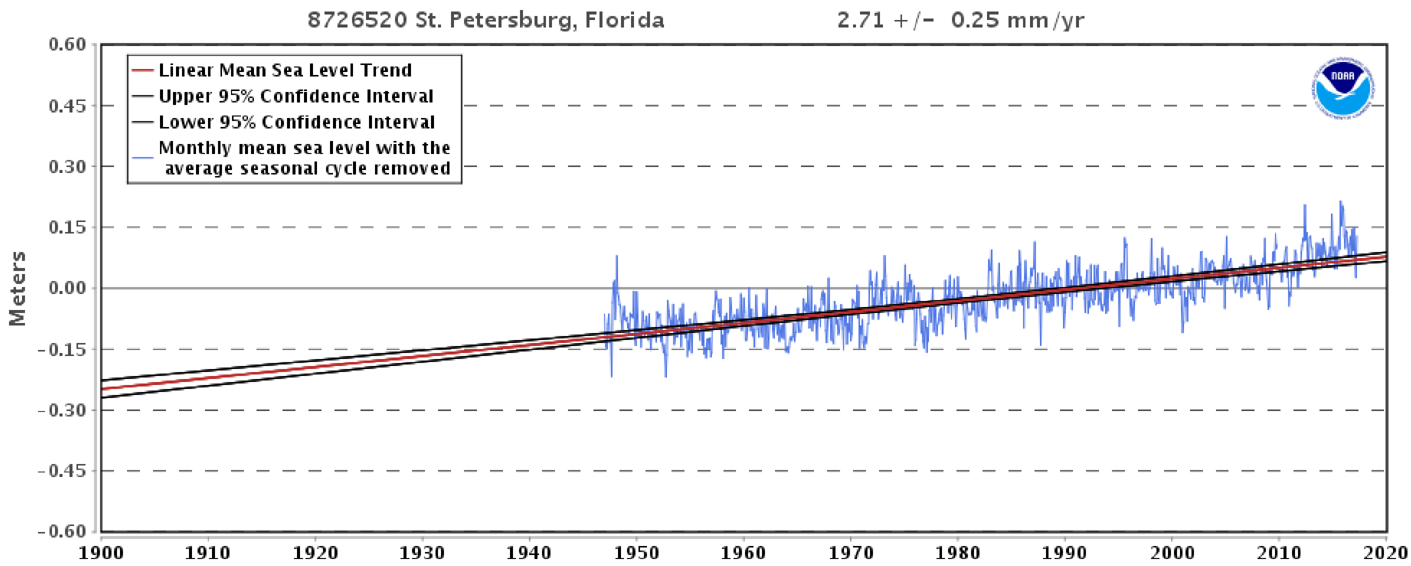


Figure 4. Mean Sea Level Trend from St. Petersburg Tide Gauge. Source: NOAA 2017a.

Due to the complex and nonlinear cascading effects of a warming planet and the uncertainty of glacial melting, scientists expect sea levels to rise at a faster rate in the future (Florida Oceans and Coastal Council 2010, Sweet et al. 2017). The Sarasota Bay area is already experiencing effects of sea level rise, particularly on the barrier islands. For example, parts of Longboat Key and Siesta Key experience "sunny day flooding" when high tide reaches about 2.5 feet above current low mean sea level (Figures 6 and 7). At this height, saltwater inundates docks and storm drains and floods nearby streets. Although this currently only coincides with extreme high tide events, more frequent flooding is expected as sea level continues to rise. Heavy precipitation and storm surge will only exacerbate coastal flooding, all of which can negatively impact water quality and put immense pressure on coastal resources.

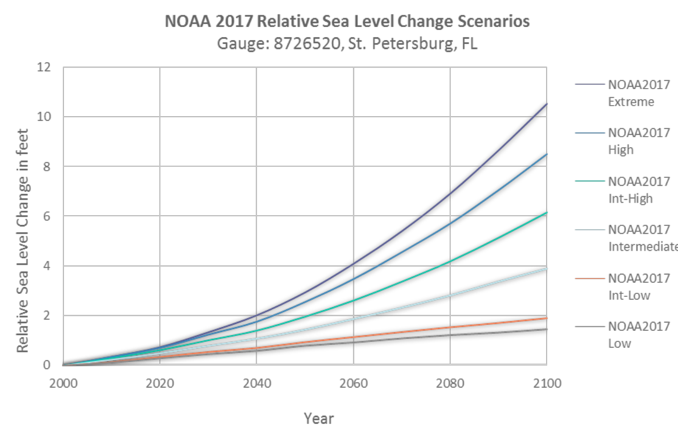


Figure 5. Projected sea level rise from 2000 - 2100 at St. Petersburg tide gauge using NOAA et al. 2017 projections. Source: generated from USACE 2017.

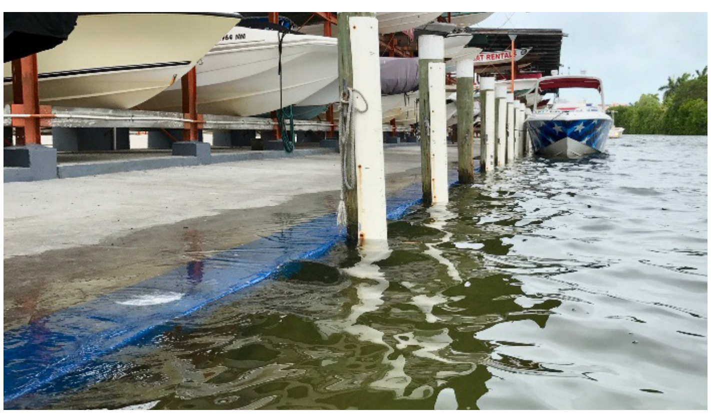


Figure 6. Marina on Siesta Key during a May 2017 King Tide. Photo credit: Brant McCarville.

Figure 7. Seawater coming up through a storm drain on Longboat Key during a May 2017 King Tide. Photo credit: SBEP.

Precipitation

The Sarasota Bay area receives an average of 56 inches of rain per year (SBEP CCMP 2014), with the rainy season generally occurring May through October and the dry season November through April. Inland areas can receive up to 10 more inches of rain than coastal areas (Figure 8, Jones Edmunds & Associates and Janicki Environmental 2012).

Florida is a narrow peninsula influenced by complex air-sea interactions and located at the dynamic boundary between the tropics and extratropics. These factors contribute to variable precipitation patterns across multiple temporal and spatial scales, even within the peninsula. As a result, caution is warranted when downscaling results to the Greater Sarasota Bay Watershed from studies conducted at global, regional (e.g., Southeastern United States), or statewide geographic scales. This caveat is especially relevant for analyses of average annual and seasonal precipitation trends.

Precipitation variability in Florida results from complex interactions between externally forced and internally generated variability (Kirtman et al. 2017).
Externally forced variability results from both natural (e.g., changes in solar output and volcanic activity) and anthropogenic (e.g., changes in carbon dioxide concentrations from fossil fuel emissions, methane from natural gas production, or land-use and land-cover) influences. Greenhouse gasses, including methane and carbon dioxide, cause temperatures to rise, which in turn increase the atmosphere's capacity to hold and release moisture. This phenomenon is described by the Clausius-Clapeyron relationship, where extreme precipitation events generally increase in intensity by about 6–7% for each degree Celsius of temperature increase. The Fourth National Climate Assessment assigns a high confidence level to projections that precipitation extremes will increase with increasing temperatures in the continental US (Easterling et al. 2017), including Florida.

Internally generated precipitation variability results from complex air-sea drivers, ranging from local sea breeze convection patterns to large-scale natural oscillations — including the El Niño Southern Oscillation (ENSO), Atlantic Multi-Decadal Oscillation (AMO), and Pacific Decadal Oscillation (PDO) (Misra et al. 2011, 2017).

For example, the current warm phase of the AMO brings greater tropical cyclone activity and summer rainfall to Florida (Teegavarapu et al. 2013). In the cool phase of the AMO, Florida may enter a dry period with fewer but stronger storms and prolonged droughts extending through winter and spring (Misra et al. 2011). In addition, extreme precipitation events typically occur later in the year (August to October) during AMO warm periods compared to cool periods, when they occur earlier (June to August).

Sensitivity to the influence of the AMO varies spatially in Florida and more study is required to understand its influence in the Sarasota Bay area.

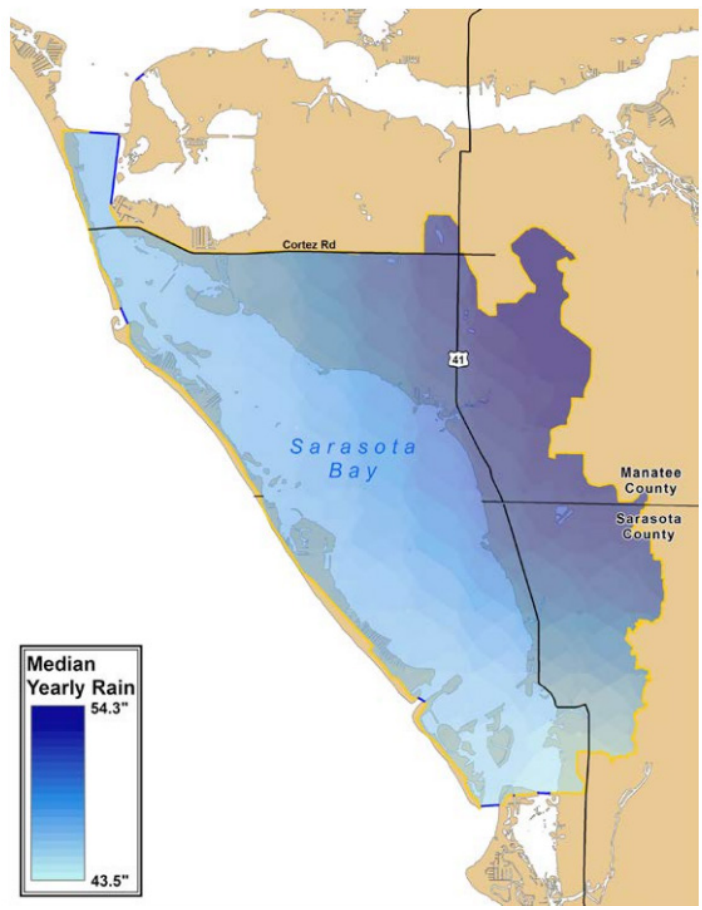


Figure 8. Median of annual rainfall from 1989–2008. Source: Jones Edmunds & Associates and Janicki Environmental 2012.

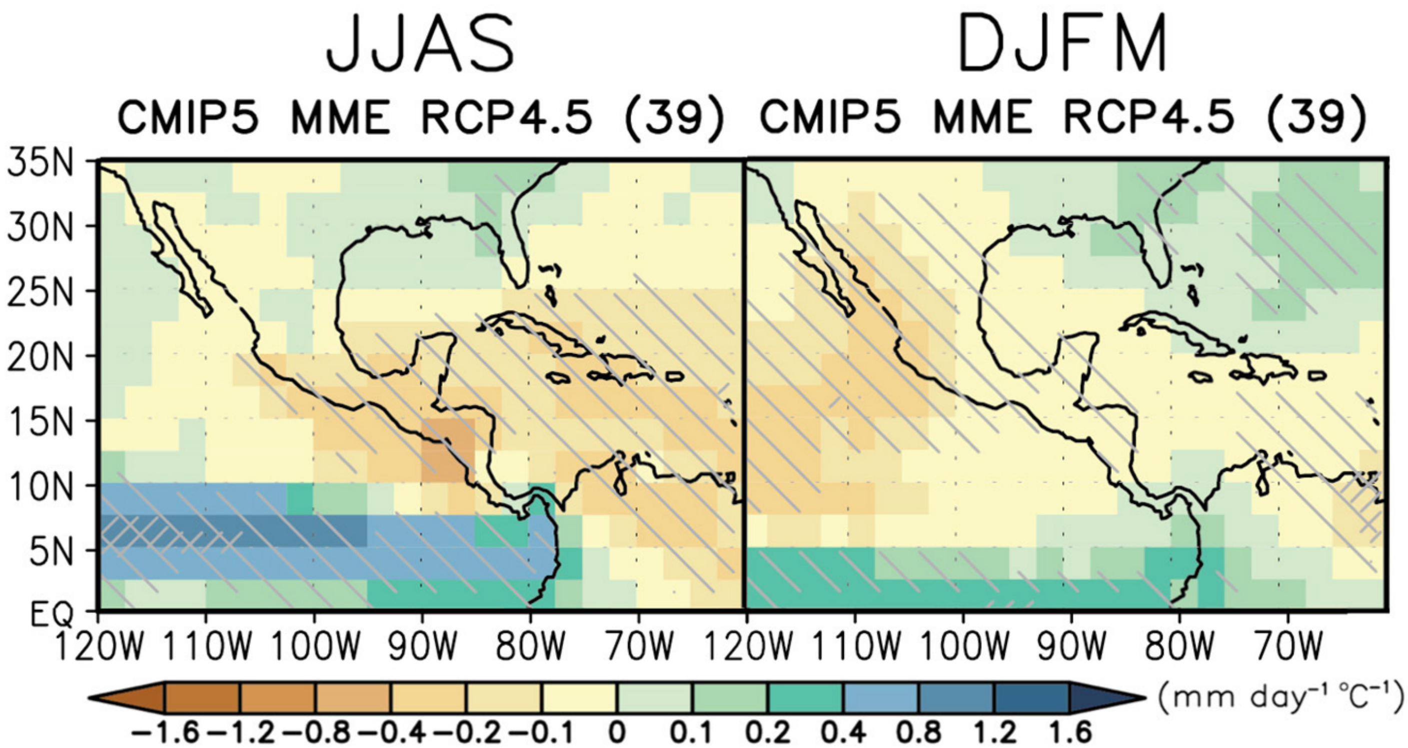


Figure 9. Maps of projected precipitation changes in 2080 –2099 with respect to 1986 –2005 in June through September (JJAS) and December through March (DJFM) using the Intergovernmental Panel on Climate Change RCP4.5 scenario with 39 CMIP5 models. Precipitation changes are normalized by the global annual mean surface air temperature changes in RCP4.5. Light hatching denotes where more than 66% of models have the same sign with the ensemble mean changes, while dense hatching denotes where more than 90% of models have the same sign with the ensemble mean change. Figure and caption source: Kirtman et al. 2018, as adapted from IPCC 2013.

Precipitation amounts during the Florida dry season tend to be larger in El Niño years compared to La Niña years (Teegavarapu et al. 2013); the PDO has similar effects, but on decadal time scales (Misra et al. 2011).

Over these associated timeframes, annual, decadal, and multi-decadal climate drivers may temporarily enhance or diminish long-term increases in extreme precipitation resulting from warming air and water temperatures (Ting et al. 2009). A better understanding of decadal and multi-decadal climatic drivers will improve our ability to more accurately project increases in precipitation intensity due to greenhouse gas warming.

Unlike projections for precipitation intensity, projections for changes in average annual and seasonal amounts of precipitation are less certain (Kirtman et al. 2017). These projections rely on modeling locally available water vapor and complex mechanisms controlling shifts in weather system circulation. According to the latest models (Figures 9 and 10), by 2100, seasonal mean precipitation in South and possibly Central Florida is projected to increase during winter and decrease during summer (Easterling et al. 2017, Kirtman et al. 2017).

Storms

West-central Florida experiences more thunderstorms than anywhere else in the United States (Figure 11). On average, the Sarasota Bay area experiences 80 days of thunderstorms per year (NOAA National Weather Service 2017). Hurricane season in Florida lasts from June 1 to November 30, with peak numbers of hurricanes and tropical storms occurring around September (NOAA 2010).

Since 1842, there have been 134 major storm events (61 hurricanes and 73 tropical storms) within 144 miles of Sarasota (Figure 12). In recent decades, the Sarasota

Bay area has experienced relatively few hurricanes. The strongest hurricanes to land near Sarasota Bay in recent years were Hurricane Irma (September 2017) and Hurricane Charley (2004). At the time of this report's preparation, damage is still being assessed from Hurricane Irma. Hurricane Charley was a category 4 hurricane that caused the evacuation of 1.4 million people and an estimated $6.8 billion in property damages (FEMA 2005). The hurricane caused significant impacts to wetlands, especially mangrove forests and bird nesting islands. Seagrass beds were scarred by debris or covered by sand and sediment. In some areas, up to 90% of vegetation died or was severely damaged (Meyers 2005).

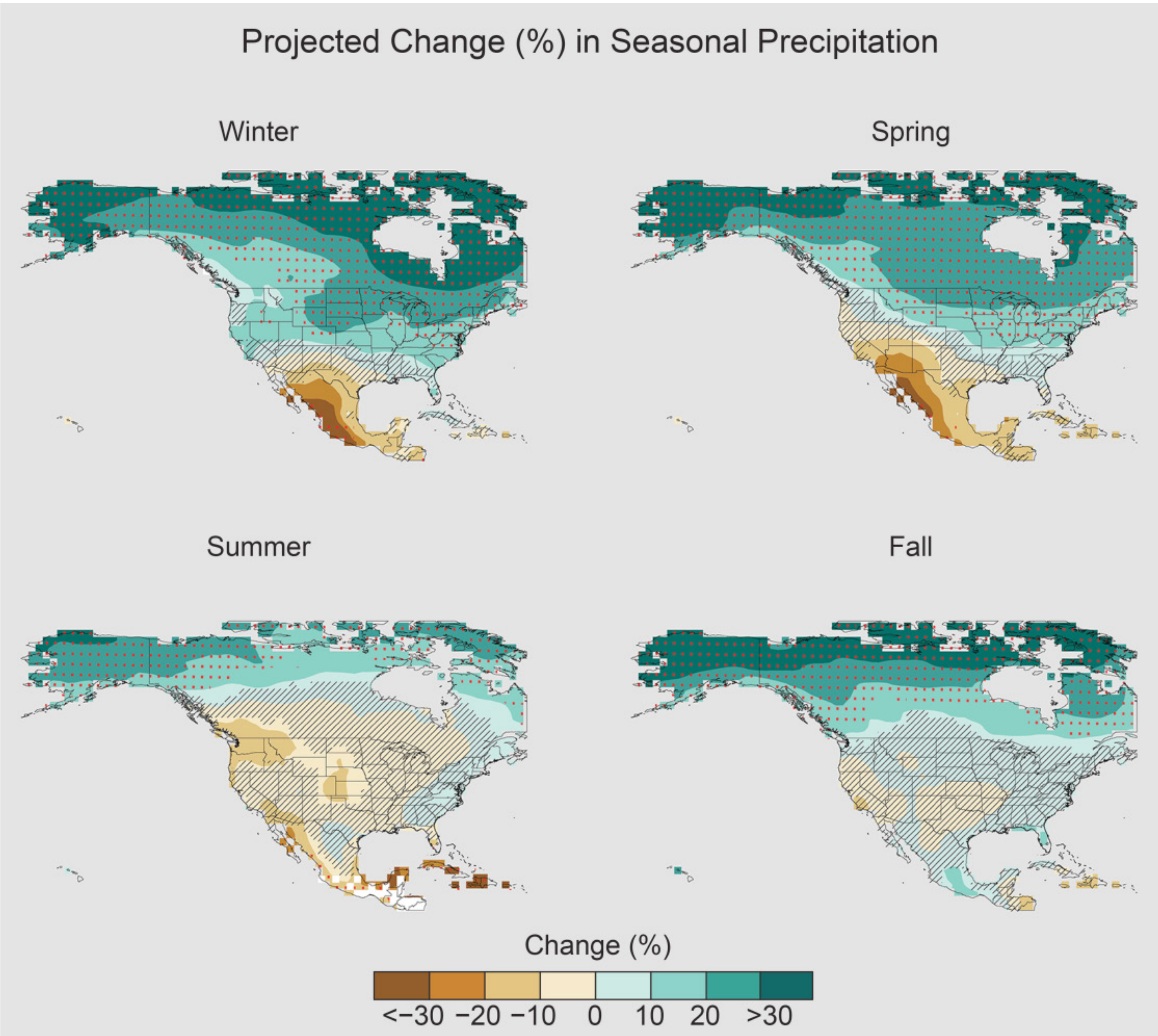


Figure 10. Projected change (%) in total seasonal precipitation for 2070–2099 using the higher Intergovernmental Panel on Climate Change scenario (RCP8.5). The values are weighted multimodel means and expressed as the percent change relative to the 1976–2005 average. Stippling indicates that changes are assessed to be large compared to natural variations. Hatching indicates that changes are assessed to be small compared to natural variations. Blank regions are where projections are assessed to be inconclusive. Data source: World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project. Figure and caption source: NOAA National Centers for Environmental Information, as published in Easterling et al. 2017.

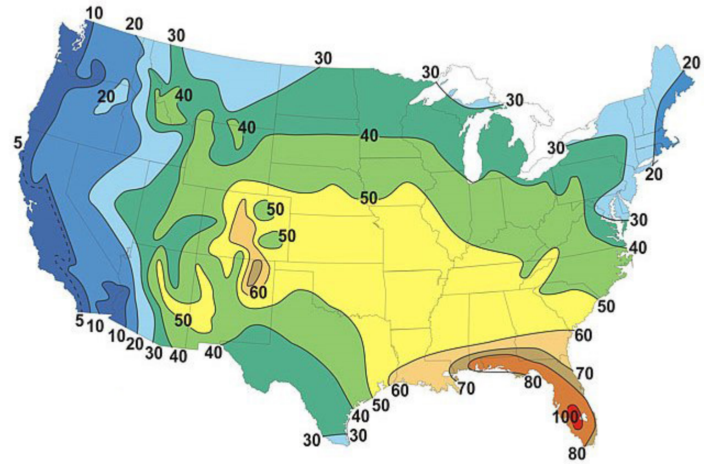


Figure 11. Average number of annual thunderstorm days. Source: NOAA National Weather Service.

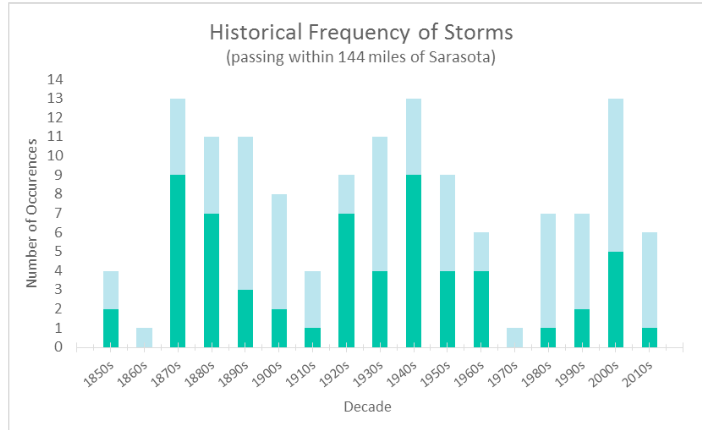


Figure 12. The Frequency of tropical storms and hurricanes passing within 125 nautical miles, or about 144 statute miles of Sarasota (NOAA 2017). This distance represents the average diameter of a hurricane strike zone. Source: NOAA National Hurricane Center 2017.

Hurricanes can impact the health and safety of natural ecosystems and the built environment. Theory and modelling simulations suggest that hurricane intensity may increase under warmer climate conditions, but there is not yet a clear detectable trend (Kossin et al. 2017). Detecting hurricane trends with sufficient confidence remains challenging, in part because historical data is heterogeneous in time and place among the various locations that collect and analyze data (Kossin et al. 2013) and a large number of variables interact to control hurricane frequency, size, and duration including changes in ocean circulation, volcanic activity, Saharan dust outbreaks, and greenhouse gases and sulfate aerosols (Kossin et al. 2017). More research is needed to understand how climate change will affect hurricane threats in Southwest Florida.

Flooding from hurricane precipitation and storm surge can vary considerably under different conditions of wind speed, storm velocity and direction, and local bathymetry and topography (Figures 13 and 14). Because the Gulf Coast of Florida is sited on a gradually sloping part of the

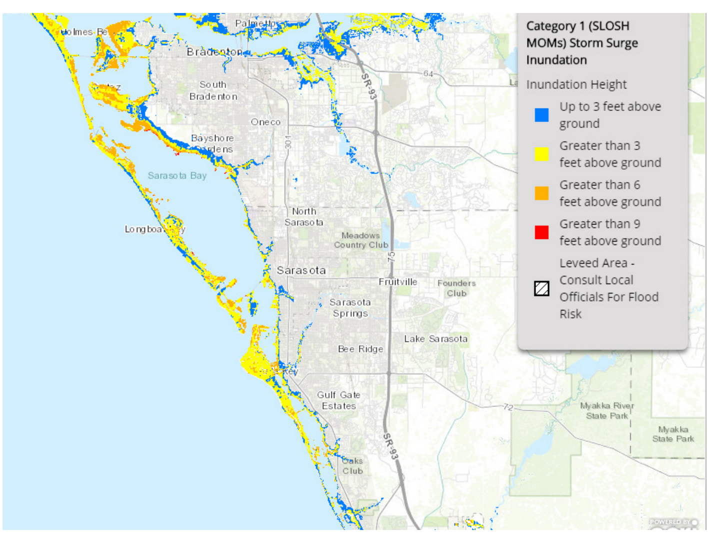


Figure 13. Flood prone areas during a hypothetical category 1 hurricane. Source: NOAA 2017b.

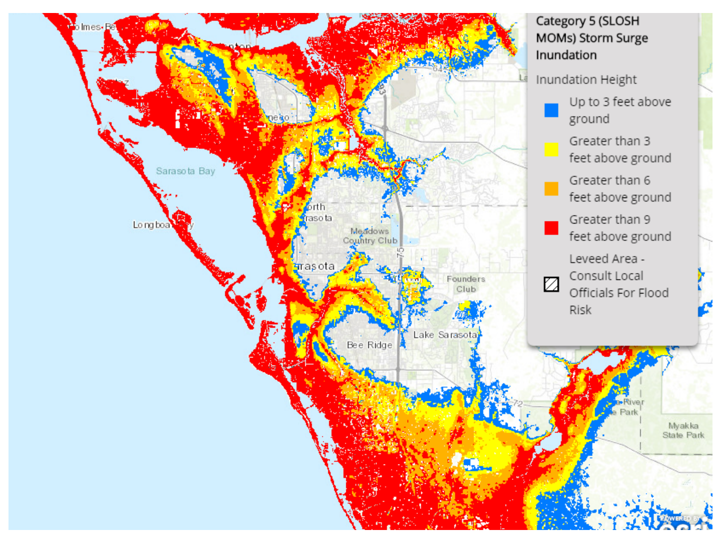


Figure 14. Flood prone areas during a hypothetical category 5 hurricane. Source: NOAA 2017b.

continental shelf, there is greater storm surge potential as compared to the Atlantic coast, where the offshore slope is steeper. According to a recent study, Sarasota is the 7th most vulnerable city to storm surge in the United States, with Tampa and Fort Myers ranking 1st and 5th, respectively (Karen Clark & Company 2015).

Compounding effects of sea level rise and storms may cause significant alterations in habitat, hydrology, and water quality in the bay. With support from EPA's Climate Ready Estuaries Program, SBEP designed an online Sea Level Rise Map Viewer in 2014 to illustrate the additive effects of multiple stressors. The flooding predicted by a one foot rise in sea level (NOAA's Intermediate Scenario for 2030–2040) coupled with a 6 foot storm surge (as reported in Charlotte Harbor during Hurricane Charley; FEMA 2005) would impact much of the natural coastal habitat in the Sarasota Bay Watershed (Figure 15).

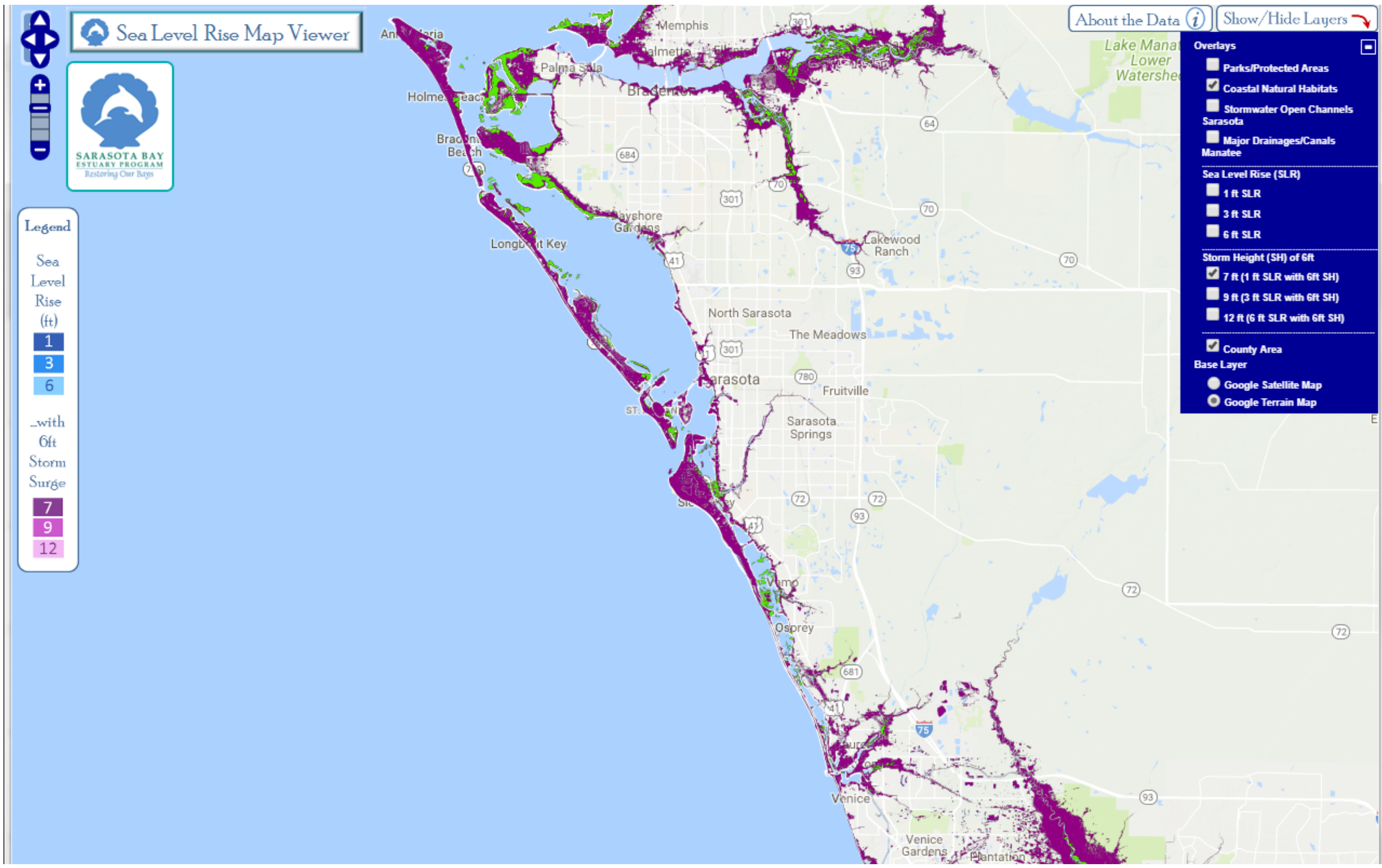


Figure 15. Flood prone areas with 1 foot of sea level rise and 6 feet of storm surge. Natural coastal habitats are shown in green; inundated areas are overlaid in purple. Source: SBEP Sea Level Rise Map Viewer.

Air Temperature

The Sarasota-Manatee region has a humid, subtropical climate — with hotter, wetter summers and cooler, drier winters. From about May to October, air temperatures range from the 70s to the low 90s degrees F, and from November through April, they range from the low 50s to the high 70s degrees F. The average temperature throughout the year is 73.7 degrees F (Florida Climate Center 2014). Since the early 1900s, temperatures in Florida have risen about one degree F (Figure 16) and are expected to increase by another 1–10 degrees F by 2100. While there has been no significant change in average daytime temperatures, frequency of very warm nights has increased over the last 20 years (Figure 17, Runkle et al. 2017).

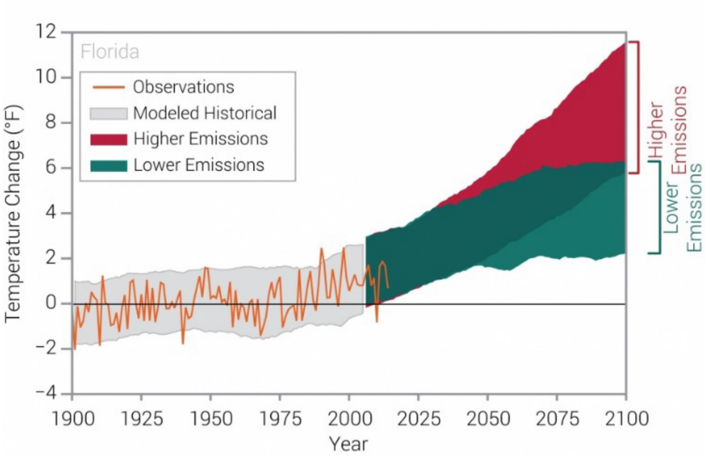


Figure 16. Observed (1900-2014) and projected near-surface air temperature for Florida. Source: Runkle et al. 2017.

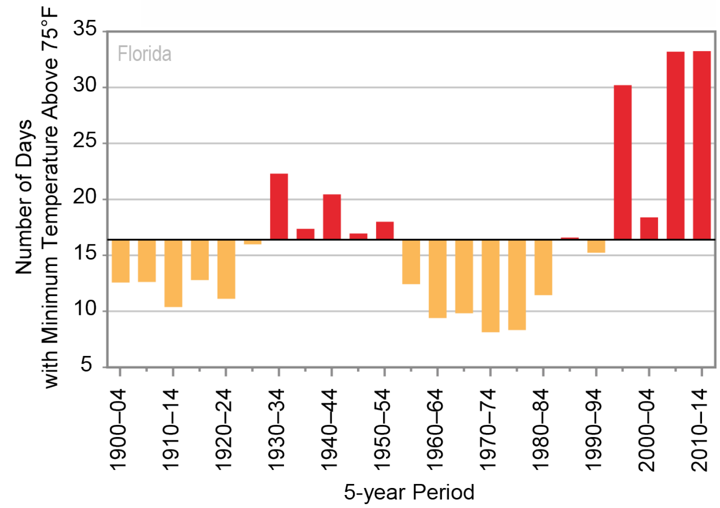


Figure 17. Number of nights with minimum temperatures above 75°F for Florida. Source: Runkle et al. 2017.

Water Temperature

Because Sarasota Bay is relatively shallow, water temperatures are highly variable and dependent on air temperature, wind, and other weather conditions. Bay temperatures tend to fluctuate between 60–85 degrees F, but can reach extremes from the mid 30s to the high 90s degrees F (USF Water Institute 2017). From the late 1990s to the present, there have been more days with near 100 degree F maximum temperatures than any of the previous forty years (Figure 18). Water temperatures in Sarasota Bay tributaries follow a similar trend as bay temperatures, but are even more sensitive to changes in air temperatures and inputs of warm stormwater runoff.

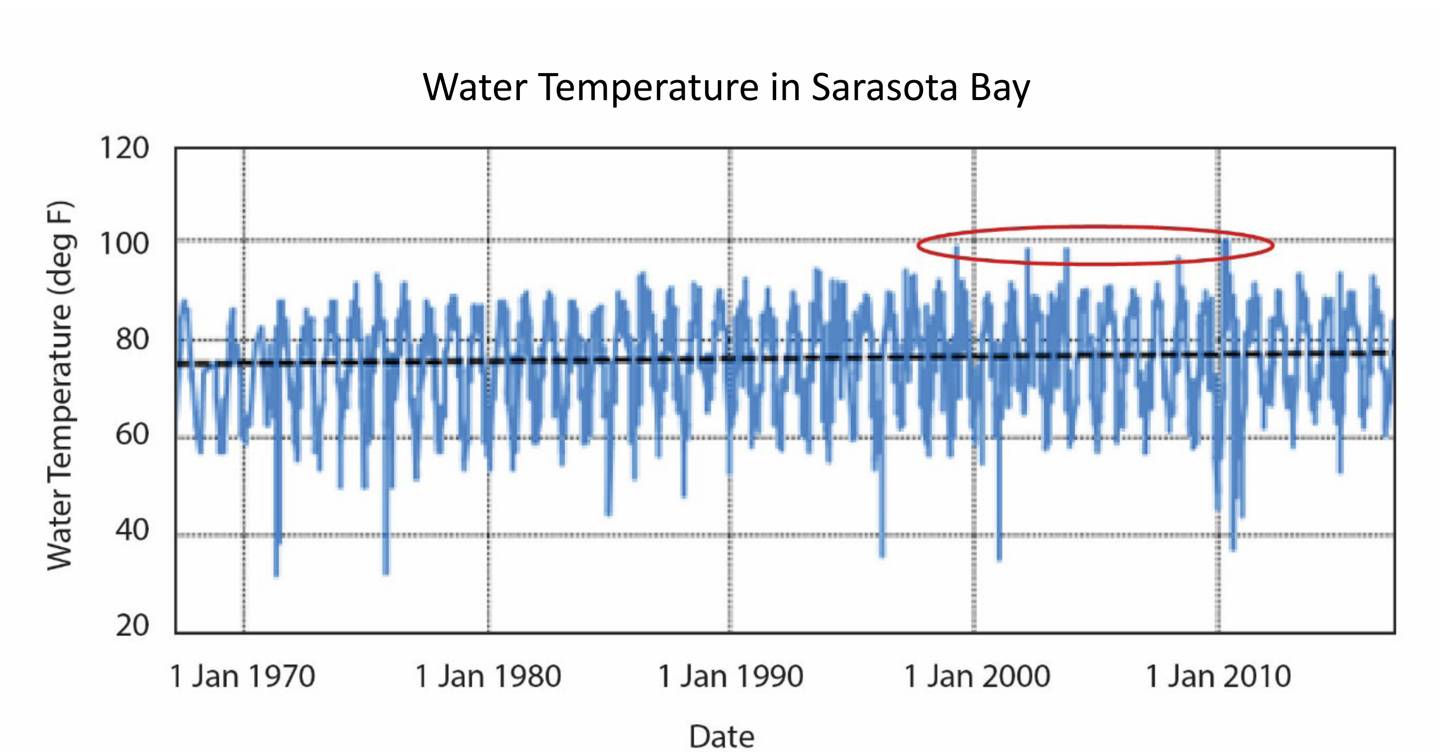


Figure 18. Water temperature in Sarasota Bay. Source: adapted from USF Water Institute 2017.

Ocean Acidification

Since the Industrial Revolution, oceans have absorbed about 30% of carbon emissions produced by humans (Sabine 2004). Atmospheric carbon dioxide diffuses into oceans and reacts with sea water to produce carbonic acid, increasing the acidity (lowering the pH) of seawater. As a result, global surface seawater pH has decreased by 0.1 units since the late 19th century (Rhein 2013) and is expected to decrease another 0.3–0.4 units by 2100 (Caldeira 2005). As pH decreases, the availability of carbonate ions, which many marine organisms use to build shells and skeletons, also decreases. This decrease is predicted to be more severe at low and mid latitudes, but may occur first at southern latitudes. Aragonite, a form of calcium carbonate commonly used by marine organisms, may become unsaturated in the Southern Ocean within the next 50 years (Figure 19), which is sooner than previously predicted (Orr et al. 2005).

In coastal systems, local conditions as well as atmospheric carbon dioxide absorption drive acidification. The decay of organic material from low oxygen-high nutrient loading environments (Wallace et al. 2014), acidic river water (Salisbury et al. 2008), and coastal upwelling of carbon dioxide-rich waters can greatly affect local pH conditions (Feely et al. 2008). These factors can reduce the carbon buffering capacity of coastal ecosystems and cause them to acidify more readily than other areas in the open ocean. For example, by the end of 2100, the pH of the Northern Gulf of Mexico is expected to decline by 0.74 units, which is a larger drop than is expected for other open water systems (Cai et al. 2011).

Due to the multitude of acidification drivers, coastal pH values can exhibit high spatial and temporal variability. In metabolic-intense ecosystems, such as seagrass meadows, mangroves, salt marshes, coral reefs, and macroalgal beds, daily changes in pH can range as high as 1.0 units (Duarte 2013). This variability poses challenges for identifying local trends and predicting future pH conditions.

Ocean acidification poses a threat to all organisms that build calcium carbonate shells and skeletons. Lower pH can also affect behavior in fish, making them less able to detect and avoid predators (Munday, 2010). It can also cause changes in nutrient cycling (Hallegraeff 2009) and growth rates of harmful algae (Errera et al. 2014). Ocean acidification in estuarine and coastal areas has important consequences for shellfish harvesting, offshore aquaculture, fishing, and nursery habitats (Hu et al. 2013).

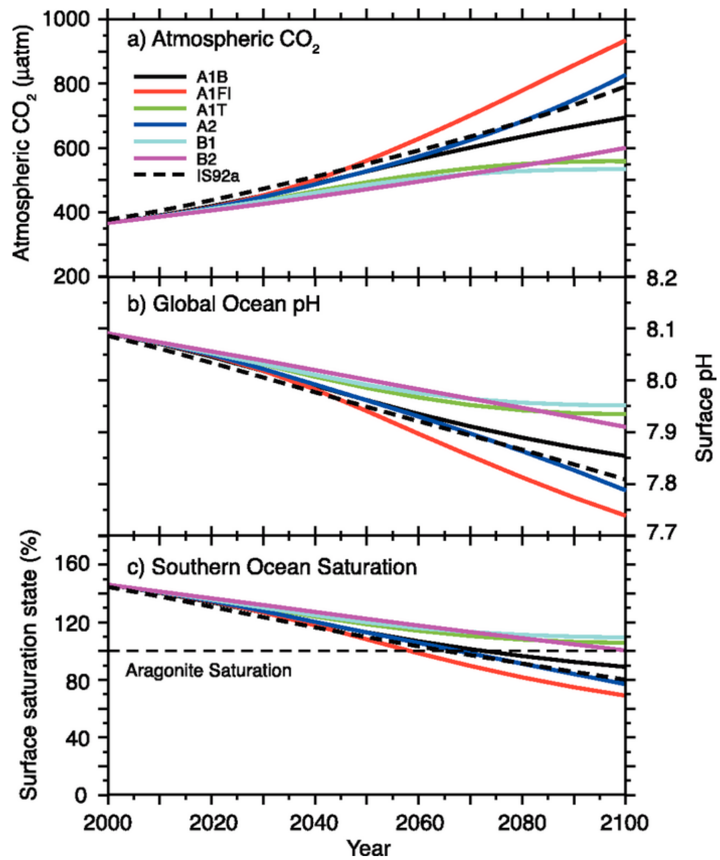


Figure 19 (top) Projected atmospheric CO2 for the six IPCC Special Reports on Emission Scenarios (SRES); (middle) projected global average surface pH; (bottom) projected average saturation state of aragonite in the Southern Ocean. Source: modified from Orr et al. (2005) as cited in IPCC 2007.

V. RISK ANALYSIS

Methods for Threat Identification and Risk Analysis

SBEP and the Science and Environment Council of Southwest Florida jointly organized a community forum held on November 10, 2016 to obtain stakeholder input about regional vulnerabilities to potential climate change stressors. Fifty-five participants from 24 stakeholder organizations participated in one large group discussion, together with 11 subject matter experts. Task, process, and note-taking professionals facilitated the discussion. Forum structure and management were designed to provide participants a general introduction to the purpose and objectives of SBEP's Climate Vulnerability Assessment, and then to generate a broad list of potential climate related impact to CCMP Goals. Six CCMP Action Plan Goals were addressed with participants who were asked to consider the question: "With respect to the specific climate changes stressors of sea level rise, increased air and water temperatures, altered precipitation patterns, and ocean acidification, what are the possible threats from climate change that could impact achieving the goal?" Over 100 participant responses were recorded during the workshop. These responses, together with additional threats identified by SBEP staff and other subject matter experts, were refined and consolidated into a final list of 54 threats from four climate stressors across six CCMP Action Plan Goals.

Peer-reviewed research papers, grey literature, agency reports and expert opinion were used to assess the nature and relative importance of each identified threat, based on their likelihood and consequence, spatial and temporal scale, and impacted habitat. Scores were assigned according to the following rubric:

Likelihood: What is the probability that the threat will occur?

Low: it could happen
Medium: it probably will happen
High: it definitely will happen

Consequence: What is the impact of the threat on the Goal and Objectives of the CCMP Action Plan?

Low: not as important as other problems. The impact or challenge is not much worse than current challenges or non-climate related challenges.
Medium: a serious challenge. The impact negatively affects and degrades the bay environment.
High: major disruption and challenge; goal may be impossible to achieve. The impact results in loss of bay and coastal habitats and/or priority species.

Spatial extent: Is the threat isolated or widespread?

Low: isolated; occurs at a specific site.
Medium: localized; occurs across a particular area or habitat.
High: widespread; occurs across most of the estuary or watershed.

Time horizon: How soon will the problem begin?

Low: more than 30 years.
Medium: 10–30 years.
High: 0–10 years, already occurring.

Threats were mapped to a Likelihood-Consequence matrix for each of six CCMP Action Plans. Threats with High-High or High-Medium scores were ranked as most important for climate adaptation planning (red quadrants). Threats with High-Low or Medium-Medium scores were ranked as important for climate adaptation planning (yellow quadrants). Threats with Medium-Low or Low-Low were ranked as less important for climate adaptation planning (green quadrants).

Likelihood-Consequence matrices were reviewed by local experts in wastewater, stormwater, wetlands, ocean acidification, water chemistry, fisheries, and seagrass. Finally, matrices were presented to the SBEP Technical Advisory Committee and the SBEP Citizens Advisory Committee for review and discussion.

Climate Change Threats and Impacts on CCMP Goals

Climate change stressors will interact with effects from other anthropogenic stressors — cumulatively, synergistically or even antagonistically to each other (reviewed in Marcogliese 2008). First order climate stressors will interact with second and third order effects across multiple temporal and spatial scales. Often, these effects will translate into predictable long-term consequences to habitat and living resources; but in many cases, specific outcomes may be complex, non-linear, cascading, threshold-dependent and difficult to predict with reasonable certainty. Therefore, effective resource management must be adaptive and sensitive to new information as it arises and climate change progresses.

photo credit: David Shafer

SBEP CCMP: Wastewater Treatment and Reclamation Action Plan

Goal: Improve Water Transparency

Table 1. Likelihood-Consequence Matrix for climate change related threats to the SBEP 2014 CCMP Wastewater Treatment and Reclamation Action Plan. Threats are driven by climate stressors including warming temperature (T), changes in precipitation (P), sea level rise (S), and ocean acidification (O).

Likelihood of Impact Occurrence	Low	Medium	High
High		(7) Changes in growth rates and survival of algae, bacteria, and viruses (T,P,O)	(2) Failure of low lying wastewater lift stations and other conveyance infrastructure due to flooding (S,P)
Medium	(5) Changes in nitrogen transport and denitrification due to higher ground water levels (S,P)	(3) Reduced capacity of irrigated lands to absorb treated wastewater during the wet season (T)	(4) Septic system failures due to ground water saturation (S,P) (1) Emergency releases of partially treated wastewater from treatment facilities overloaded by inflow and infiltration during storm events (S,P)
Low	(6) Failure of underground storage tanks and industrial waste storage ponds (S,P)		

Consequences of Impact on the Action Plan Goal

Algal blooms are the primary impediment to achieving water transparency in Sarasota Bay (SBEP CCMP 2014). Because nitrogen is the limiting nutrient for algal growth in Sarasota Bay, it is the primary pollutant of concern for managing water transparency. Nitrogen loading to Sarasota Bay comes primarily from stormwater and wastewater inputs, with a smaller contribution from atmospheric deposition (SBEP CCMP 2014). In 1995, SBEP articulated and adopted a nitrogen-loading reduction strategy in their CCMP Wastewater and Stormwater Action Plans (SBEP CCMP 1995). The strategy is ongoing (SBEP CCMP 2014) and has three objectives: 1) eliminate direct wastewater discharge to the bay by reclaiming wastewater for alternative supply; 2) treat stormwater in priority watersheds; and 3) Implement public outreach and education programs to reduce nitrogen runoff from residential and commercial properties.

Together with partners, SBEP coordinated a 64% reduction in nitrogen loading to the bay between 1989–2014, resulting in all bay waters meeting state or federal water quality standards (CCMP 2014). As a result, seagrass coverage increased 54 percent since 1988 and is now 29 percent above restorable 1950s levels (SWFWMD 2016).

The primary goal of SBEP CCMP's Wastewater Treatment and Reclamation Action Plan is to improve water transparency in the bay by reducing wastewater contamination. Implementation of this Plan has reduced nitrogen loading from wastewater treatment plants and septic systems by 95% (SBEP CCMP 2014). Climate stressors, including rising sea level, changes in precipitation, warmer temperatures, and ocean acidification can threaten the effectiveness of wastewater treatment and reclamation infrastructure and practices.

Centralized Wastewater Treatment

Most wastewater produced in the Greater Sarasota Bay Watershed is treated in large centralized Wastewater Treatment Plants (WWTPs). Infrastructure associated with conveyance of untreated and treated wastewater includes sewer mains, force mains, interceptor pipes, lift stations, and privately owned sewer laterals. Wastewater is collected at its source, conveyed to a WWTP, and treated. Treated wastewater, which still contains elevated nutrient levels, can be discharged through a number of different pathways, including discharge into surface waters, injection into underground wells and aquifers, release to infiltration basins and spray fields, or delivery to re-use irrigation systems. Reducing surface water discharges of treated wastewater is a priority objective in SBEP's CCMP (1995, 2014) and most have been eliminated. For example, the City of Sarasota's new deep injection well system can dispose of up to 18 MGD of treated wastewater from its WWTP, eliminating about 9 MGD of treated wastewater discharge from entering Hog Creek and Whitaker Bayou (Cummings 2015). The City of Bradenton completed a project in 2016 to transfer 100% of its reclaimed water to Lakewood Ranch for landscape irrigation. This project reduced direct surface water discharge of treated wastewater in Manatee County by 90%. Effectiveness of centralized wastewater treatment systems may become impacted by a variety of climate stressors.

(1) Emergency releases of partially treated wastewater from treatment facilities overloaded by inflow and infiltration during storm events

Sanitary sewer system capacity in the Sarasota Bay watershed was not designed to accommodate groundwater or stormwater. Nevertheless, groundwater or stormwater can enter the system through inflow (stormwater enters through unauthorized connections) and infiltration (stormwater or groundwater enters through broken, permeable or defective pipes, manhole covers or other infrastructure). Increased heavy rainfall and flooding can increase infiltration rates of deteriorated, leaky, or broken sanitary sewer infrastructure. Rising groundwater levels (from increased heavy precipitation or sea level rise) can also increase infiltration rates.

Heavy rainfall can overwhelm discharge options. If excess groundwater or stormwater enters the sanitary sewer system, it can exceed discharge operating capacity and cause emergency discharges from WWTPs. For example, after heavy rains in October 2016, the City of Sarasota's deep injection well reached its operating capacity and 124,000 gallons of treated wastewater had to be released into Whitaker Bayou (Sarasota Herald Tribune Staff Report 2016, October 4). Heavy rainfall during Hurricane Hermine in September 2016 resulted in stormwater infiltration of the sanitary sewer system on Siesta Key. The Siesta Key WWTP, which normally treats about 1.5 million gallons of wastewater per day (MGD), became overloaded when its 2.6 MGD treatment capacity was exceeded. Utility officials were forced to discharge 3.3 million gallons of partially treated wastewater into the Grand Canal, which runs through Siesta Key neighborhoods to Roberts Bay, or risk overflow of raw sewage (Murdock 2016).

The Siesta Key WWTP is the last surface water wastewater discharge facility in Sarasota County and is scheduled to be decommissioned in December 2017. It will be replaced with a new master pump station with triple redundancies, designed to prevent discharges into the Grand Canal (Hackney 2016). When the Siesta Key WWTP is retired in December 2017, all significant surface water discharges to Sarasota Bay will be eliminated — an important milestone for SBEP and its partners.

(2) Failure of low lying wastewater lift stations and other wastewater conveyance infrastructure due to flooding

Lift stations pump wastewater from lower to higher elevation to enable gravity flow through shallow conveyance infrastructure. If excess groundwater or stormwater enters the sanitary sewer system, it can overwhelm capacity and cause backups and overflows from manholes and lift stations. Backups and overflows at wastewater conveyance infrastructure remain a problem, and may be exacerbated by more intense rainfall events. Lift stations operate using electrical components including pumps and valves, motors, power supply, equipment control and alarm systems (EPA 2000). There is relatively low potential for modern municipal lift station electrical systems to fail due to flooding and tidal inundation. However, they are susceptible to failure in storms when power is disrupted. Generally, older, smaller, privately-maintained units might be more susceptible, depending on their location and design.

(3) Reduced capacity of irrigated lands to absorb treated wastewater during the wet season

Currently, about 65 percent of treated wastewater from WWTPs in the Greater Sarasota Bay Watershed is reclaimed for beneficial uses (SBEP CCMP 2014). Sarasota Bay area has a network of re-use irrigation pipes serving planned residential and commercial developments. Increased heavy precipitation and rising groundwater levels can saturate soils and reduce their storage capacity (Brouwer et al. 1985). This can reduce the capacity of irrigated areas to absorb reclaimed water. Increased heavy rainfall can also decrease demand for reclaimed water for irrigation.

Onsite Wastewater Treatment

While most wastewater in the Greater Sarasota Bay Watershed is treated by WWTPs, some is still treated by smaller onsite wastewater treatment systems (OWTS), also known as septic systems. Conventional septic systems use a tank to trap solids, perforated pipes to remove water, and a drain field to treat contaminants where water percolates through layers of soil. Treatment performance of the drain field depends on availability of an appropriate volume of unsaturated soil — characterized by low moisture and high oxygen levels — where microbes can break down bacteria and nutrients before wastewater reaches the water table. Rising sea levels, warmer temperatures, and increased heavy rainfall events can diminish septic system performance and release harmful nutrients and bacteria into the environment.

(4) Septic system failures due to ground water saturation

Higher amounts of rainfall and rising sea levels can elevate water tables, and warmer temperatures can reduce oxygen content in soils. These conditions can diminish treatment capacity of septic drain fields (Meeroff et al. 2008, Bloetscher et al. 2010, Cooper et al. 2016). If the volume of unsaturated soil is insufficient to treat septic tank effluent before it reaches the water table, nutrients and bacteria can be transported to surrounding waterbodies through groundwater (Arnade 1999, Bloetscher and Van Cott 1999, Lipp et al. 2001).

(5) Changes in nitrogen transport and denitrification due to higher ground water levels

Denitrification is the microbial-facilitated stepwise reduction of nitrate to nitrite, nitric oxide, nitrous oxide and finally dinitrogen gas. It is the dominant natural pathway by which nitrogen is removed from water. Denitrification occurs in oxygen-depleted environments, such as groundwater or saturated soils, where sufficient supplies of nitrate and organic matter exist. Denitrification rates increase with increasing soil saturation. As a result, increased heavy precipitation that increases soil saturation and elevates groundwater levels can increase the rate of nitrogen removal from groundwater and soils.

Rates of denitrification also increase with temperature (Veraart et al. 2011), though may vary among systems (Seitzinger 1988, Barnard et al. 2005). Temperature-dependent denitrification rates may further be amplified by coupled temperature-dependent processes. For example, higher temperatures can result in reduced solubility of oxygen in water and greater respiration rates of aerobic organisms — contributing to decreased oxygen and increased denitrification (Veraart et al. 2011). Thus, increased denitrification rates might have positive implications for water quality. In contrast, they might increase production of nitric oxide and nitrous oxide, which are greenhouse gases that can react with ozone and sunlight to produce nitric acid, a constituent of acid rain. Furthermore, higher ground water levels and saturated soils may leach organic nutrients more readily into stormwater runoff during heavy precipitation events. See threat *(13) Increased denitrification in saturated soils leading to decreased nutrient loads in stormwater*.

(6) Failure of underground storage tanks and industrial waste storage ponds

Underground industrial storage tanks used to store petroleum and other hazardous substances can fail due to faulty materials, installation, operation, or maintenance — contaminating soil and groundwater (EPA 2008b). Rising sea levels can increase groundwater salinity and elevate groundwater levels, and increased heavy precipitation can increase groundwater levels and saturate soils. These stressors can accelerate corrosion of underground structures and lead to premature failure. Aging and poorly maintained industrial waste storage ponds can also overflow under conditions of high precipitation, releasing pollution into the environment.

(7) Changes in growth rates and survival of algae, bacteria and viruses

Untreated wastewater contains environmentally harmful nutrients, bacteria, and viruses. Failures of wastewater treatment systems can release these pollutants into the environment. Climate change stressors can magnify their impact.

With adequate light availability, warmer waters and higher nutrient levels are likely to increase algal growth rates, causing blooms (EPA 2013). Algal blooms can damage aquatic environments by blocking sunlight and depleting waters of oxygen needed by organisms. Some algae can produce toxins harmful to other aquatic species and humans, exacerbating the impact of a bloom. These 'harmful algal species' may have a competitive advantage over non-harmful species under conditions of warmer temperatures, higher nutrients, and ocean acidification (Paerl and Huisman 2008, Hallegraeff 2010, EPA 2013). Warmer-water species might expand their distributional range at the expense of colder-water species.

Infectious agents, including bacteria, viruses, and protozoa, and their associated vector organisms, like mosquitoes, flies, and ticks, have optimal ranges of environmental conditions for survival and reproduction (Patz et al. 2003). If an agent and vector exist in the lower end of their optimum range, increased temperatures may magnify their environmental impact by increasing rates of development, incubation, replication, transmission, persistence, and survival (EPA 2013). If they exist at the higher end of their optimum range, higher temperatures may depress their impact. Warmer temperatures can also alter duration of the transmission season and the geographic range of agent and vector. Increased heavy rainfall, flooding, and humidity increases available breeding habitats for mosquitoes, and their eggs hatch faster at warmer temperatures.

In general, magnitudes, seasonal timing, and composition of algal and bacterial communities may change due to increased growth rates, water stratification, changes in predation pressure and selectivity, and changes in nutrient supply. However, climate change stressors can affect algae and bacteria on all biological levels of organization, including organismal (physiology, morphology and behavior); population (niche shifts, dispersion and recruitment); community (size, composition, diversity, interspecific interactions and trophodynamics) and ecosystem (food webs) (Guinder and Molinero 2013).

These variables and their interactions are further complicated by genetic and phenotypic plasticity, species-specific adaptive capacity, and other dynamics. As a consequence, specific long-term effects of future climate change on algae and bacteria will be complex and difficult to accurately predict (e.g., Beardall and Raven 2004, Hallegraeff 2010). See related threats *(33) Changes in nutrient cycling and primary productivity, especially for HABs*; and *(40) Increased viral, bacterial, fungal, and parasitic infections of marine mammals, fish, bivalves, crustaceans, and seagrasses*.

SBEP CCMP: Stormwater Treatment and Prevention Action Plan

Goal: Improve Water Transparency

Table 2. Likelihood-Consequence Matrix for climate change related threats to the SBEP 2014 CCMP Stormwater Treatment and Prevention Action Plan. Threats are driven by climate stressors including warming temperature (T), changes in precipitation (P), sea level rise (S), and ocean acidification (O).

Likelihood of Impact Occurrence	Low	Medium	High
High	(16) Inefficient drainage and capacity of stormwater pipes due to sea level rising above the level of outfalls (S)	(19) Increased growth rates of bacteria and algae in waterways (T,P)	(8) Increase or decrease in episodic volume and velocity of freshwater to tidal creeks and the bay (P) (9) Increased sedimentation due to greater erosion and scour from tributaries (P) (10) Increased concentration of pollutants (nutrients, chemicals, bacteria and trash) in runoff after prolonged periods of drought (P) (18) Reduced capacity of mangroves to buffer against upstream sediment and nutrient inputs due to loss of habitat (S)
Medium	(20) Creeks and waterways clogged by invasive plants (T)	(11) Failure of stormwater ponds due to increase in water table level limiting water percolation into underlying soils (S,P) (14) Wash-out of coastal stormwater vaults, retention ponds, bioswales or vegetated areas (S,P) (15) Lack of appropriate sites for relocating stormwater control structures (S,P) (23) Increased direct and indirect atmospheric deposition of nitrogen (T,P) (24) Increased use of chemical treatments in stormwater ponds to reduce more frequent algae blooms (T,P)	
Low	(13) Increased denitrification in saturated soils leading to decreased nutrient loads in stormwater [positive effect](P) (17) Reduced efficiency of nutrient removal by coastal stormwater ponds due to saltwater inundation leading to stress on pond vegetation (S) (22) Increase in metal ions in the bay due to acid rain and corrosion of metal stormwater pipes (P,O)	(12) Decreased function of biological treatment systems due to drought (T,P) (21) Increased concentrations of pollutants due to increased solubility with increasing temperature and OA (T,O)	

Consequences of Impact on the Action Plan Goal

The primary goal of SBEP CCMP's Stormwater Treatment and Prevention Action Plan is to improve water quality in the bay by reducing stormwater loading. Today, stormwater is the largest contributor of pollution to Sarasota Bay (SBEP CCMP 2014). Stormwater can carry excess nutrients, bacteria, sediments, debris, metals, pesticides, and petroleum products to the bay. Excess nutrients in stormwater can stimulate algal growth, resulting in blooms. Decomposing algae can deplete oxygen levels in water, leading to hypoxia and death of fish and other organisms. Algal blooms and sedimentation can reduce water transparency, which has implications for seagrasses and aquatic organisms that rely upon them for food and shelter. Increased freshwater pulses during more intense precipitation events or decreased freshwater flow during prolonged drought can disrupt relationships between shoreline habitats and salinity zones. This can impact non-mobile organisms dependent on more stable salinity regimes (e.g., oysters).

Precipitation

On average, 56 inches of rain falls annually on the Greater Sarasota Bay Watershed, mostly during summer months (SBEP CCMP 2014). Historically, shallow sheet flows of rainwater moved slowly over a mosaic of diverse, natural habitats in the Greater Sarasota Bay Watershed — including sloughs, wetlands and ponds — allowing water to percolate into the ground and recharge aquifers. Rapid population growth replaced natural areas with impervious surfaces, which increased the quantity and decreased the quality of stormwater entering waterways and the bay.

Older coastal neighborhoods were developed without stormwater treatment infrastructure, allowing untreated stormwater to flush directly into waterways and the bay. Newer neighborhoods provide better stormwater management and treatment, consisting mainly of vegetated swales, canals, and stormwater detention ponds. Climate stressors, including rising sea levels, changes in precipitation, warmer temperatures, and ocean acidification will affect the quality and quantity of untreated stormwater entering the bay as well as the efficacy of stormwater treatment, where it exists.

(8) Increase or decrease in episodic volume and velocity of freshwater to tidal creeks and the bay

Changes in precipitation will translate, either directly or indirectly, into changes of freshwater input into creeks and the bay. Variation in the quantity, timing, velocity, and location of freshwater input into estuaries is an important factor determining their chemical, physical, and ecological characteristics (reviewed in Morrison and Greening 2011).

In creeks, appropriate levels of freshwater flows are important to maintaining functional riparian zones, sediment transport patterns, stream channel morphologies, and appropriate life history cues for fish and other organisms (Richter et al. 1996, 1997). Low salinity habitats in tidal creeks are important nursery areas for fish and invertebrates (Peebles and Flannery 1992, Peebles 2005, Krebs et al. 2007). Even small changes in freshwater inflows can result in large changes in salinity, potentially decoupling favorable benthic and shoreline habitat qualities with suitable salinity regimes, and negatively affecting the suitability of these areas as nursery habitat (e.g., Estevez et al. 1991). Sudden flashes of freshwater inflows can flush juvenile fish and invertebrates from more favorable habitats.

Prolonged episodes of drought can impact tidal creeks by reducing water levels, possibly creating barriers for movement of aquatic organisms. Lower water levels can also increase predation efficiency on aquatic animals by birds and other predators. Warmer temperatures can interact with shallow waters to stimulate algal blooms, which can lead to hypoxia and death of aquatic organisms.

(9) Increased sedimentation due to greater erosion and scour from tributaries

Changes in freshwater inflow to creeks and the bay due to climate change stressors will contribute additional stress to hydrological systems already burdened by heavy anthropogenic modifications, including diversions, dams, impervious surfaces, and straightening, deepening, and hardening of creek channels (channelization). Larger pulses of freshwater from more intense rainfall events can increase erosion — resulting in increased sediment, dissolved material, and particulate material loading to waterways and the bay (Morrison and Greening 2011).

(10) Increased concentration of pollutants (nutrients, chemicals, bacteria, and trash) in runoff after prolonged periods of drought

Prolonged periods of drought can increase the concentration of pollution carried by stormwater during the "first flush" when precipitation resumes. Such pulses of pollution can overwhelm the capacity of natural and manmade systems to reduce pollution concentrations.

(11) Failure of stormwater ponds due to increase in water table level limiting water percolation into underlying soils

Stormwater ponds capture and store excess rainfall, and provide habitat where vegetation can remove excess nutrients and water can percolate into the ground. Increased heavy precipitation might overwhelm current stormwater pond capacity, causing overflows and runoff. Increased heavy precipitation can also elevate groundwater levels and reduce the storage and drainage capacity of stormwater ponds, diminish their functionality to treat contaminants, and result in overflow and runoff before water can percolate. See related threat *(4) Septic system failures due to ground water saturation*.

Sea level rise can also reduce soil storage capacity for rainfall because groundwater levels near the coast can rise in equilibrium with saltwater. Low lying areas may experience greater flooding due to diminished rainwater drainage and elevated groundwater levels. Sea level rise and saltwater intrusion can elevate coastal groundwater levels, diminish the drainage capacity of coastal stormwater ponds, and lead to their failure.

(12) Decreased function of biological treatment systems due to drought

Prolonged periods of drought and warmer temperatures can kill shoreline or littoral shelf vegetation, diminishing the treatment capacity of ponds and swales when precipitation resumes. Prolonged drought can lower groundwater levels and increase the storage and treatment capacity of soils; however, dry, hardened soil surfaces can initially resist infiltration and percolation when precipitation resumes.

(13) Increased denitrification in saturated soils leading to decreased nutrient loads in stormwater

One benefit of increased heavy precipitation may be that increased volumes of saturated soil can increase rates of denitrification, leading to decreased nitrogen loads in stormwater, soils, and groundwater. In contrast, saturated soils might prevent infiltration and percolation of stormwater, and lead to greater polluted stormwater runoff. See related threat *(5) Changes in nitrogen transport and denitrification due to higher ground water levels*.

Sea Level Rise, Storm Surge and Coastal Flooding

(14) Wash-out of coastal stormwater vaults, retention ponds, bioswales, or vegetated areas

Storm surge can lead to wash-out of coastal stormwater vaults, retention ponds, bioswales, or vegetated areas. This may result in loss of stormwater retention and treatment capacity, which can lead to increased water pollution. Sea level rise and increased heavy precipitation will exacerbate these threats.

(15) Lack of appropriate sites for relocating stormwater control structures

If stormwater infrastructure is compromised or lost in coastal or other flood-prone areas, there may be a lack of appropriate sites nearby for relocation. Sea level rise and increased heavy precipitation may increase the vulnerability of existing structures, and may reduce the suitability of nearby areas for relocation. Even if suitable alternative sites are identified, private property rights may create challenges.

(16) Inefficient drainage and capacity of stormwater pipes due to sea level rising above the level of outfalls

Sea level rise can reduce drainage efficiency and capacity of stormwater pipes if water rises above the level of outfalls. This can lead to coastal flooding and increased stress on adjacent stormwater infrastructure.

(17) Reduced efficiency of nutrient removal by coastal stormwater ponds due to saltwater inundation leading to stress on pond vegetation

Saltwater inundation due to sea level rise and increased storminess can reduce the efficiency of vegetation to remove nutrients if existing plants cannot tolerate increased salinity. This may be a short-term problem if freshwater plants are replaced by more salt-tolerant species.

(18) Reduced capacity of mangroves to buffer against upstream sediment and nutrient inputs due to loss of habitat

Sea level rise can cause coastal squeeze, where saltwater wetland habitats are reduced in size or lost altogether due to coastal structures blocking natural upland migration (Gilman et al. 2008). The buffering capacity of mangroves to reduce nutrients, sediment, and other pollution loading to the bay may be reduced or lost (Harbison 1986).

Temperature and growth rates

(19) Increased growth rates of bacteria and algae in waterways

Warmer, wetter conditions can facilitate the growth and persistence of bacteria and algae, and increase toxicity of stormwater pollutants (Lovett 2010). This can result in deteriorated water quality and transparency, which can have harmful cascading effects in bay ecosystems. See related threats *(7) Changes in growth rates and survival of algae, bacteria and viruses*; and *(33) Changes in nutrient cycling and primary productivity, especially for HABs*.

(20) Creeks and waterways clogged by invasive plants

Warmer temperatures and increased nutrient runoff can stimulate plant growth, leading to clogged waterways and increased flooding. Use of chemical treatments to reduce the presence of fast-growing invasive vegetation in waterways could cause harm. See related threat *(24) Increased use of chemical treatments in stormwater ponds to reduce more frequent algae blooms*.

Increased chemical pollutants

(21) Increased concentrations of pollutants due to increased solubility with temperature and ocean acidification

Most chemical pollutants have greater solubility in water at higher temperatures and lower pH. Climate change stressors are expected to elevate water temperatures and lower pH, which can result in higher pollution loadings in stormwater.

(22) Increase in metal ions in the bay due to acid rain and corrosion of metal stormwater pipes

Acid rain can change the pH of waterways and harm aquatic organisms. Acid rain is produced when compounds like sulfur dioxide and nitrogen oxides react with water, oxygen, carbon dioxide, and other chemicals in the atmosphere to form acidic pollutants. Human impacts, including power plants and motor vehicle emissions, are the dominant source of sulfur dioxide and nitrogen oxides in the Sarasota Bay airshed. Motor vehicle emissions tend to impact the environment locally, whereas tall stacks on power plants can help transport pollutants hundreds of miles before deposition (TBEP CCMP 2017). Acidic airborne pollutants can return to earth as dry deposition or wet deposition through rainfall. Therefore, increased heavy rainfall events may lead to increased acid rain. Acid rain can corrode metal, releasing metal ions into the environment, which can harm aquatic and terrestrial organisms.

Ocean acidification can increase corrosion of metal stormwater pipes. Rising sea level can transport seawater into coastal stormwater outfalls and it can salinize groundwater. Both mechanisms can accelerate corrosion of metal pipes, releasing metal ions into the environment. Many of the existing metal stormwater pipes in Sarasota County have been lined, reducing or eliminating metal contact within pipes. However, the outside of existing metal pipes remains vulnerable to corrosion by groundwater. Local experts believe this may be a low likelihood – low consequence threat.

(23) Increased direct and indirect atmospheric deposition of nitrogen

Power plants and vehicles are significant sources of atmospheric nitrogen, which can be deposited to bay waters directly from rainfall and dust or indirectly through stormwater runoff carrying atmospheric nitrogen deposited on the watershed. Increased nitrogen loading can result in algal blooms and cascading harmful effects to the bay ecosystem. Increased heavy precipitation events may increase atmospheric nitrogen deposition.

To a lesser degree, warmer air temperatures may increase generation of nitrogen oxides from power plants due to increased demand for air-conditioning. Nitrogen emissions from Tampa Bay area power plants are declining due to power plant upgrades, including replacing coal-burning plants with natural gas facilities and installing nitrogen reduction equipment on stacks (TBEP CCMP 2017). Although Sarasota Bay and its watershed are located in the same airshed as Tampa Bay, where many of the area's power plants are located, vehicles likely contribute more atmospheric nitrogen to Sarasota Bay's airshed (TBEP CCMP 2017). Continued improvements to fuel efficiencies of cars and trucks and development of more energy efficient buildings and appliances will further reduce nitrogen emissions on a per capita basis. Uncertainty regarding the balance of reduced per capita nitrogen emissions versus increasing energy use due to population growth was an important consideration in ranking this threat as a medium likelihood and medium consequence.

(24) Increased use of chemical treatments in stormwater ponds to reduce more frequent algal blooms

Increased nutrient loading to stormwater ponds due to increased heavy precipitation and runoff, combined with warmer water temperatures, can lead to more frequent algal blooms. Landscape managers in Sarasota and Manatee Counties commonly use copper sulfate, a powerful algaecide, to control algal blooms. They may increase the use of copper sulfate if algal blooms increase. Copper sulfate accumulates in sediments as a heavy metal precipitate and is highly toxic to fish and aquatic invertebrates (EPA 2008a, 2009b). Copper toxicity to fish increases in waters with high amounts of bioavailable cupric ion, low pH, low dissolved organic carbon, lower buffering capacity, or lower concentration of calcium ions (Flemming and Trevors 1989, Extonet 1994). As a result, acid rain may increase copper sensitivity in fish. Exposure to copper can also impair olfaction in fish (e.g., McIntyre et al. 2008). Copper sulfate-induced sudden death and decay of algal blooms can lead to hypoxia and mortality of aquatic organisms (NPIC 2012). Copper sulfate can also be mildly toxic to birds (EPA 2009b).

SBEP CCMP: Freshwater and Saltwater Wetlands Action Plan

GOAL: Restore shoreline and wetland habitats and eliminate further losses

Table 3. Likelihood-Consequence Matrix for climate change related threats to the SBEP 2014 CCMP Freshwater and Saltwater Wetlands Action Plan. Threats are driven by climate stressors including warming temperature (T), changes in precipitation (P), sea level rise (S), and ocean acidification (O).

Likelihood of Impact Occurrence	Low	Medium	High
High		(28) Changes in wetland species composition and zonation (S,T,P) (30) Spread of invasive species (S,T,P)	(25) Loss of shallow intertidal habitat, including mangroves, salt marsh, and beaches, due to upland barriers to migration (S) (33) Changes in nutrient cycling and primary productivity, especially for HABs (T,OA)
Medium			(27) Loss of freshwater wetlands due to changes in hydrology from extended drought and/or flooding (T,P) (31) Loss of native plant and animal species due to temperature intolerance (T) (32) Changes in plant pests and diseases leading to habitat loss (S,T,P,O)
Low	(26) Reduced coastal habitat function and restoration opportunities due to abandoned coastal structures (S) (29) Change in microclimates created by forested wetlands (T,P)		

Consequences of Impact on the Action Plan Goal

Fresh and saltwater wetlands provide water storage and filtration, nutrient cycling, and essential habitat for fish and wildlife. Significant losses of wetland habitat have occurred due to historic human land-use. To counter this trend, more than 1,550 acres of wetlands have been restored since 1995 with the help of SBEP partners and volunteers. SBEPs Five Year Habitat Restoration Plan aims for the creation or restoration of 29 acres of wetlands per year.

Sea level rise threatens coastal wetlands and is now considered when designing new restoration projects to enhance habitat resiliency. Changes in precipitation and warming temperatures also threaten wetlands by affecting water balance and soil characteristics. Increased flooding and prolonged drought may make wetland communities more susceptible to sedimentation and erosion, pollutants, pests and disease, and competition from exotic species leading to local extirpation. Loss of habitats and changes in wetland community structure are expected with climate change. These changes have important implications for restoration efforts (Sherwood and Greening 2014, Hobbs et al. 2011).

Loss of Habitats

(25) Loss of shallow intertidal habitat, including mangroves, salt marsh, and beaches, due to upland barriers to migration

Sarasota Bay experiences a small tidal flux of 2–3 feet and gradual elevation changes from shoreline to upland. The bay's narrow elevation-related ecological zones have been relatively stable for several millennia. Climate stressors may bring relatively rapid change to coastal wetlands, and threaten the critical ecosystem services they provide to bay waters, fish, and wildlife. Coastal wetlands are vulnerable to inundation and drowning if the rate of soil accretion cannot keep pace with sea level rise (Gillman et al. 2008, Nyman et al. 1993). Engineered structural adaptations to sea level rise, such as shoreline hardening, reservoirs, diversions, or tidal barriers, can restrict sediment transport and reduce the capacity of wetlands to accrete and keep pace with sea level rise (Twilley et al. 2007). Coastal squeeze, where natural upslope habitat migration in response to sea level rise is prevented by sea walls, roads, and development, will also lead to loss of shallow intertidal habitat, including mangroves, salt marsh, and beaches (Torio and Chmura 2013). See related threat *(44) Decrease in juvenile fish, shellfish, and bird feeding, breeding, and refuge habitat due to loss of coastal wetlands and natural shorelines*.

(26) Reduced coastal habitat function and restoration opportunities due to abandoned coastal structures

Coastal structures will likely experience more frequent physical stress and loss of structural and functional integrity from coastal flooding and storm-driven waves due to sea level rise and potentially more intense storms. Sea walls, piers, road beds, sidewalks, swimming pools, stormwater vaults, building slabs, and foundations will likely fail sooner, requiring accelerated maintenance, additional armoring, or abandonment (EPA 2009a). Hardened shorelines or abandoned structures will limit opportunities for natural recruitment or active restoration of coastal wetland habitats and functions.

(27) Loss of freshwater wetlands due to changes in hydrology from prolonged drought and/or increased flooding

Reduced rainfall during droughts, greater evaporation, and diversions of surface waters for drinking water supply may alter traditional hydroperiods and hydrology. This can lead to loss of freshwater wetlands, which require periodic flooding to maintain species assemblages and habitat function. Although some ephemeral wetlands are resilient to drought, when organic soils are dehydrated for long periods, oxidation can permanently degrade the capacity of soil chemistry to support nutrient cycling (McLeod et al. 2011). Warmer, drier conditions can also lead to more wildfires that can spread to parched wetland habitats not well adapted to fire. Conversely, more extreme rainfall events can lead to more frequent flooding and drowning of wetlands (Twilley 2007).

Changes in species and community structure

(28) Changes in wetland species composition and zonation

A suite of climate stressors, including rising sea level, warmer air and water temperatures, changes in precipitation (flooding and drought), and changes in water chemistry will drive changes in wetland species composition and zonation (Twilley et al. 2001, Root et al. 2003, FWCC 2016). Sea level rise will alter the timing, depth, and duration of saltwater inundation and salinity gradients. Salt or brackish wetlands may replace freshwater wetlands along tidal creeks. Low-lying freshwater wetland forests may transition to tidal wetlands with saltwater intrusion into soils and increased frequency of overwash (Raabe and Stumpf 2016, DeSantis et al. 2007). Due to their superior ability to trap sediments and build elevation, mangrove forests may overtake salt marsh, which is susceptible to subsidence and erosion when underlying peat layers collapse (Beever 2012, Glick and Clough 2006, Doyle et al. 2003). Increased carbon dioxide in the atmosphere may stimulate growth rates in both mangroves and marsh grass.

(29) Change in microclimates created by forested wetlands

Changes in precipitation and evaporation can influence groundwater depth and location, which can affect soil moisture, salt-balance, and drainage critical to maintaining wetland microclimate and habitat community structure (Twilley 2007).

(30) Spread of invasive species

Warmer air and water temperatures may drive exotic tropical species to extend their geographic ranges northward, potentially gaining advantage over established native species due to climate induced changes in the frequency of fire, freezes, or drought.

(31) Loss of native plant and animal species due to temperature intolerance

Warmer temperatures and drought may increase stress for native wetland plants and animals, leading to increased mortality and potential local extirpations of fish, amphibians, and water-dispersed plants (Twilley et al. 2001, Thomas 2006, FFWCC 2016).

(32) Changes in plant pests and diseases leading to habitat loss

If warmer temperatures result in fewer winter freezes, plant pests and pathogens typically held in check by episodic colder weather may become more abundant and problematic. Warming may also increase humidity, which can favor spread of fungal diseases. Expanded geographic ranges of hosts or pathogens can stimulate disease outbreaks among formerly disjunct populations (Harvell et al. 2010).

(33) Changes in nutrient cycling and primary productivity, especially for HABs

Climate change will drive complex interacting physical and chemical changes in seawater, including temperature, pH, salinity, transparency, nutrient availability, and stratification. These changes can alter nutrient cycling, productivity, and species composition of phytoplankton and algae communities in bays and creeks (Hallegraeff 2009). Different combinations of altered physiochemical conditions may favor some species over others, with specific outcomes uncertain. In general, increased temperature, increased nutrients, and ocean acidification may favor growth of harmful species (Paerl and Huisman 2008, Hallegraeff 2010). See related threat *(7) Changes in growth rates and survival of algae, bacteria and viruses*.

SBEP CCMP: Fisheries and Living Resources Action Plan

GOAL: Restore and sustain fish and other living resources

Table 4. Likelihood-Consequence Matrix for climate change related threats to the SBEP 2014 CCMP Fisheries and Living Resources Action Plan. Threats are driven by climate stressors including warming temperature (T), changes in precipitation (P), sea level rise (S), and ocean acidification (O).

Likelihood of Impact Occurrence	Low	Medium	High
High	(39) Increased wildfire and increased difficulty and risk with prescribed fire due to longer dry periods (T,P) (42) Change in animal migratory and dispersal patterns due to habitat changes (S,T,P) (45) Increased carbon sequestration in mangroves, seagrass meadows, and marshes (positive effect)(T,O)	(37) Increase in growth rate of harmful algal blooms (toxicity uncertain) (T,O) (40) Increased viral, bacterial, fungal, and parasitic infections of marine mammals, fish, bivalves, crustaceans, and seagrasses (T,P,O) (41) Spread of exotic and invasive fish and animal species, especially jellyfish (S,T,P)	(38) Changes in fish, crustacean and bivalve species composition, distribution, growth, survival, and fitness (S,T,P,O) (43) Changes in seagrass cover and epiphytes due to changes in water clarity, temperature, depth, and pH (S,T,P,O) (44) Decrease in juvenile fish, shell-fish, and bird feeding, breeding and refuge habitat due to loss of coastal wetlands and natural shorelines (S,T,P)
Medium		(34) Decreased dissolved oxygen in bays, tributaries and ponds (T,O) (35) OA and nutrient hot spots in creeks, canals and bayous due to decomposing organic matter, including HABs (T,O)	(46) Reduced fish nursery habitat in streams and rivers due to compressed isohaline zones (S,P)
Low		(36) Cascading food chain effects due to OA impacts on calcifying plankton (uncertain effect) (O)	

Consequences of Impact on the Action Plan Goal

Sarasota Bay has a great abundance and diversity of fish, wildlife, and other living resources. Acreages of seagrass meadows in Sarasota Bay now exceed restorable 1950s levels. They cycle nutrients, stabilize sediments, and provide food and essential habitat for many aquatic organisms, including 70% of the bay's fishery species. More than 115 species of fish (over 50 important to commercial and recreational fisheries) live in Sarasota Bay. Tidal creeks are being monitored and studied as critical juvenile fish habitat and refugia. In addition, SBEP has created hard bottom habitat in the form of artificial reefs and oyster reefs. The bay supports several island bird rookeries, and restoration efforts for scallops and clams are underway.

Fish, wildlife, and other living resources are threatened by climate stressors that can alter the physical, chemical, and biological characteristics of the estuary. Multiple climate stressors may increase physiological stress in fish and wildlife, create shifts in community interactions, and result in loss of important habitat.

The differential capacity of species to cope with altered communities and environmental conditions will disrupt the interconnectedness among species and restructure communities (Root et al. 2003). These complex interacting factors can have cascading effects through the estuarine ecosystem.

Changing habitat conditions

(34) Decreased dissolved oxygen in bays, tributaries, and ponds

Hypoxia (low oxygen) in coastal waters can be exacerbated by warmer water temperatures, stratification, and eutrophication. Whereas low dissolved oxygen can be a natural feature of some lakes, ponds, and creek segments — and in fact, life stages of some speces rely on low oxygen waters as refugia — severe or prolonged hypoxic conditions can lead to significant mortality of fish and invertebrates (Glick and Clough 2006). Heavy precipitation can result in the formation of a freshwater lens at the mouth of tidal waterbodies, preventing mixing of underlying bay waters and degrading the value of this important habitat for fish and other invertebrates. Warmer water reduces oxygen solubility. High water temperatures can kill aquatic organisms in shallow waterways with limited mixing and can accelerate microbial decay, leading to hypoxia (FOCC 2009). Localized hypoxia can also develop at depth in coastal waters when excess nutrients cause algal blooms, which later die and decay on the seafloor. Organisms capable of controlling their vertical location in the water column may have competitive advantages over those that can't. For example, cyanobacteria (blue-green algae) and dinoflagellates, which can control their depth in the upper layer of a stratified water column, can block sunlight to organisms unable to migrate to the surface (O'Neil et al. 2012, EPA 2013).

(35) OA and nutrient hot spots in creeks, canals, and bayous due to decomposing organic matter, including HABs

Excess nutrients can cause ocean acidification through eutrification (Sunda and Cai 2012).Excess carbon dioxide released from microbial activity can create localized hotspots of low pH, especially in deeper layers of stratified waters and in canals and bayous with limited mixing (Wallace et al. 2014). In coastal waters, eutrophication and freshwater inputs can influence acidity to a greater extent than atmospheric carbon dioxide (Beavers 2016).

(36) Cascading food chain effects due to OA impacts on calcifying plankton (uncertain)

Changes in estuary pH can change the structure and function of planktonic and microbial communities, in both free-living forms and those symbiotic or epiphytic to seagrasses, corals, sponges, and bivalves — with a negative impact on host health (Hallegraeff 2010). Ocean acidification reduces calcification rates of all aquatic calcifying organisms, including plamkton and coralline algae (Kuffner et al. 2008). Under lower pH conditions, changes in nutrient cycling are likely, with increased primary productivity, increased nitrogen fixation, and decreased nitrification (O'Brien et al. 2016). See related threat *(33) Changes in nutrient cycling and primary productivity, especially for HABs*.

(37) Increase in growth rate of harmful algal blooms

Incidence of nuisance or toxic algal blooms, such as cyanobacteria, *Karenia brevis* and *Pyrodinium bahamense*, is expected to increase with increased temperature and eutrophication of coastal waters (Paerl and Huisman 2008). Some harmful algal blooms (HABs) produce toxins that sicken and kill fish, shellfish, manatees, dolphins, sea turtles, and birds. Even nontoxic HABs can kill by reducing water clarity, smothering seagrass and other aquatic vegetation, and causing hypoxia when they decay.

Temperature or OA related increases in algal growth rates do not necessarily correlate with increased toxicity of the organism. For example, growth rates for the planktonic algae responsible for red tide, *Karenia brevis*, will increase at high levels of ocean acidification, but cell toxicity will not (Errera et al 2014). See related threats (*7) Changes in growth rates and survival of algae, bacteria and viruses*; and *(33) Changes in nutrient cycling and primary productivity, especially for HABs*.

(38) Changes in fish, crustacean, and bivalve species composition, distribution, growth, survival, and fitness

Ocean acidification (OA) will disrupt the mineral balance in water and make it more difficult for marine organisms, such as shellfish, plankton, and corals, to produce and maintain calcium carbonate, the primary component of their skeletons and shells. For animals, maintaining intracellular pH balance under more acidic conditions requires more metabolic energy, decreasing overall reproduction and survival. Ocean acidification can cause deformities in larval stages, increasing mortality. In some shellfish and fish, especially in the juvenile stages, OA can also impair metabolism, immune system, sensory functions, and reproduction (Strong et al. 2014, Morrison et al. 2015). Overall, ocean acidification may profoundly impact the entire marine food web and negatively affect recreational and commercial fisheries.

Optimal temperature ranges vary considerably among species, but tropical and subtropical species tend to have a relatively narrow range and may be more sensitive to climate change (Morrison et al. 2015). Warmer air and water temperatures can affect metabolism, reproduction, foraging, and predator-prey interactions. Important estuary-dependent gamefish, like snook and tarpon, have optimal temperature ranges less than 20 degrees F (Glick and Clough 2006). Warmer temperatures expected by the end of the century could exceed the thermal tolerance for shellfish, such as crabs, shrimp, and oysters, and finfish, such as Striped Bass, Flounder, and Spotted Seatrout (Glick and Clough 2006). In sea turtles, sex determination is temperature dependent, so higher temperatures in nests might cause skewed sex ratios, leading to existential risk (Polaczanska et al. 2009). Higher temperatures, combined with eutrophication and ocean acidification, create conditions favorable for increased abundances of jellyfish (Richardson et al. 2009).

Oysters live in a narrow physiochemical zone, where they receive regular tidal inundation and freshwater input that creates an optimal salinity regime. Oyster reefs may grow in elevation at pace with sea level rise in some locations, but they face other climate stressors including ocean acidification, eutrophication and algal blooms, disease, and parasites (Rodriguez et al. 2014). Oyster reefs located at the mouths of tidal creeks will likely migrate upstream with sea level rise, but may find limited substrate availability in the narrower creek beds.

(39) Increased wildfire and increased difficulty and risk with prescribed fire due to longer dry periods

With more frequent or intense droughts, natural fire regimes can shift, bringing risk of more intense and long-burning wildfires. Loss of groundcover can lead to increased sedimentation in waterways via erosion. While fire is a natural and necessary feature of many upland habitats, there may be increased burn risk for desiccated wet mesic or hydric habitats that are not well-adapted to frequent wildfire. As a result, use of prescribed fire as a landscape management tool to maintain habitat conditions for plants and animals may become more difficult and risky in some locations (Scott 2008).

Changes in species and community structure

(40) Increased viral, bacterial, fungal, and parasitic infections of marine mammals, fish, bivalves, crustaceans, and seagrasses

Growth rates and geographic ranges of marine pathogens may increase with water temperature (Glick and Clough 2006). Increases in disease outbreaks are correlated with temperature increases, as seen in Eastern oyster disease in the Gulf of Mexico during warm, dry La Nina years, and with some coral diseases in South Florida. However, mechanisms for pathogenesis among marine invertebrates and seagrasses are largely unknown (Harvell et al. 2010). Emergence of new disease pathways may have the most impact, as expanded geographic range of hosts or pathogens may stimulate disease outbreaks among formerly disjunct populations. Animals already under physiological stress from other climate-related factors, such as hypoxia and ocean acidification, will be more susceptible to disease (Devitt et al 2012). See related threat *(7) Changes in growth rates and survival of algae, bacteria and viruses*.

(41) Spread of exotic and invasive fish and animal species, especially jellyfish

While Florida is a hotspot for endemism in the subtropics, non-native and invasive species are also widespread. Almost all of the exotic fish species established in Florida in recent years are subtropical or tropical. While warmer temperatures will facilitate a northern range expansion of cold-limited native species, the ranges of exotic and invasive species, such as lionfish and tilapia, will likely expand as well. Spread of exotic and invasive species can impact native species through competition, predation, and disease (Cameron Devitt 2012). Changes in physical habitat characteristics due to changes in temperature, pH, sea level, and precipitation will reorganize community interactions, shifting dominance of some species and causing local extirpations of others. For example, increasing temperature and coastal eutrophication will favor jellyfish over bony fish (Richardson et al. 2009). As biogeography is redefined, the functional difference between native and exotic species — and which species require management intervention and which can be tolerated — may become more blurred (Walther 2009).

(42) Change in animal migratory and dispersal patterns due to habitat changes

For many species, environmental cues determine the timing of life-history events. Climate driven changes in seasonal patterns of temperature and precipitation can alter the timing of migration, dispersal, reproduction, and growth — especially for migratory fish and birds (NAS 2015, Morrison 2015). Because these phenological changes are species-specific, a temporal mismatch can occur for food and habitat availability. Mis-timed species interactions can decouple predator and prey, plant and forager, and plant and pollinator relationships, or create direct competitors. Furthermore, new combinations of species behaviors and interactions may create new “no-analog” communities with altered biodiversity and ecological function (Stralberg et al. 2009).

Loss of habitat

(43) Changes in seagrass cover and epiphytes due to changes in water clarity, temperature, depth, and pH

As a primary indicator of water quality, healthy and abundant seagrass cover is an important CCMP Goal. Because seagrasses require sunlight for photosynthesis, improved water transparency allows sunlight to penetrate to greater depths, increasing the available habitat where seagrass can grow. Light penetration can be reduced by increased water depth due to sea level rise, increased turbidity from erosion and runoff due to more intense storms, and increased growth of phytoplankton due to increased temperature and nutrients. Reduced light and rising sea levels can cause migration of seagrasses and associated epiphytes from deeper edges towards shallower flats and shorelines. Growth rates and redistribution of seagrass and epiphytes will likely be accelerated by elevated carbon dioxide and temperature in bay waters, except in shallow areas with limited mixing where nutrient and temperature hot spots may cause algal blooms and die-offs (Paerl and Huisman 2008).

More carbon dioxide in water may stimulate seagrass photosynthesis, which can increase water pH (make it less acidic) and increase availability of calcium carbonate. As a result, seagrasses may reduce impacts to organisms susceptible to ocean acidification, particularly shellfish and fish, and serve as a refuge (Manzello et al. 2012).

(44) Decrease in juvenile fish, shellfish, and bird feeding, breeding, and refuge habitat due to loss of coastal wetlands and natural shorelines

Mangroves provide protected nursery habitat for fish, crustaceans, shellfish, and colonial birds. Together with detritus and organisms associated with their roots, they provide important forage and habitat for fish, oysters, shrimp, and birds. Where coastal wetland accretion and growth cannot keep pace with sea level rise and where upland barriers to uplope migration prevent it, critical coastal habitats will likely drown and become open water

(Torio and Chmura 2013). Fragmentation and loss of mangrove forest and salt marsh will negatively impact estuarine organisms. See related threat *(25) Loss of shallow intertidal habitat, including mangroves, salt marsh, and beaches, due to upland barriers to migration*.

(45) Increased carbon sequestration in mangroves, seagrass meadows, and marshes

Coastal habitats will be impacted by climate change, but will also have an important role in mitigating its effects. Tidal wetlands and seagrasses take up carbon dioxide and store "blue carbon" in plant biomass and associated wet soils. Blue carbon ecosystems – seagrass beds, mangroves, and salt marshes – store carbon at roughly 25 times the annual rate of temperate and tropical forests, due to high primary productivity and efficiency in trapping sediments and associated carbon transported by runoff and tidal flow (Mcleod et al. 2011).

(46) Reduced fish nursery habitat in streams and rivers due to compressed isohaline zones

Rising sea level and/or changes in flow due to drought will shift tidally influenced portions of creeks and rivers upstream, lengthening the upstream reach of stratified estuarine conditions and compressing the upper isoahaline zones. Isohaline zones have distinct chemical and physical characteristics that create important habitat for plankton, macroinvertebrates, and fishes (Jassby et al. 1995). Juvenile fishes especially rely on these upstream isohaline zones as nursery habitat. See related threat *(8) Increase or decrease in episodic volume and velocity of freshwater to tidal creeks and the bay*.

SBEP CCMP: Recreational Use Action Plan

GOAL: Increased managed access to Sarasota Bay and its resources

Table 5. Likelihood-Consequence Matrix for climate change related threats to the SBEP 2014 CCMP Recreational Use Action Plan. Threats are driven by climate stressors including warming temperature (T), changes in precipitation (P), sea level rise (S), and ocean acidification (O).

Likelihood of Impact Occurrence \ Consequences of Impact on the Action Plan Goal	Low	Medium	High
High			(47) Reduced and/or restricted public access to beaches, coastal parks, and natural areas due to shoreline stabilization measures, tide control structures, reduced clearance under bridges, and flooding (S,P)
Medium		(48) Recreation and ecotourism business conditions may be destabilized, reducing public access to Bay resources (S,T,P,O) (49) Reduced participation in outdoor Bay-related recreation, volunteering, and education due to extreme weather conditions, pests, diseases, and reduced water quality (T,P,O) (50) Increased negative interactions between humans and wildlife in decreased or shifting natural areas (S,T)	
Low	(51) Changes to birding and ecotourism activities due to changes in species composition and/or change in migration timing (S,T) (52) Extended recreational boating season and increased boating activity (T)		

The Sarasota Bay area is known for beach-going, fishing, kayaking, sailing, wildlife viewing, and other recreational pastimes. These popular activities are a primary draw for many of the 2.5 million tourists who visit each year (Downs & St. Germain Research 2016) and contribute to the quality of life and well-being of local residents. Sarasota Bay plays an important role in both the economic and cultural value of the region. Accounting for all direct and indirect benefits Sarasota Bay resources contribute to the economy, the bay is valued at $11.8 billion (Hindsley 2012).

Maintaining public access to recreational opportunities in the bay is important to the identity and vitality of the region. The primary goal of SBEP's Recreational Use Plan is to enhance recreational opportunities while protecting bay resources from user impacts. Implementation has resulted in improvements in boater safety and management of highly frequented areas as well as the creation of ecological parks. Since 1995, SBEP and its partners have taken measures to ensure appropriate access and use of the bay and its resources, from establishing parks, hosting guided ecotours, to ensuring protective speed zones and channel marking for seagrass and wildlife.

Climate change may reduce the accessibility of recreational opportunities in Sarasota Bay. Warmer temperatures and more intense storms may decrease participation in outdoor activities. Rising seas and changes in ecosystem structure may restrict physical access to common recreational areas, which can put more stress on other areas and resources.

Public Access

(47) Reduced and/or restricted public access to beaches, coastal parks, and natural areas due to shoreline stabilization measures, tide control structures, reduced clearance under bridges, and flooding

Sea level rise and changing precipitation patterns pose flood risk to natural and developed areas. Higher seas will reduce the amount of land in beaches and coastal parks available to residents and visitors and reduce access to boat ramps, kayak launches, bridge clearance, and other safe entranceways and passageways to the bay. Without resiliency planning for coastal areas, increased flood risk will likely cause bayfront landowners to stabilize shorelines with seawalls, bulkheads, rip rap, and dense vegetation — which will further reduce bay access. In 1992, SBEP surveys revealed that one of the primary recreational uses of the bay was simply gazing at the seascape. The accessibility of the bay viewshed may become more impacted as coastal communities implement various stabilization measures.

(48) Recreation and ecotourism business conditions may be destabilized, reducing public access to Bay resources

Increased sea levels and flooding may reduce the number and availability of access points, like kayak launches, boat ramps, and trails. This may disrupt tour operators and rental businesses, causing them to reduce or suspend operations. For example, the Lido Key mangrove tunnels are one of the most popular kayaking locations in the Sarasota Bay area. Many tour companies base their operations there because it is a key launch point with parking. Due to its low elevation, flooding and erosion may increasingly render it inaccessible. SBEP's ecotourism program, Bay Wise Kayak Tours, relies on various public kayak launches to provide free guided excursions to roughly 82 people every year. Flooding at these launch points would greatly reduce the organization's ability to deliver this program.

Participation

(49) Reduced participation in outdoor bay-related recreation, volunteering, and education due to extreme weather conditions, pests, diseases, and reduced water quality

SBEP hosts 10-15 volunteer events that engage 300 volunteers annually. These events include rigorous outdoor activities like planting native trees and shrubs, pulling invasive vegetation, building and deploying oyster reefs, and cleaning up local beaches and parks. In addition to citizen volunteer opportunities, SBEP works with Around the Bend Nature Tours to provide outdoor field trips to roughly 1,600 K-12 students every year. Warmer air temperatures and more intense storms may shorten the duration and seasonal time frame for these activities. Increased runoff can pollute coastal waters, making them unsafe for volunteers and students. Warmer conditions that promote pests or harmful algal blooms might also inconvenience or endanger volunteers and students, reducing participation in and effectiveness of important SBEP programs.

(50) Increased negative interactions between humans and wildlife due to changes in or loss of natural areas

As temperatures warm and sea levels rise, areas supporting plant and wildlife communities will migrate and overlap with developed areas. In addition, developed areas may shift away from flood zones to occupy lands traditionally used by wildlife. Limited beach access due to sea level rise, coupled with restricted areas for nesting birds or turtles, may cause crowding and controversy over access and use.

Recreational Use Impacts

(51) Changes to birding and ecotourism activities due to changes in species composition and/or change in migration timing

Sarasota is a popular birding destination with a high diversity of native and migratory species. Roughly 336 bird species have been spotted in Sarasota County since 1987 (Sarasota Audubon Society 2014). Tourists from all over the world come to visit birding hotspots like Myakka River State Park and the Celery Fields. As temperatures warm and ecosystems change, phenology, abundance, and diversity of resident and migrant species may shift. Warmer temperatures may exclude temperate species, but may accommodate new tropical species. Depending on how wildlife patterns emerge, recreational use of natural areas and ecotourism opportunities for birding may increase, decrease, or remain unchanged.

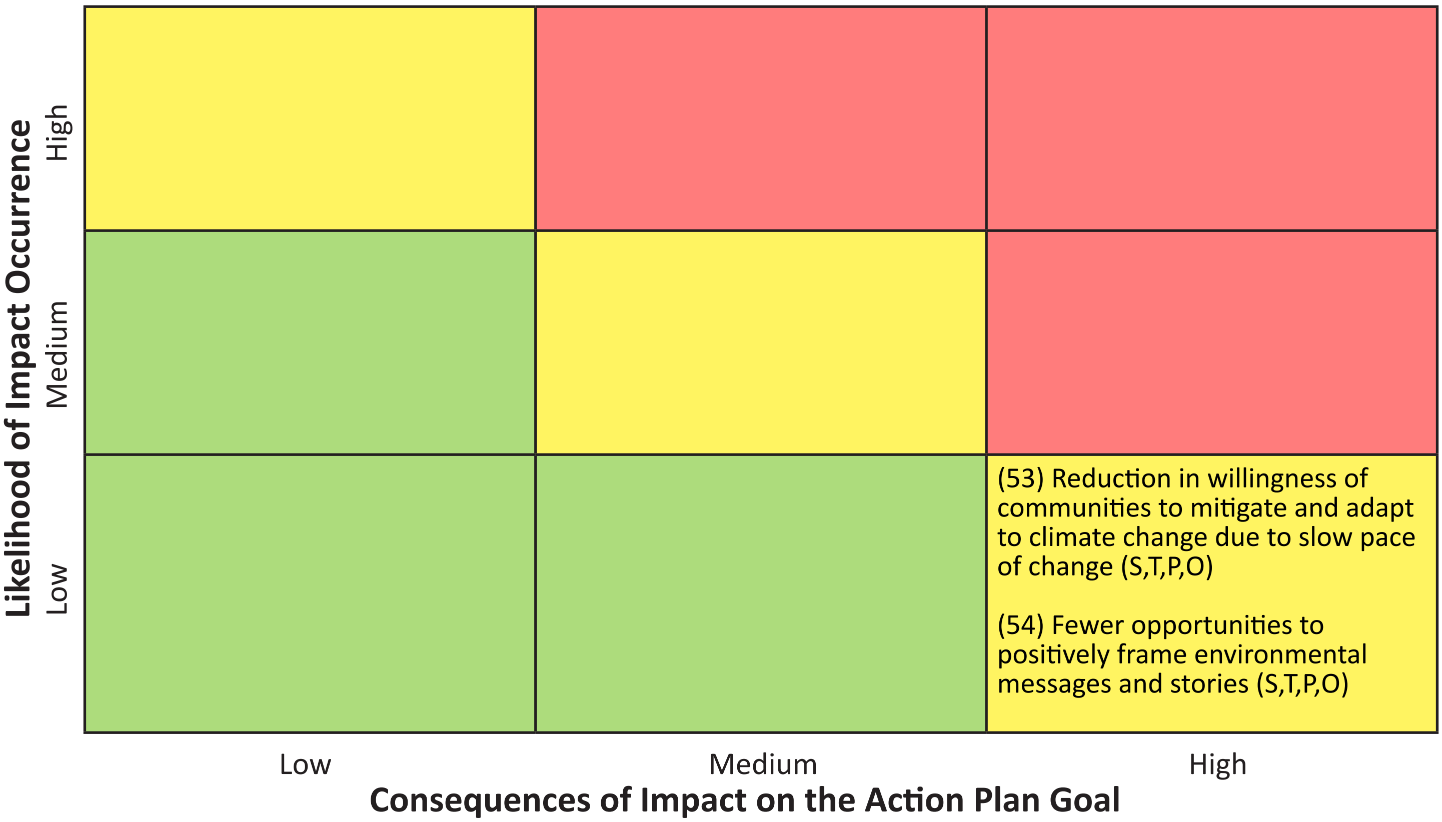
(52) Extended recreational boating season and increased boating activity

As water and air temperatures rise, boater activity and duration of boating season may increase in Sarasota Bay. Although longer boating seasons will allow for more recreational opportunities, increased use of bay resources may impact water quality, habitats, and fish and wildlife. Overfishing, seagrass scarring, increased pollution, and higher occurrence of boater-manatee accidents may result.

SBEP CCMP: Citizen Participation Action Plan

GOAL: Engage, educate, and encourage environmental stewardship of Sarasota Bay

Table 6. Likelihood-Consequence Matrix for climate change related threats to the SBEP 2014 CCMP Citizens Participation Action Plan. Threats are driven by climate stressors including warming temperature (T), changes in precipitation (P), sea level rise (S), and ocean acidification (O).



Studies show that personal connections to outdoor places are linked with pro-environmental behavior (Obery 2017). In 2011, SBEP added a Citizen Participation Action Plan to its CCMP to encourage and provide opportunities for environmental stewardship. Through education, communication, and public events, SBEP offers a diverse range of engagement opportunities. The primary goal of SBEP's Citizens Participation Plan is to increase public awareness about the link between activities in the watershed and their impact on the bay to promote better environmental stewardship. This includes encouraging water and energy conservation, Florida-friendly landscaping, low impact development, and citizen science and environmental monitoring. Climate change may affect the appeal of stewardship opportunities in Sarasota Bay.

(53) Reduction in community willingness to mitigate and adapt to climate change due to slow pace of change

Although Sarasota-Manatee is already experiencing impacts from sea level rise, ocean acidification, warmer temperatures, and changes in precipitation, when people talk about climate change, they frame its worst consequences as something that will happen in the future (Pahl 2014). This perception creates a disconnect between current actions and climate impacts, and reduces the perceived urgency of the issue.

Many of the consequences of climate change are indirect; they involve time lags and require mitigation from multiple entities. It may be challenging for many people to justify changing their thoughts or behavior now to adapt to something that is happening gradually or won't happen until the distant future. The mindset that one person can't make a difference also remains a barrier to action. People may be less willing to take personal responsibility to implement practices like Florida Friendly Landscaping™ or Low-Impact Development if they feel their actions won't make a difference. This type of thinking may also impact participation rates in and the effectiveness of SBEP's stewardship programs and events that specifically target climate adaptation.

(54) Fewer opportunities to positively frame environmental messages and stories

As the impacts of climate change increase in frequency and severity, it may become more challenging for SBEP staff to highlight positive environmental stories and solutions. Negative messaging from other environmental leaders may reduce citizen engagement with SBEP-lead conservation and restoration activities in Sarasota Bay. Furthermore, if climate impacts occur more frequently and with increasing severity, public attention and effort may shift away from educational and restoration activities offered by SBEP and more toward repair, clean up, and protection of personal property. For example, after Hurricane Irma in September 2017, SBEP cancelled multiple educational trainings during and after the storm due to unsafe conditions, lack of power, and the need to give communities time to repair and take care of their own businesses, homes and families.

VI. CONCLUSIONS

Climate change will threaten natural systems already under stress from anthropogenic threats. Existing resource management challenges may become more urgent and new ones may develop. Climate change is already impacting SBEP management goals and will continue to do so in the future. This planning-level risk-based Vulnerability Assessment serves as a starting point for prioritizing and integrating climate change impacts into long term planning. Across the six CCMP goals, 72% of the identified threats were associated with the Stormwater, Wetlands, and Fish & Wildlife CCMP Action Plans (Table 8). These Action Plans also had more threats with high likelihood of occurrence and serious consequences. Most threats were attributed to multiple stressors — most often warmer temperatures and changes in precipitation (Table 9). Change in precipitation was most often a cause of the most important threats. Monitoring these stressors will be important to effective adaptive management of SBEP CCMP priorities.

Table 7. Summary of threats as ranked in the Climate Risk Matrix for each Action Plan across all climate stressors.

ACTION PLAN	Less Important	Important	Most Important	Total
Wastewater	2	1	4	7
Stormwater	6	6	5	17
Wetlands	2	0	7	9
Fish & Wildlife	1	5	7	13
Recreational Use	3	2	1	6
Citizen Participation	0	2	0	2
Total	14	16	24	54

Table 8. Summary of instances Climate Stressors were indicated as cause of threats across all CCMP Action Plans.

Climate Stressor	Less Important	Important	Most Important	Total
Sea Level Rise	6	8	14	28
Temperature	7	11	14	32
Precipitation	7	11	19	37
Ocean Acidification	4	6	7	17

Although most threats were specific to one particular CCMP Action Plan, there were several that spanned multiple CCMP Action Plans. Algal blooms, for example, which are exacerbated by multiple climate change stressors, were mentioned in Wastewater, Stormwater, Wetlands, Fish & Wildlife, and Recreation Action Plans. Infrastructure vulnerabilities were mentioned in multiple Action Plans as well.

Limitations and Further Study

This Vulnerability Assessment identified 54 threats arising from four climate stressors that present a range of challenges to achieve CCMP goals. Considering the interconnected nature of climate change stressors and their threats, it is certain that threats and their prioritization will change over time. Threats arising from climate stressors will interact with threats from ongoing and new anthropogenic stressors to produce outcomes that may be complex, non-linear, cascading, threshold-dependent and difficult to predict with reasonable certainty.

Scientific understanding of climate change and how it may impact natural and built environments is growing. In parallel, conservation, restoration, mitigation, and adaptation management tools are being developed and tested. As these fields evolve, effective resource management must remain adaptive and sensitive to new information and management tools as they arise and climate change progresses.

This assessment took a qualitative approach to risk analysis, relying on peer-reviewed research papers, grey literature, agency reports and the knowledge and judgement of local experts and stakeholders. There are limitations in current scientific understandings of local climate impacts and in the availability of local, historical data on water temperature, precipitation, and coastal ocean acidification. Identifying these gaps has already informed the development of the SBEP Technical Advisory Committee's list of Research and Technical Needs. This list will be used to prioritize research and technical projects during the five-year term of the next SBEP CCMP (2019–2024). Continuing to consider the effects of climate change on the management framework for Sarasota Bay over time will be fundamental to the continued success and efficacy of the Sarasota Bay Estuary Program.

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