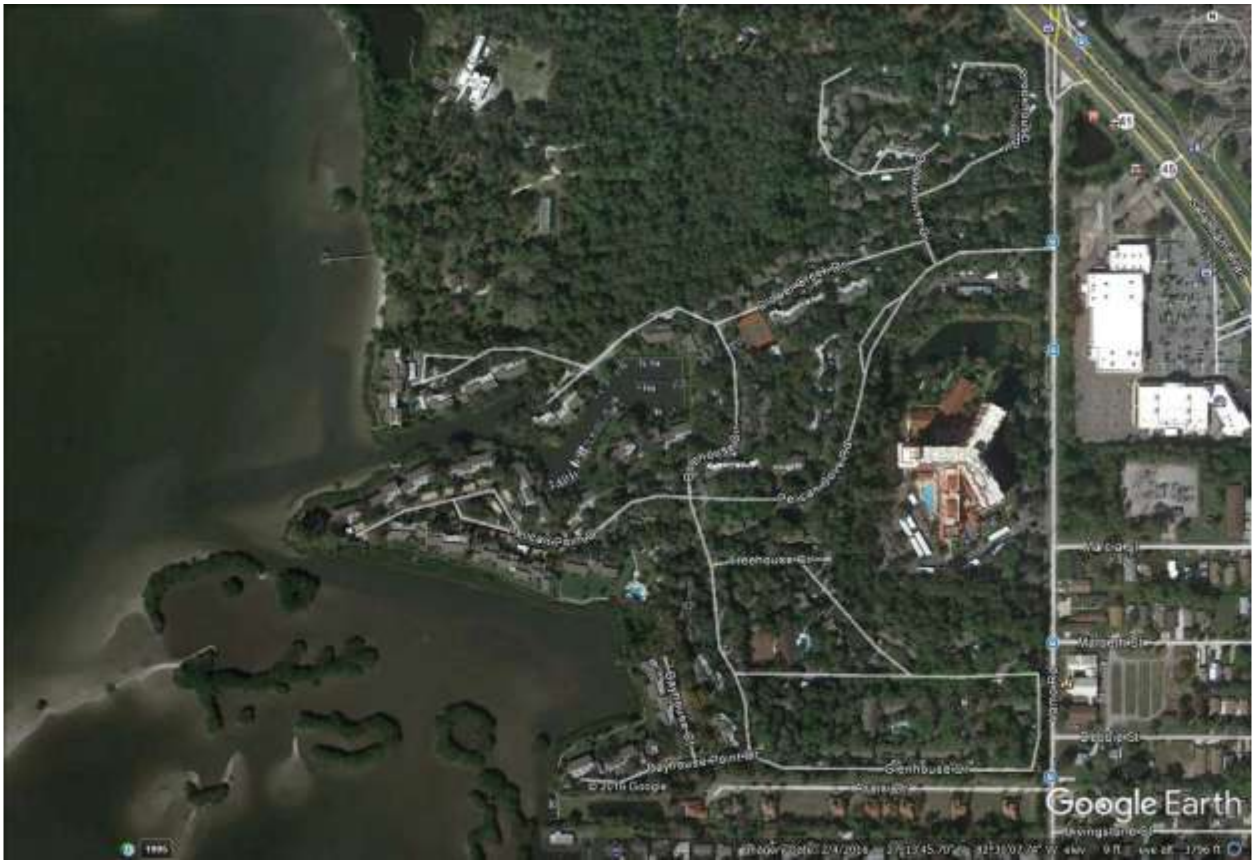
The Pelican Cove Community Climate Change Vulnerability Assessment

Southwest Florida Regional Planning Council



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SWFRPC and climate change planning

The **Charlotte Harbor National Estuary Program** (CHNEP, www.chnep.org) and the **Southwest Florida Regional Planning Council** (SWFRPC, www.swfrpc.org) have completed significant fundamental work to address sea level rise and other climate change issues to date (Beever 2009 in Fletcher 2009).

In the late 1980's the SWFRPC completed hurricane storm surge modeling and maps that have been used by the region and local governments to guide land use decisions, infrastructure investments, and conservation lands acquisition. This early work and resulting decisions have increased resiliency associated with sea level rise.

In 2003 the SWFRPC collaborated with local scientists and EPA's Office of Atmospheric Programs, Climate Change Division, on the "Land Use Impacts and Solutions to Sea Level Rise in Southwest Florida" project. The project resulted in sea level rise projections by probability and year, along with maps that represent the near worst case scenario. Public participation was actively sought throughout the project; the progress and outputs of the project will be communicated to local governments, stakeholder groups and the public at large for use in developing coastal and land use planning, and avoidance, minimization, mitigation and adaptation of climate change impacts throughout the CHNEP study area.

Throughout 2008 the SWFRPC and CHNEP prepared a Regional Vulnerability Assessment for the counties shared by the two agencies. A database with climate effects and adaptation options forms the core of the assessment. The work was funded by EPA Region 4. As one of 6 Climate-Ready Estuary pilot programs, CHNEP and SWFRPC are partnering with the City of Punta Gorda to develop a city-specific Adaptation Plan, which will implement recently adopted city comprehensive plan policies related to climate change.

Information and technical assistance are provided from the Pelican Cove Condominium Association, the South Florida Water Management District, the Charlotte Harbor National Estuary Program, and the Intergovernmental Panel on *Climate Change* (IPCC).

Table of Contents

Executive Summary

Pelican Cove and Southwest Florida are currently experiencing climate change. The natural estuarine peninsula setting of Pelican Cove coupled with extensive investment close to the coast have placed the community at the forefront of geographic areas that are among the first to suffer the negative effects of a changing climate. More severe tropical storms and hurricanes with increased wind speeds and storm surges have already severely damaged both coastal and interior communities of southwest Florida. Significant losses of mature mangrove forest, water quality degradation, and barrier island geomorphic changes have already occurred. Longer, more severe dry season droughts coupled with shorter duration wet seasons consisting of higher volume precipitation have generated a pattern of drought and flood impacting both natural and man-made ecosystems. Even in the most probable, lowest impact future climate change scenario predictions, the future for southwest Florida and Sarasota County will include increased climate instability; wetter wet seasons; drier dry seasons; more extreme hot and cold events; increased coastal erosion; continuous sea level rise; shifts in fauna and flora with reductions in temperate species and expansions of tropical invasive exotics; increasing occurrence of tropical diseases in plants, wildlife and humans; destabilization of aquatic food webs including increased harmful algae blooms; increasing strains upon and costs in infrastructure; and increased uncertainty concerning variable risk assessment with uncertain actuarial futures. Maintaining the status quo in the management of coastal and estuarine ecosystems in the face of such likely changes would result in substantial losses of ecosystem services and economic values as climate change progresses.

This vulnerability assessment examines the potential effects of climate change within the Pelican Cove Community and identifies specific vulnerabilities of 1) the shoreline and water quality to potential sea level rise and other coastal storm risks and how these risks may negatively impact the environment in the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay; 2) from flooding and runoff caused by potential sea level rise and increased rain fall and storm activities including how these risks may negatively impact the environment in the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay, as well as structures, grounds, and infrastructure at Pelican Cove; and 3) to the structures, grounds, and infrastructure from trees that are most susceptible to wet soils and high winds.
At the current measured rates of sea level rise for Litter Sarasota Bay, Pelican Cove can expect 1 foot of eustatic sea level rise above the current mean tide by the year 2131; 2 feet of eustatic sea level rise above the current mean tide by the year 2245; and 3 feet of eustatic sea level rise above the current mean tide by the year 2341. Many climate change models with strong scientific bases anticipate a rapid acceleration of sea level rise above the current measured rate, caused by more rapid melting of land based ice in glaciers and the polar zones, increased releases of Green House Gases from human activities, agricultural practices, and natural sources released from melting . This set of models predict faster sea level rise such that Pelican Cove can expect 1 foot of eustatic sea level rise above the current mean tide by the year 2051; 2 feet of eustatic sea level rise above the current mean tide by the year 2085; and 3 feet of eustatic sea level rise above the current mean tide by the year 2120.

Storm surge events from tropical storms will increase due to the higher sea level stand combined with a higher severity of storms and impact Pelican Cove sooner than the eustatic sea level rise effects. All of Pelican Cove is within the Category 3 storm surge zone, approximately half of the community is in the Category 2 storm surge zone and all of the estuarine shoreline Bayhouse and Harborhouse is in the Category 1 storm surge zone. For all directions of storm approaches with the exception of a storm crossing the state from east to west. Areas along Clower Creek within Pelican Cove are also in the Category 1 and 2 Strom Surge zones. The extent of these surges will reach further upslope and inland with the increased standing sea level. In addition rapid run-off from the urbanized impervious surfaces or the headwaters of Clower Creek will during rainy storms flood the riparian areas of Pelican Cove much more quickly even if the tide is low and wind fetch is blowing westward during a storm.

The existing drainage infrastructure of Pelican Cove depends upon rapid discharge to receiving waters,

Construction at Pelican Cove began in 1975 as six separate condominium associations which eventually merged into a single condominium association with six neighborhood. The stormwater drainage and treatment system of Pelican Cove reflects this old design that had limited detention/retention and quick discharge to tidal waters. The road system within Pelican Cove reflects a strong dependence upon the road surface shape to direct surface water run-off directed to central gutter groves, edge swales and small basin stormwater ponds. Much of the non-point stormwater discharge goes directly into Sarasota Bay, Clower Creek or the Harbor basin without much treatment other than grassed surfaces. In some areas there is no treatment before road and building runoff enters the estuary directly. This is particularly true at the terminus of roadways and through directed pipes entering the Yacht Basin.

Some portions of the roads hold water in shallow pools without drainage until the water reaches sufficient height to exceed the depression’s depth or evaporation does its work. These were typically along road edges at junctures with parking slots. The grassed swale system behind Bayhouse Building #5B is a good functional feature. Unfortunately this type of stormwater treatment is not replicated and may not be possible in the Harborhouse area or in locations like Bayhouse Building #8 where there is insufficient distance between buildings and the Bay and a sharp drop-off to a rip-rap and Australian pine shoreline.

The area facing north in front of *Bayhouse Buildings #8 and #9*; and the west facing shoreline of Harborhouse #21 have the most exposure to wind fetch generated waves with subsequent erosion,. The south facing Bayhouse Buildings #7, #6, #5B and Bayhouse Buildings #2 and #1 are wee protected by the mangrove islands that stop wave action and calm wind effects coming from the south and west. The wider mangrove shoreline hedges are more robust on the south facing shoreline. Both the Yacht Basin and Clower Creek above the juncture with the Yacht Basin Channel are depositional environments accumulating significant silt deposits above the original channel bottoms.

Erosion occurs on-site from three basic causes wave action from the Bay, flow down Clower Creek, and run-off from land surfaces. The current areas of Bay-side erosion is the area not protected by flanking mangrove islands at *Bayhouse Buildings #8 and #9*; and the west facing shoreline of Harborhouse #21. These areas already have been hardened with rip-rap behind vegetation fringes. There is erosion between buildings #8 and #9 where4 there is a discontinuation of rip-rap and water running off the Pelican Point Drive coupled with excess water coming from misdirected irrigation sprinkler heads run down slope into the area near the mouth of Clower Creek. Erosion is also occurring from areas behind Bayhouse #9 at a very low wooden board barrier that is being over-watered above it and is not retaining soil as it appears it was intended to do.

From site inspection the area of Bayhouse Buildings #7, #6, #5B and Bayhouse Buildings #2 and #1 have approximately 8 feet of elevation above the high tide mark. The Bayhouse Buildings #8, #9, and #10 appear to have 5 feet of elevation above current high tide.

East of the road bridge Clower Creek is blocked by vegetation that has grown across the creek bed and a significant amount of fallen vegetation has fallen into the creek and/or tangled into the living vegetation. This includes both native mangroves and exotics like Brazilian pepper.

Clower Creek is significantly silted in with fines representative of a long period of upland run-off deposition. The salinity barriers below the bridge are filled to the control elevation with silt, providing little to no capacity for settling of more silt and turbidity.

The vegetation of Pelican Cove reflects a canopy that is composed of an original coastal oak hammock uplands flanked by a mangrove shoreline that has been invaded by the typical invasive exotics that move into disturbed areas and then landscaped intentionally as a form of botanical garden with a wide diversity of non-native species disperse among the residential and common areas. There are 82 species of trees at Pelican Cove at this time. There are 29 (35.37 %) native tree species on-site with oaks and cabbage palm the most common. There are 52 (63.41%) species of non-native tree species.

Twenty-one tree species have the highest wind resistance. Seventeen of the trees with the best wind resistance are natives, of the non-native trees with high wind resistance all are palms naturally adapted to high winds of their original home environment.
Fourteen tree species have medium wind resistance, 30 species have medium to low wind resistance, and 17 have low wind resistance. Only 2 of the species with the lowest wind resistance are native, the red cedar and laurel oak. The other 15 include some of the worst invasive plant exotics in Florida including Australian pine, melaleuca, and carrotwood
T
he vegetation understory is principally exotic species ranging from sod grasses to typical nursery landscaping species like hibiscus and periwinkles and several invasive exotic species including Brazilian pepper, wedelia, and exotic ferns as well as some toxic species like cats-eye and Devil's trumpet.

There are pockets of coastal hammock shrubs with sea grape, inkberry, sea ox-eye daisey, silver buttonwood, and palmettos found shoreward of the mangrove fringes in the Bayhouse and lower Clower Creek areas.

The trees with low and medium to low wind resistance are potential dangers to buildings, property and human safety from wind through branch break and utility damages. Some are allopathic and prevent species other than their offspring from living or sprouting in their vicinity.

Introduction

The climate is changing. It has been changing since the formation of the atmosphere and the presence of water as vapor, liquid, and ice on the surface of the earth. Since the Pliocene and throughout the Pleistocene and Holocene (Current) Eras, global temperatures have risen and fallen with concomitant changes in air temperature and chemistry, hydrology, geomorphology, habitats, plant and animal species, sea level, and water temperature and chemistry. With the advent of human civilization and the recording of historical records, changes in the climate have changed human economy, human health, human infrastructure and human land use (Thomas 1974).

Climate change is currently occurring and more change is to be expected. The question for Southwest Floridians is not *whether* they will be affected by climate change, but *how much* they will be affected and in what ways including the degree to which it will continue, how rapidly change will occur, what type of climate changes will occur, and what the long-term effects of these changes will be (FOCC 2009).

Southwest Florida is particularly vulnerable to the effects of climate change. Topography is flat, naturally poorly drained and not very high above existing sea level. The majority of conservation lands and the regional economy have major investments within close proximity of the coast or lake water bodies. The savanna climate is naturally extreme, even without new perturbations.

Pelican Cove Condominium Association is a 75-acre gated community on Little Sarasota Bay in Sarasota, Florida, Originally the site was an old Florida landscape with towering palms, oaks, exotic fruit and nut trees, and a half mile panoramic view of the bay. During the 1930's the property was modified by the importation of melaleucas, Australian pines, sago palms and other exotic plantings. The property was developed during the 70's and early 80's, at the vanguard of ecologically oriented designs. Wherever possible the existing natural and exotic plant setting was left in place creating a close-to-nature habitat.

Pelican Cove is a coastal community and as such is vulnerable to the effects of hurricanes, tropical storms, and extra-tropical storms. Climate projections indicate increases in the strength and intensity of these storms as well as sea-level rise which will increase the likelihood of flood events. Pelican Cove is an environmentally friendly community and as such is concerned about the health of the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay.

In view of the concerns noted above, Pelican Cove commissioned an Adaptation Study to provide a clear roadmap for addressing these issues. The purpose of this study is to prepare a course of action and design criteria that defines Pelican Cove's vulnerabilities in three important areas and provide methods to reduce potential damage to the environment, buildings, grounds and infrastructure due to impact from these events. The study includes three specific areas of concern which are: shoreline and water quality, drainage and erosion, and landscaping.

Shoreline and Water Quality: Pelican Cove's shoreline is vulnerable to the effects of climate change including not only sea level rise, but also such factors as elevated temperatures, and overland erosion and flooding from runoff from heavier rainfall events. In addition, our natural environment and property values are dependent on the health of the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay. This report identifies specific vulnerabilities of the shoreline and water quality to potential sea level rise and other coastal storm risks and how these risks may negatively impact the environment in the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay.

Drainage and Erosion: Pelican Cove is situated at a lower elevation than much of the surrounding properties and is vulnerable to overland erosion and flooding related to runoff from heavier rainfall events. The erosion and runoff may impact the health of the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay. In addition, Pelican Cove's storm sewer system was designed to utilize sheet flow directly into the surrounding waterways. The potential sea level rise and storm surge associated with hurricanes, tropical storms and extra tropical storms increases vulnerabilities to flooding. This report identifies specific vulnerabilities from flooding and runoff caused by potential sea level rise and increased rain fall and storm activities including how these risks may negatively impact the environment in the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay, as well as structures, grounds, and infrastructure at Pelican Cove.

Pelican Cove is a heavily forested community with many large mature trees and a heavy understory. The landscaping is vulnerable to wet soils and high winds associated with hurricanes, tropical storms, and extra tropical storms. In addition, the proximity to Little Sarasota Bay provides special concerns for runoff of chemicals or fertilizer that could impact the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay. In addition, Climate Projections suggest possible changes in weather patterns that may alter the types of plants that thrive in our area. This report identifies specific vulnerabilities to the structures, grounds, and infrastructure from trees that are most susceptible to wet soils and high winds. It identifies plant and tree species at Pelican Cove that are causing a negative impact on the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay based on their need for fertilizer, pesticide and irrigation.

Figure 1: The Pelican Cove Community with boundary marked in blue.

Residents and visitors alike benefit economically from the natural resources of the study area. The agriculture, championship fishing and tourism industries, for example, are directly related to the quality of the natural environment. Natural resources also provide jobs and industry earnings as well as other public and private benefits such as recharging groundwater aquifer water supplies and providing fish and wildlife habitat.

A functional environment provides clean drinking water for homes, soil and fertilizer for crops, and wading birds and other wildlife to complement a canoe trip through the mangroves. However, none of these resources are limitless, although they are often treated as such. Tourists and residents are drawn to southwest Florida because of many natural amenities. Tourists demand clean beaches or they will seek other destinations with their vacation dollars. Likewise, residents are entitled to a healthy community, yet have a stewardship responsibility to ensure its health. The strength of the economy rests on the quality of the environment and nearly every household and occupation is in some way affected by the health of the ecosystem.

Conversion of natural landscapes to build environments has a cost in addition to that of permits, blueprints, materials and labor: loss of those "goods and services" that derive from natural ecosystems. Natural ecosystems directly or indirectly support a multitude of jobs, provide essential services for communities and make this a place to enjoy. Tourism, along with residential and commercial development, plays the dominant role in the coastal economies of Sarasota. Although the outputs of goods, services and revenues from all sectors of the economy are constantly changing, it is useful to understand the economic value associated with the current activities, amenities and nonuse satisfaction levels dependent on natural resources. Economic activities that are affected by environmental quality range from recreational fishing to construction. Natural habitats, water quality and freshwater flows are necessary to maintain the amenities and natural resources that sustain fishing, tourism, recreation and a multitude of other businesses. For example, agriculture requires that the water used for irrigation and livestock meet certain water quality standards. Mining operations require adequate quantities of water, but they are also charged with meeting state water quality regulations for any water they release. The quality and economic output of these activities is dependent on the extent and quality of the natural resources they consume.

The economy of Florida is one of the most vibrant in the country, but is also extremely vulnerable to climate change. Because so much of Florida's economy is natural resource-dependent, factors that affect local, regional and global climate will impact the state's future. This section will describe Florida's major economic sectors, from the estuaries to the inland areas, emphasizing those sectors' vulnerabilities to climate change.

The Current Climate of Southwest Florida

In discussions of climate change, it is important to note the difference between weather and climate. The difference largely amounts to time scale and trends. While "weather" is generally accepted to be the atmospheric conditions over a short period of time, "climate" refers to the long term, accumulated trends in atmospheric conditions. According to the IPCC, "climate change" refers to changes in those trends over time scales of not less than "decades or longer" (IPCC editor A.P.M. Baede document named WG-1 http://www.ipcc.ch/pdf/glossary/ar4-wg1.pdf accessed on 6/29/09).

The climate of southwest Florida, including Sarasota is subtropical or tropical savanna (Hela 1952). This results in alternating wet season flooding (between June and September) and severe dry season drought from November to April). Typically, between 18 to 23% of annual rainfall occurs in dry season and 60 to 72% of the rainfall occurs in wet season (Drew and Schomer 1984). Seasonal wetlands, such as hydric pine flatwoods, become saturated and attain standing water in the middle to late wet season (Beever and Dryden 1992). It is interesting to note that the distribution of large, landscape scale hydric pine flatwoods in southern Collier and southern Lee Counties corresponds with areas of higher rainfall isopleths of 60+ inches annually (Bamberg 1980).

Rainfall in the wet season follows a bimodal pattern, with the first peak in May or June and the second in September or October. It is of note that this pattern corresponds with peak flowering periods for the understory components of the freshwater wetland plant community. Thunderstorms are more frequent (over 100 annually) in the Fort Myers area, in the center of the southwest Florida, than at any other location along the eastern Gulf coast (Jordan 1973) and seventy-five percent of these storms occur in the summer (Jordan 1973, Duever et al. 1979). Short duration, high intensity thundershowers are the result of cyclic land-sea breeze convection in a diurnal pattern peaking during late afternoon or early evening. Thunderstorm rainfall can be very local, resulting in differences of up to five inches per month between areas less than five miles apart (Duever et al. 1976). Individual cloud volumes during thunderstorms in south Florida can range from 200 to 2,000 acre-feet (Woodley 1970).

Wind patterns of south Florida are determined by the interaction of prevailing easterly tradewinds, local diurnal convective patterns in the summer, and continental cold fronts in the winter. Summer wind patterns are dominated by a daily wind shift that peaks between noon and 2:00 P.M., with an onshore sea breeze during the day and an offshore land breeze at night. Winter dry season cold fronts occur approximately once a week (Bamberg 1980). On a seasonal basis, the highest average wind speeds occur in late winter and early spring, and the lowest speeds occur in the summer. Localized strong winds of short duration are generated by summer thundershowers, extreme cold fronts, and tropical storms (Bradley 1972). On a typical day, wind speed is lowest at night, increasing through the day to the afternoon, and decreasing again in the evening (Gutfreund 1978).

Temperature in southwest Florida is primarily controlled by latitude and maritime influences (Bradley 1972). The mean annual temperature is 74 degrees Fahrenheit, the average January temperature is 64 to 65 degrees Fahrenheit, and the average August temperature is 82 degrees Fahrenheit. Southwest Florida is one of only two areas in the southeastern United States where air temperatures exceed 90 degrees Fahrenheit more than 120 days of the year. Typically, there is a 1 degree Fahrenheit difference between Charlotte County and Collier County. More inland areas display a greater daily range in temperature than coastal habitats.

In winter, sharp drops in temperature occur following cold fronts containing cool, dry arctic air from Canada. Cooling begins after sunset and reaches the lowest temperatures at dawn.

Temperature gradients of about six to 15 degrees F can occur between coastal and inland areas a few miles apart. A similar gradient of about six to 10 degrees F occurs between high, dry land (xeric pine flatwoods) and adjacent moist lowlands (hydric pine flatwoods). On calm, cold, clear nights, frost may form in moist inland areas. A severe freeze occurs approximately once every 20 years (Bamberg 1980). According to the Federal Emergency Management Agency, since 1953, disaster declarations were made in Florida six times for freezing conditions (FEMA 2009). The mean annual relative humidity averages approximately 75% with the highest (80-90%) in early morning and lowest (50-70%) in the afternoon. Seasonal differences are not great: mean relative humidity tends to be lowest in April (71%) and highest in summer and fall (80%). "Evapotranspiration" refers to the sum of evaporation and plant transpiration into the atmosphere. Evapotranspiration from the saturated soils of wetlands is an important control of sea breeze intensity and the formation of convective thunderstorms. Because evapotranspiration is a cooling phenomenon, land-to-water gradients are reduced, convective processes are reduced, and recently rained-upon areas receive less rainfall. The effect is a natural feedback mechanism that results in a more even spatial distribution of seasonal rainfall (Bamberg 1980). This can also ameliorate the tendency towards formation of tornadoes over hot convective dry lands. Evapotranspiration estimates for southwest Florida range from 30 to 48 inches per year (Drew and Schomer 1984).

Southwest Florida is particularly vulnerable to weather related disasters including hurricanes and coastal storms, tornadoes, seasonal floods, landscape scale wildfires, thunderstorms/high wind, drought/heat waves, coastal erosion, sinkholes, and winter storms and freezes.

Hurricane season (June 1 to November 30) is especially brutal on southwest Florida. No one in the region lives more than 75 miles from the coast, and while storms have effects wherever they strike, they have particularly heavy impacts in coastal areas. Storm surges, wave action, high winds, and heavy rainfall can all combine to produce effects that slow or shut down life in coastal communities, disrupt normal activities, damage property, and injure people (Florida Sea Grant Coastal Storms website).

South Florida is subject to more hurricanes than any other area of equal size in the United States (Gentry 1974). The area is subject to both Atlantic and Caribbean hurricanes. Of the 38 hurricanes that passed over southwest Florida from 1901 to 1971, 30 occurred between August and October (Jordan 1973). Tropical storms strike about once every three years in southern

Collier County and once every five years in the northern extents of the Southwest Regional Planning Council area (Bamberg 1980).

The three primary climatic effects of hurricanes are high wind, storm surge, and heavy rain. Wind force increases by the square of the wind speed such that a 93 mph wind exerts four times as much force as a 47 mph wind. When hurricane winds attain 249 mph, as in the 1935 Labor Day hurricane, the effects on forested ecosystems, including tree fall, substrate disturbance, and propagule (cone) distribution, can be devastating.

Hydrometer logical hazards associated with hurricanes include coastal flooding caused by storm surge; windstorms due to extremely strong winds; riverine flooding caused by heavy rains; and, tornadoes. The low sea level hugging topography, over population of the near coastal zone and limited to inadequate evacuation and helter systems place southwest Florida in the danger zone for major disaster.

From 1873 to 1993, Southwest Florida experienced forty-nine tropical cyclones of hurricane intensity. The map below shows the hurricanes that passed by and through the Region, including earlier years, going back to 1851 (Southwest Florida Regional Hurricane Evacuation Study 2005).

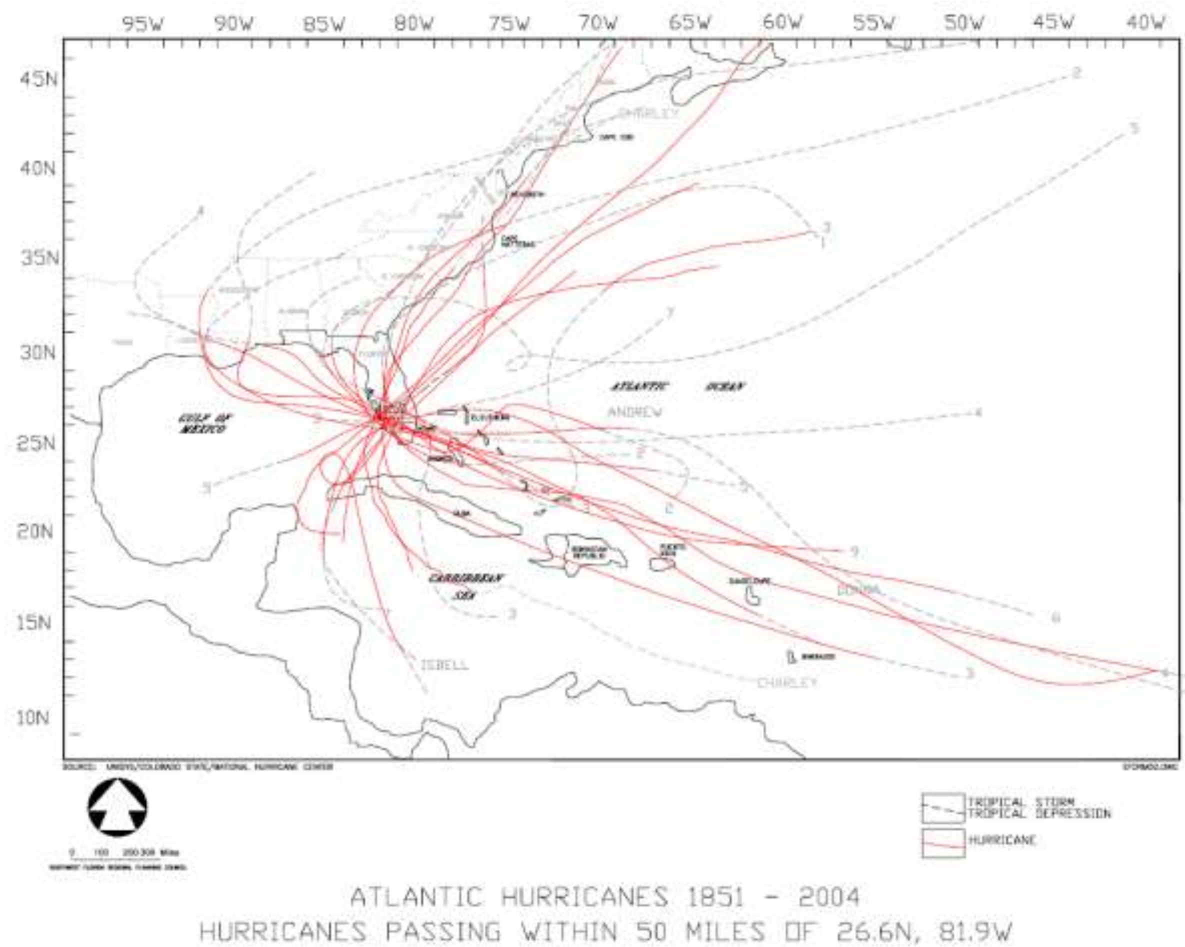


Figure 2: Atlantic Hurricanes Passing within 50 miles of 26.6 N, 81.9 W for the period of record from 1851 to 2055

Between 1994 and 2004 alone, there were 15 hurricanes and tropical storms. These more recent storms resulted in 16 deaths, 833 injuries, and $5.8 billion in property damage and $300.5 million in crop damage.

While studies have shown that there is no clear, long-term trend in the number of tropical storms per storm season (IPCC 2007b; Webster et al. 2005), there have been multi-decadal scale trends in storm frequency. These trends indicate that southwest Florida is currently in an active period (Goldenberg et al. 2001). While storms can occur at any time of year, over 97 percent of North Atlantic tropical storm activity occurs from June to November (Landsea et al. 1994). Storm intensity trends indicate that the power of Atlantic tropical cyclones is rising rather dramatically and that the increase is correlated with an increase in the late summer/early fall sea surface temperature over the North Atlantic (IPPC 2007b).

Assessment of Significant Potential Climate Changes and Their Effects

Florida is one of the most vulnerable areas in the world to the consequences of climate change, especially from increased hurricane severity, sea level rise, and climatic instability leading to drought and flood. Regardless of the underlying causes of climate change, global glacial melting and expansion of warming oceans are causing sea level rise, although its extent or rate cannot as yet be predicted with certainty.

The five major stressors of climate change addressed in this document are: changes in the ratio of atmospheric gases; changes in air temperature and water vapor; changes in water body temperature; changes in water chemistry; and changes in sea level. In conceptual modeling these changes are called “drivers,” and for each driver, the effects on southwest Florida’s coastal resources are described in terms of what is known, what is probable, and what is possible. “Probable” means that an effect is highly likely to occur in the future, while “possible” means that it may occur, but that predicted impacts must be carefully qualified to reflect the level of variable certainty. Currently, none of the predicted effects is expected to benefit Florida’s natural resources or human population, although this perspective may change as new knowledge becomes available. The potential impacts of climate change on the state’s infrastructure, human health, and economy are significant (FOCC 2009).

The Intergovernmental Panel on Climate Change (IPCC), a scientific intergovernmental body, was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme (UNEP). It is made up of a large, diverse group of scientists, governmental representatives, and individuals from around the world (IPCC 2008, FOCC 2009). The panel uses a scientific peer review process to assess the latest scientific, technical, and socioeconomic findings, providing decision makers and others with an objective source of information concerning climate issues (IPCC 2008). In 2007, both the Intergovernmental Panel on Climate Change and former U.S. Vice President Al Gore Jr. were awarded the Nobel Peace Prize "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change" ((IPCC 2008, FOCC 2009, Nobel Foundation 2007).

In 2013, the Panel issued its fifth report on global climate change (previous reports were issued in 1990, 1995, 2001, and 2007 with supplements and additional reports in intervening years) (IPPC 2013). Building on earlier work, the report presents the findings of three major working groups: physical science of climate; impacts, adaptation, and vulnerability; and mitigation (IPCC). The work of the IPCC 2013) forms some of the assumptions this report is based upon.

In this report, the list of significant potential effects on the human and native ecosystems in the southwest Florida project study area from anticipated climate change was derived from review of 354 professional source documents from federal, state, local, academic and planning sources.

These documents are listed under in the Citations of the Southwest Florida Comprehensive Climate Change Vulnerability Assessment.

A total of 84 potential effects, in 12 categories, Air Temperature and Chemistry, Altered Hydrology, Climate Instability, Geomorphic Changes, Habitat and Species Changes, Sea Level Rise, Water Temperature and Chemistry, Human Economy, Human Health, Infrastructure, Land Use Changes, and Variable Risk were identified in the vulnerability assessment and are listed as follows:

Air Temperature and Chemistry

1. Elevated atmospheric carbon dioxide
2. Increased rate of smog formation from higher temperatures
3. Hydrology, water quality and habitats in wetlands affected by increased air temperatures
4. Geomorphology and habitats at coastlines changed by increased air temperatures
5. Increased unhealthful levels of ozone pollution
6. Increased global surface temperatures
7. Disruption of timing of seasonal temperature changes

Altered Hydrology

8. Altered timing of seasonal changes
9. Erosion, flooding and runoff at coastlines from changes in precipitation
10. Agricultural yields altered due to changes in rainfall patterns and amounts
11. Drought caused by increased atmospheric temperatures
12. Lower stream flows caused by droughts
13. Increased frequency of droughts and floods resulting from rising sea temperatures
14. Increased flooding from higher base water level stage at coast and in groundwater

Climate Instability

15. Higher humidity from increased atmospheric/aquatic temperatures
16. Higher maximum temperatures, more hot days and heat waves over nearly all land areas
17. Higher, stronger storm surges
18. Increased hurricane intensity
19. Increased precipitation including heavy and extreme precipitation events
20. Increased storm frequency and intensity
21. 5 to 10% increase in hurricane wind speed due to rising sea temperatures
22. Sustained climate change
23. Wildfires resulting from increased atmospheric temperatures (in combination with increased drought)

24. Altered rainfall and runoff patterns

Geomorphic Changes

25. Ground subsidence caused by sea level rise
26. Increased ground subsidence due to sediment changes from sea level rise
27. Coastlines altered by erosion
28. Reduced ability of barrier islands to shield coastal areas from higher storm surges.
29. Greater instability of beaches and inlets
30. Slower drainage of freshwaters through flooded estuaries and river mouths.

Habitat and Species Changes

31. Regional increase or decrease of wetlands due to changes in precipitation
32. Changes to phenology of anadromous fishes
33. Changes to amphibian populations' ranges, health, and phenology
34. Changes to phenology of pest and beneficial insects
35. Conversion of wetlands to open water
36. Decreased animal health affected by increased air temperatures
37. Northward relocation of ecosystems
38. Increased harmful algal blooms
39. Increased numbers and altered ranges of jellyfish
40. Die-offs of sponges, sea urchins, and seagrasses (immobile fauna) due to increased sea surface temperatures
41. Coral bleaching and death of corals due to increased sea temperatures
42. Migration of low marsh into high marsh
43. Moth phenology shifts to earlier dates.
44. Loss of wetlands due to retreating shorelines
45. Migration/depletion of seagrass beds due to sea level rise
46. Changes in wetlands due to sea level rise
47. Shift in bird behavior phenology
48. Spread of invasive native species
49. Spread of invasive non-native species
50. Decreased biodiversity due to increased temperatures
51. Changes in aquatic food webs
52. Changes in terrestrial food webs
53. Major faunal range shifts

Sea Level Rise

54. More rapid sea level rise than previously predicted
55. Alteration of hydrology, water quality and habitats in wetlands

56. Erosion caused by sea level rise
57. Geomorphologic, hydrological and water quality changes at coasts
58. Sea level rise resulting from increased temperature and expansion of water volume
59. Sea level rise resulting from the melting arctic ice sheet
60. Higher high tides
61. Larger wind driven waves in deeper estuaries

Water Temperature and Chemistry

62. Acidification of marine waters
63. Increase in hypoxia (low dissolved oxygen)
64. Changes in sea water and estuarine water salinity
65. Geomorphic, hydrologic, and ecologic changes at the coastline caused by increased sea surface temperatures
66. Coastlines affected by increased sea surface temperatures
67. Marine thermal stratification
68. Increased salinity in aquifers and groundwater
69. Increased winter lake temperatures
70. Changes in nutrient supply and nutrient recycling, and food webs

Human Economy

71. Ecosystem services affected by changes in estuarine water quality
72. Increased threats to coastal potable water supplies
73. Reduction in ecosystem services due to adaptations to climate change
74. Economic consequences for
    - commercial fisheries,
    - sports fisheries,
    - coastal tourism,
    - coastal development,
    - transportation development, and
    - critical facilities.
75. Increased potential financial damage from storms resulting from increasing population growth and wealth structure
76. Alteration of the state's tourist economy due to highly variable temperatures

Human Health

77. Changes in waterborne disease and parasitism due to increased temperatures

Infrastructure

78. Additional regulation of energy providers (power plants)
79. Physical changes in infrastructure from higher atmospheric temperatures
80. Physical stress on infrastructure due to sea level rise

Land Use Changes

81. Human habitation pushed inland due to sea level rise
82. Reduction in the amount of land available for conservation due to sea level rise

Variable Risk

83. Insurance risk models become obsolete due to increased atmospheric and/or aquatic temperatures
84. Insurance risk models become obsolete due to sea level rise

A useful tool that can be used to organize thinking regarding important ecosystem components and climate change processes is the nomenclature and hierarchy of conceptual ecological models (National Research Council 2000). Conceptual ecological models show how ecosystems have become stressed, identify the sources of these stressors, identify the major ecological effects of these stressors, and identify appropriate indicators (attributes) of these ecological effects. The links in the models between the stressors and attributes in effect become the working hypotheses that explain why the natural systems have been altered and degraded (National Research Council 2000). Changes in **Air Temperature and Chemistry**, and **Water Temperature and Chemistry**, are the stressors that result in **Climate Instability**, and **Sea Level Rise**. Subsequent ecological effects include **Altered Hydrology, Geomorphic Changes, Habitat and Species Changes**, and **Land Cover/Land Use Changes**.

Potential Climate Futures

I. Potential sea level rise and other coastal storm risks and how these risks may negatively impact the environment in the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay.

The evaluation of the potential sea level rise and coastal storm risks for Pelican Cove is derived from direct USGS measurements of sea level rise on the southwest Florida Coast and the work of the IPCC in 2007 and 2013 regarding climate change consensus among the scientists of the world.

Known Sea Level Changes and Events

Florida's geologic history has consisted of cycles of sediment deposition and erosion in response to sea level changes over the last 65 million years (Figure 3) (Florida's Geological History and Geological Resources (FGHGS) 1994). The most "recent" geologic history (1.8 million years ago to present) has been a time of worldwide glaciations, widely fluctuating sea level and the emergence of humankind (FGHGS 1994). This geologic period is called the Quaternary Period and is made of two geologic epochs, the Pleistocene Epoch (1.8 million to 10,000 years ago) and the Holocene (Recent) Epoch (10,000 years ago to the present).

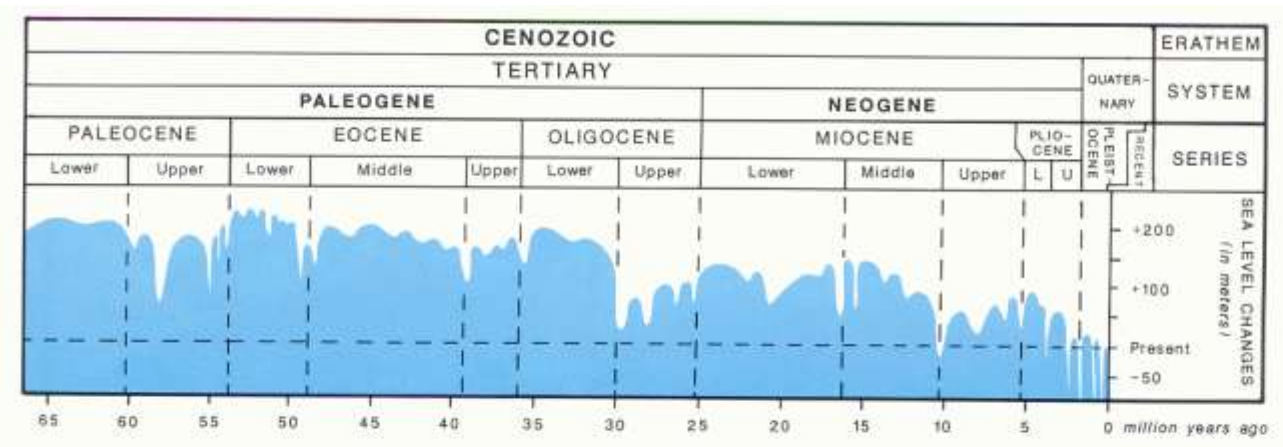


Figure: 3 Sea level changes during the last 65 million years

The Pleistocene Epoch is known as the "Ice Age" and includes at least four great glacial periods. During each period huge ice sheets covered much of the northern United States. Seawater was the primary water source for the expanding glaciers, causing sea level to drop as much as 300 feet below present level. Between glaciations the Florida shoreline attained heights 150 feet above present sea level (Figure 4).

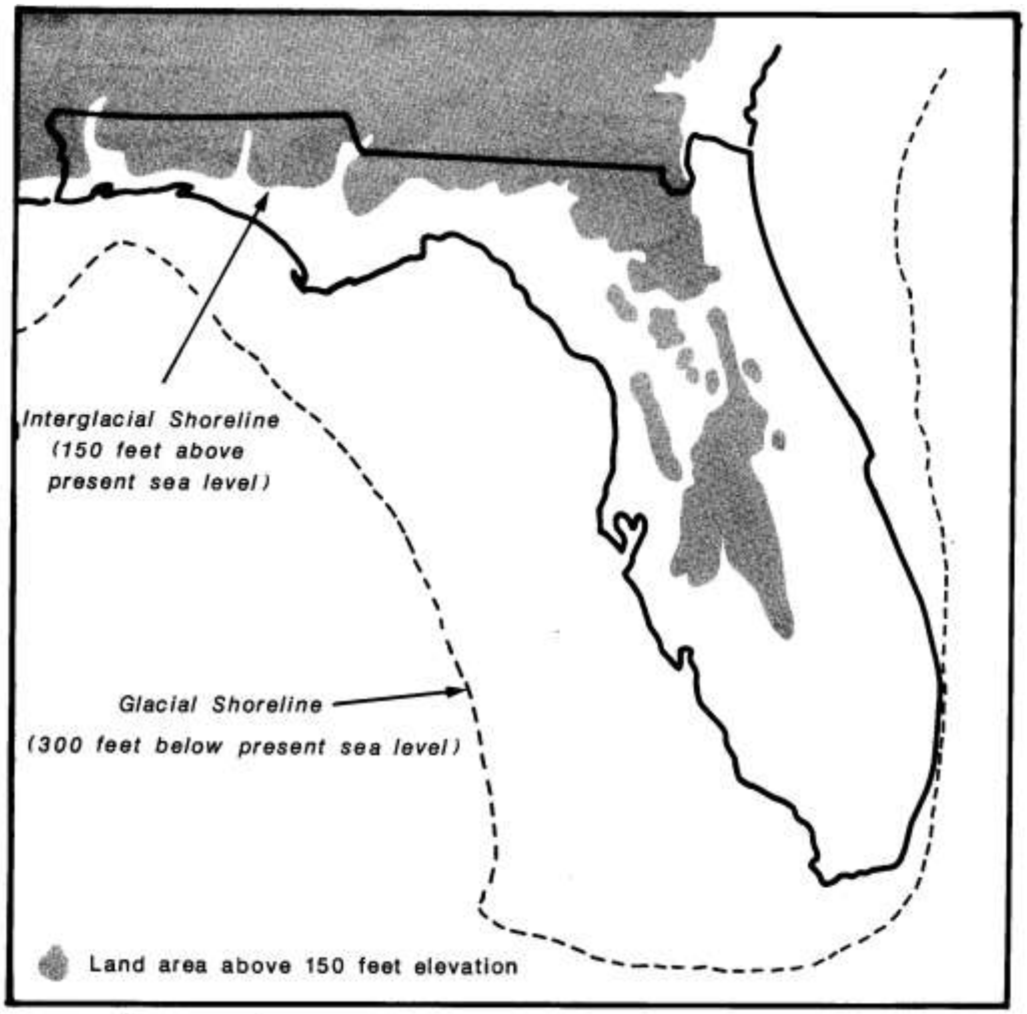


Figure 4: Shoreline of Florida between 1.8 million to 10,000 years ago

The large drop in sea level during the most recent ice age increased the land area of Florida dramatically, by as much as 100 miles west of current position (Figure 4) (FGHGR 1994). Considerably warmer interglacial intervals melted the glaciers, raising sea level and flooding the Florida peninsula as least 100 to 150 feet above the present level and creating islands.

The Holocene Epoch began 10,000 years ago during a slow warming of the Earth's climate. From a glacial low about 18,000 years ago, sea level climbed intermittently to its present level (FGHGR 1994). Beginning roughly 6,000 years ago, as two of the major ice sheets melted, sea level rose to two meters higher than its present level; evidence for this "high" stand can been seen in many parts of the state's coast (Atlas of Florida 1992).

Over the past 6000 years, as Figure 5 indicates, the sea has been rising. Throughout South Florida, during the first half of this period, the rate of rise was about 23 centimeters per century, then the rate slowed to about 4 centimeters per century. During the last one hundred years, the rate of rise has been at a rapid pace of 30-40 centimeters (Wanless et al. 1994).

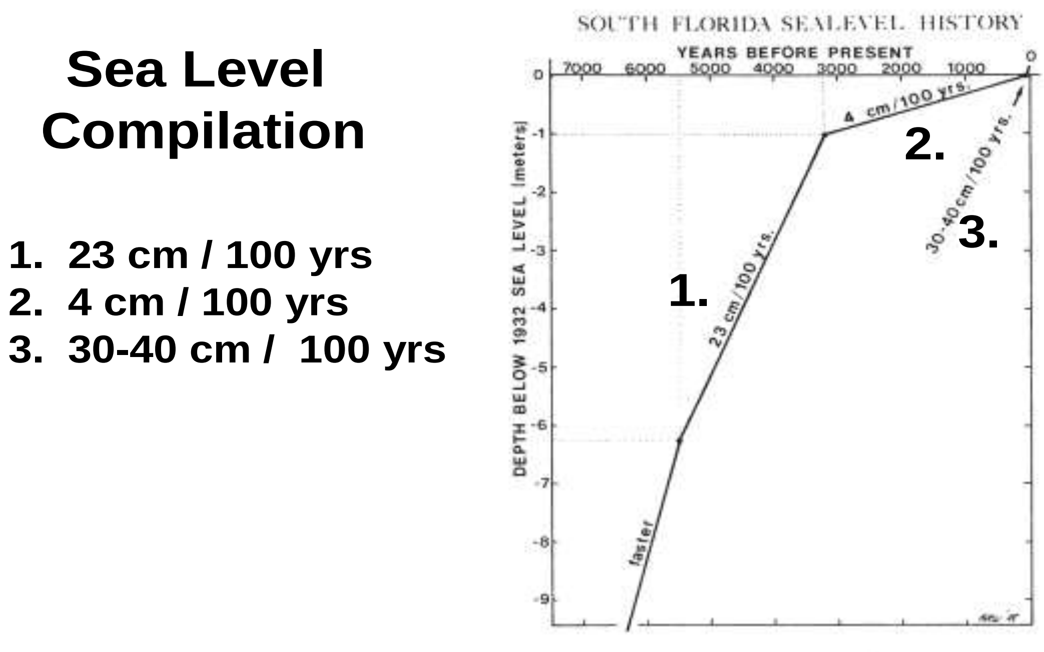


Figure 5: Sea level rise rates compiled by Wanless et al. (1994)

Paleo-sea level records from warm periods during the last 3 million years indicate that global mean sea level has exceeded 5 m (16.4 feet) above present when global mean temperature was up to 2°C warmer than pre-industrial conditions. Maximum global mean sea level during the last interglacial period (~129 to 116 ka) was, for several thousand years, at least 5 m (16.4 ft) higher than present and that it did not exceed 10 m (32.8 ft) above present, implying substantial contributions from the Greenland and Antarctic ice sheets. This change in sea level occurred in the context of different orbital forcing and with high latitude surface temperature, averaged over several thousand years, at least 2°C warmer than today {5.3.4, 5.6.1, 5.6.2, (Kopp et al., 2009, 2013; Raymo et al., 2011; Dutton and Lambeck, 2012; Lambeck et al., 2012; Raymo and Mitrovica, 2012)

For the past few thousand years, the sea level around Florida has been rising very slowly, although a persistent upturn in the rate of relative sea level rise may have begun recently (IPCC 2007b). Geological studies show that, in the past, the sea level of Florida, as well as the rest of the globe, changed much more rapidly than it has in more recent times. Distinguishing Florida-specific sea level trends from future global trends is a critical research need.

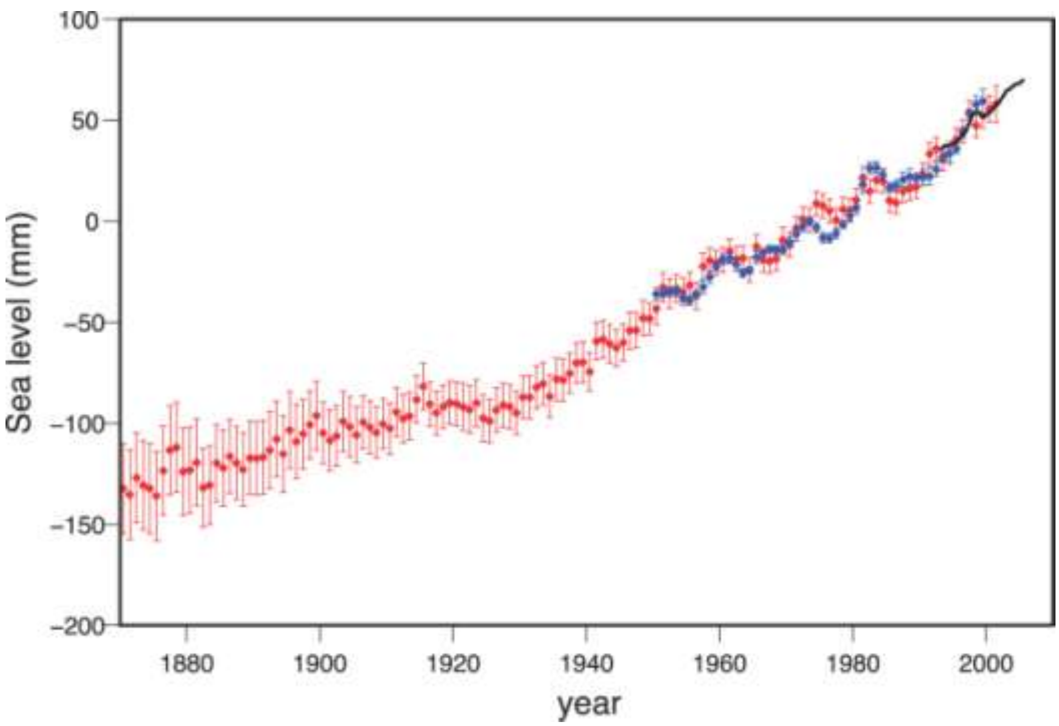


Figure 6: Annual averages of global mean sea level in millimeters
The red curve shows reconstructed sea level fields since 1870 (updated from Church and White, 2006); the blue curve shows coastal tide gauge measurements since 1950 (from Holgate and Woodworth, 2004) and the black curve is based on satellite altimetry (Leuliette et al., 2004). The red and blue curves are deviations from their averages for 1961 to 1990, and the black curve is the deviation from the average of the red curve for the period 1993 to 2001. Error bars show 90% confidence intervals.

Source: Intergovernmental Panel on Climate Change (2007) fig-5-13

Proxy and instrumental sea level data indicate a transition in the late 19th century to the early 20th century from relatively low mean rates of rise over the previous two millennia to higher rates of rise. The rate of global mean sea level rise has continued to increase since the early 20th century, with estimates of 0.013 [0.007 to 0.019] mm yr–2. The global mean rate was 1.7 [1.5 to 1.9] mm yr–1 between 1901 and 2010 for a total sea level rise of 0.19 m (0.6 feet) Between 1993 and 2010, the rate was higher at 3.2 [2.8 to 3.6] mm yr–1; similarly high rates occurred between 1920 and 1950. {Douglas, 2001; Church and White, 2006, 2011; Jevrejeva et al., 2006, 2008; Holgate, 2007; Ray and Douglas, 2011)}

Ocean thermal expansion and glacier melting have been the dominant contributors to 20th century global mean sea level rise. Observations since 1971 indicate that thermal expansion and glaciers (excluding Antarctic glaciers peripheral to the ice sheet) explain 75% of the observed rise. The contribution of the Greenland and Antarctic ice sheets has increased since the early 1990s, partly from increased outflow induced by warming of the immediately adjacent ocean. Natural and human-induced land water storage changes have made only a small contribution; the rate of groundwater depletion has increased and now exceeds the rate of reservoir impoundment. Since 1993, when observations of all sea level components are available, the sum of contributions equals the observed global mean sea level rise within uncertainties. (IPCC 2013)

The *rate* at which sea level rises is equally as important to coastal resources as how much it rises. The rate of global sea level rise increased from the 19th to the 20th century (IPCC 2007b) and has increased further since 1993 (FOCC 2009). Sea level has been rising at a rate of 0.08-0.12 inches per year (2.0-3.0 mm per year) along most of the U.S. Atlantic and Gulf coasts. The rate of sea level rise varies from about 0.36 inches per year (10 mm per year) along the Louisiana Coast (due to land sinking), to a *drop* of a few inches per decade in parts of Alaska (because land is rising). See Figure 7 for sea level trends in selected cities.

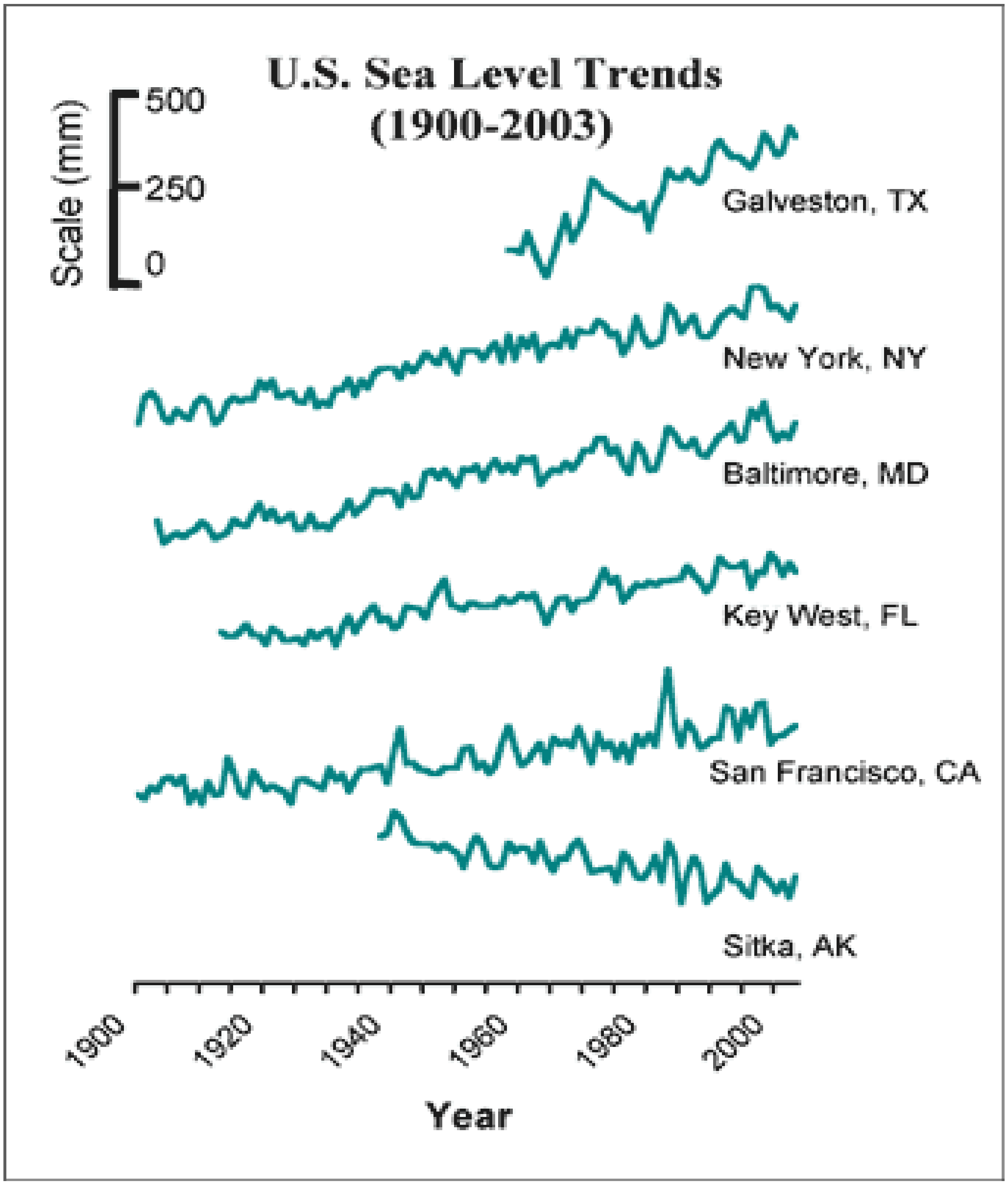


Figure 7: U.S. Sea Level Trends
Source: Monthly and Annual Mean Sea Level Station Files from the Permanent Service for Mean Sea Level (PSMSL) at the Proudman Oceanographic Laboratory

Around Florida, relative sea level has been rising at a slow but constant rate, about an inch or less per decade (Maul and Martin 1993; FOCC 2009). The historic (1947-2009) sea level rise in southwest Florida measured at St. Petersburg is 2.3 mm/yr (Walton 2007, FOCC 2009). Figure 7 provides further evidence specific to southwest Florida, measured at Key West, that sea level has been rising at an estimated rate of 3 mm/yr (Maul and Martin 1993; Savarese et al. 2002).

Since 1933, the Permanent Service for Mean Sea Level (PSMSL) has been responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges. It is based in Liverpool at the Proudman Oceanographic Laboratory (POL) which is a component of the UK Natural Environment Research Council (NERC). The PSMSL is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) established by the International Council for Science (ICSU). It is supported by FAGS, the Intergovernmental Oceanographic Commission (IOC) and NERC.

As of December 2006, the database of the PSMSL contained over 55,000 station-years of monthly and annual mean values of sea level from almost 2,000 tide gauge stations around the world received from almost 200 national authorities. On average, approximately 2,000 station-years of data are entered into the database each year (Woodworth and Player, R. 2003). Local sea level information from PSMSL is found below.

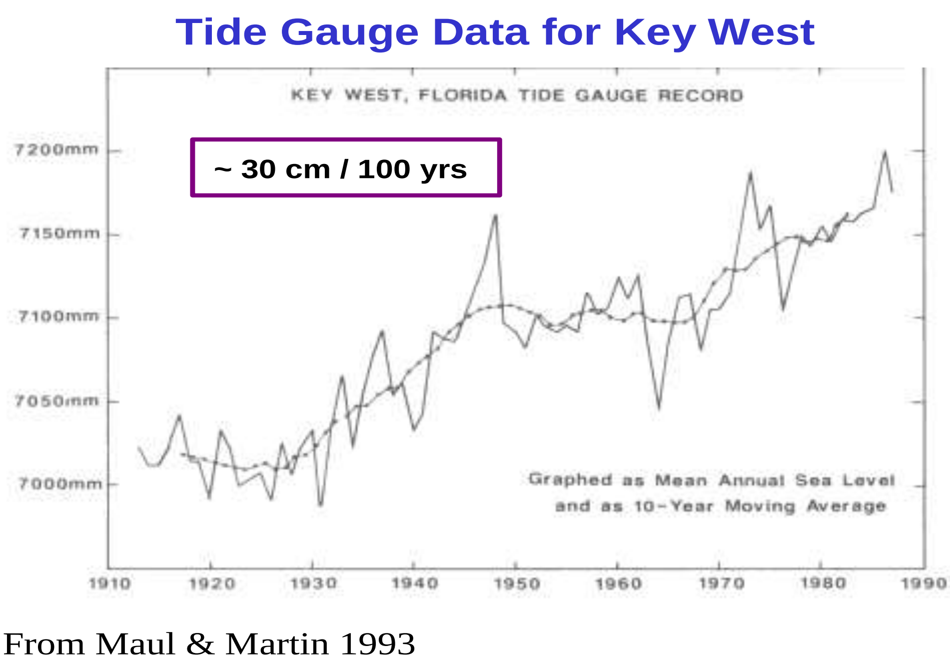


Figure 8: Mean annual sea level at Key West, Florida 1910-1990

Key: 7000 mm is 275.6 inches, 7200 mm is 283.5 inches, and 30 cm is 11.8 inches in 100 years of record

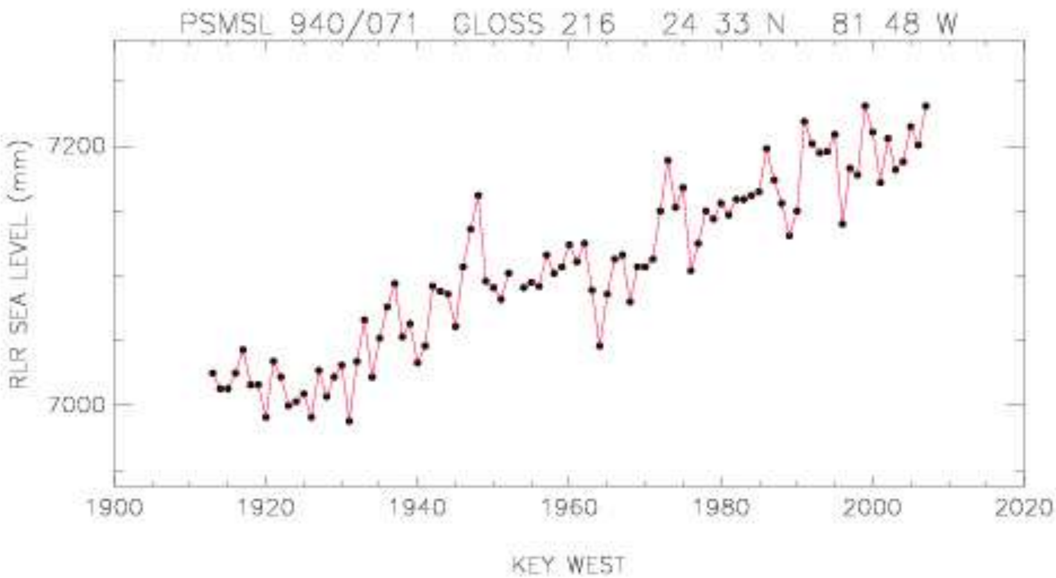


Figure 9 Mean Annual Sea Level at Key West, Florida 1910-2009

Source: Permanent Service for Mean Sea Level (PSMSL), hosted at the Proudman Oceanographic Laboratory (POL)

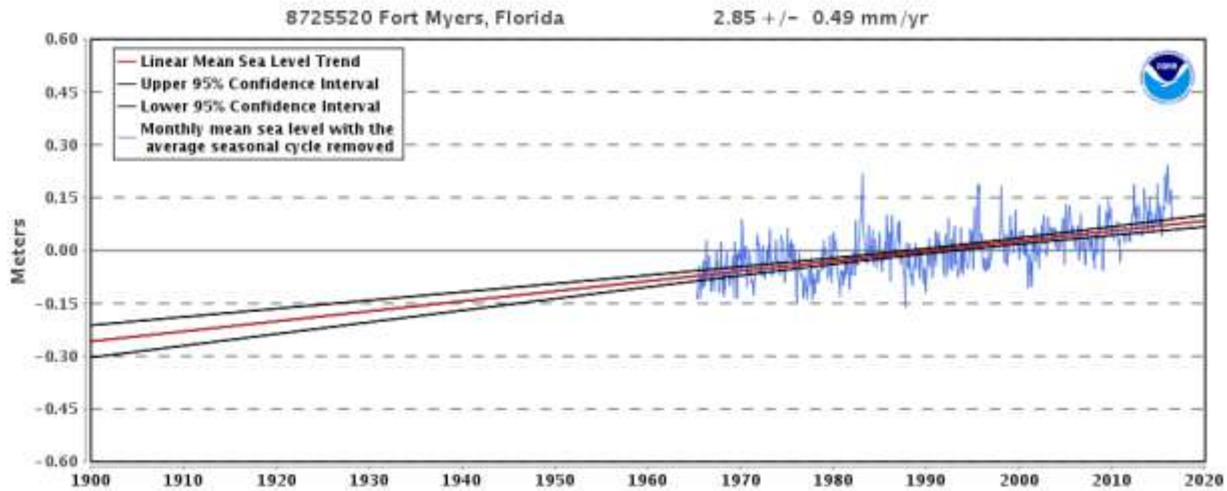


Figure 10: The mean sea level trend is 2.85 millimeters/year with a 95% confidence interval of +/- 0.49 mm/yr based on monthly mean sea level data from 1965 to 2015 which is equivalent to a change of 0.93 feet in 100 years.
Source: NOAA 2016

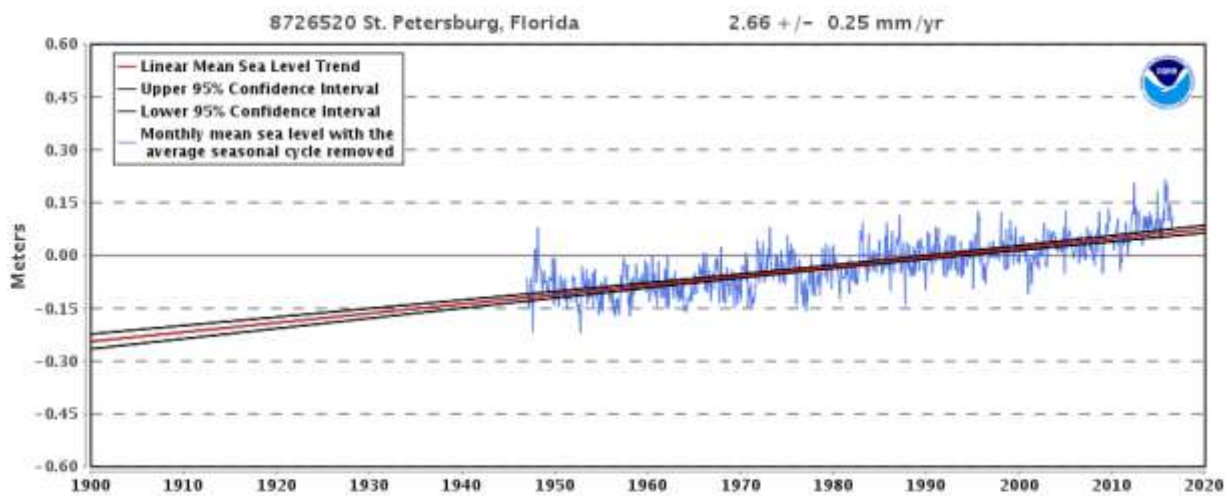


Figure 11: The mean sea level trend is 2.66 millimeters/year with a 95% confidence interval of +/- 0.25 mm/yr based on monthly mean sea level data from 1947 to 2015 which is equivalent to a change of 0.87 feet in 100 years.
Source: NOAA 2016

Potential Future Climate Effects: Sea Level

The five sea level rise "severity" scenarios were discussed in the Potential Climate Futures section beginning on page 44:

Probability (%)	2025		2050		2075		2100		2150		2200	
	cm	inches	cm	inches	cm	inches	cm	inches	cm	inches	cm	inches
Rapid Stabilization Case	41	1.8	9	3.5	13	5.3	18	7.1	22	8.8	27	10.5
90 (least)	7	2.8	13	5.0	20	7.7	26	10.4	40	15.7	53	21.0
80	9	3.6	17	6.6	26	10.1	35	13.9	53	20.8	71	28.1
70	11	4.4	20	7.8	30	11.6	41	16.3	63	24.7	85	33.6
60	12	4.7	22	8.6	34	13.2	45	17.8	72	28.3	99	39.1
50 (moderate)	13	5.1	24	9.4	37	14.4	50	19.8	80	31.4	112	44.2
40	14	5.5	27	10.6	41	16.0	55	21.8	90	35.4	126	49.7
30	16	6.3	29	11.3	44	17.1	61	24.1	102	40.1	146	57.6
20	17	6.7	32	12.5	49	19.1	69	27.3	117	46.0	173	68.2
10	20	7.9	37	14.5	57	22.3	80	31.6	143	56.2	222	87.5
5 (worst)	22	8.7	41	16.1	63	24.6	91	35.9	171	67.2	279	110.0
2.5	25	9.9	45	17.6	70	27.4	103	40.7	204	80.2	344	135.6
1	27	10.6	49	19.2	77	30.1	117	46.2	247	97.2	450	177.3
Business as Usual	29	11.3	57	22.6	86	34	115	45.3	247	97	450	177

*The results of this table are based on using Tables 9-1 and 9-2 of the USEPA Report "The Probability of Sea Level Rise". Basically, the formula is multiplying the historic sea level rise (2.3 mm/yr) in Southwest Florida (closest point used is St. Petersburg, Fl., Table 9-2) by the future number of years from 1990 plus the Normalized Sea Level Projections in Table 9-1 and Table ES-2. Two Future Climate Scenarios for Florida Stanton and Ackerman 2007

Table 1: Combined Sea Level Projections by Year for Southwest Florida

One cause of sea level rise is increased temperature and the subsequent expansion of the warmer water volume (Titus 1998; USEPA CRE 2008). The rate of global average sea level rise has increased during the late 20th century (Church and White 2006) and will accelerate further because of ocean warming and contributions from land-based ice melt from glaciers and the ice sheets of Greenland and Antarctica (IPCC 2007b). Sea level rise will continue well after 2100 even if greenhouse gas concentrations are stabilized by then (IPCC 2007b). Major inputs of water from the melting of high latitude and high altitude ice reservoirs could cause several meters of sea level rise over the centuries to come (Hansen 2007).

As a result of these increasing sea levels, Florida will probably become more vulnerable to coastal flooding and storm surges (FOCC 2009). Sea levels around the state will probably continue to rise at historical or accelerated rates in upcoming decades (FOCC 2009).

Increases in sea level will probably increase shoreline erosion. Barrier islands will likely continue to erode and migrate towards the mainland or along prevailing lateral pathways (FOCC 2009), which could eventually threaten the ecological integrity of natural communities in estuaries, tidal wetlands, and tidal rivers (FOCC 2009). As sea levels rise, shallow coastal aquifers and associated public drinking water supplies are at risk from saltwater intrusion (FOCC 2009).

Sea level rise will also exacerbate many other effects of climate change. For example, coastal shorelines, beaches, mangroves, low marsh, river and creek shorelines will experience higher tides including higher high tides, higher normal tides, and higher low tides (Titus 1998; USEPA CRE 2008; Folland & Karl 2001; IPCC 2001c).

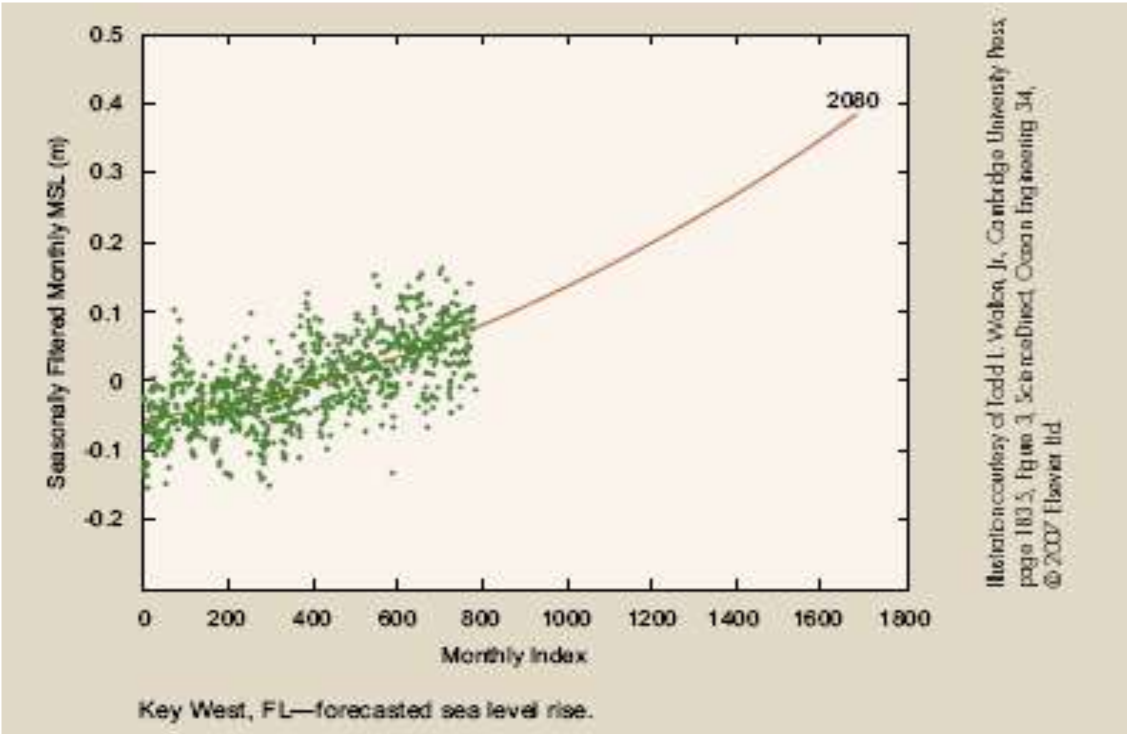


Figure 12: Forecasted Sea Level Rise at Key West, Florida

Some scientists expect more rapid sea level rise than previously predicted by IPCC 2007 (USEPA CRE 2008). One team of researchers has suggested that global sea level could rise far higher than previously forecast because of changes in the polar ice sheets, a meter or more by 2100. They assert that the IPCC projections did not include the potential impact of polar melting and ice breaking off. The IPCC, in its 2007 Fourth Assessment Report, had said that the maximum rise in sea level would be about 59 centimeters. Professor Konrad Steffen from the University of Colorado, speaking at a press conference, highlighted new studies into ice loss in Greenland, showing that it has accelerated over the last decade. Professor Steffen, who has studied the Arctic ice for the past 35 years, has said, "I would predict sea level rise by 2100 in the order of one meter; it could be 1.2 meters or 0.9 meters. But it is one meter or more seeing the current change, which is up to three times more than the average predicted by the IPCC. It is a major change and it actually calls for action." Dr John Church of the Centre for Australian Weather and Climate Research added, "The most recent research showed that sea level is rising by 3 mm a year since 1993, a rate well above the 20th century average." Professor Eric Rignot, a senior research scientist at NASA's Jet Propulsion Laboratory, said that results gathered since the IPCC report showed that melting and ice loss could not be overlooked. "As a result of the acceleration of outlet glaciers over large regions, the ice sheets in Greenland and Antarctica are already contributing more and faster to sea level rise than anticipated," he observed. Professor Stefan Ramstorf of the Potsdam Institute for Climate Impact Research said, "Based on past experience, I expect that sea level rise will accelerate as the planet gets hotter" (Shukman 2009).

Local topography and land use will greatly affect the scope and reach of whatever sea level rise occurs in Florida. The area included in this study is divided into uplands (433 square miles/277,050 acres) and wetlands (915 square miles/585,766 acres) below 10 feet in elevation, which only exist in the four coastal counties (1,348 total square miles/862,816 acres). The areas below 10 feet in elevation, (equivalent to 9.2 feet above mean sea level or subject to daily tidal inundation with 8.2 feet of sea level rise), which are subject to sea level rise impacts, comprise 22.4 percent of the region's total land area. A current population of approximately 607,000 people lives in 357,000 dwelling units (SWFRPC 2001). Millions of square feet of commercial, office and other uses exist within the study area. This area is expected to be essentially built-out in the next 50 years with a population of more than one million people.

Utilizing the most recent available land cover data from the Florida Fish and Wildlife Conservation Commission (FWC) (2003) and currently available Lidar elevations, it is possible to project the amount of habitat that would be subject to future inundation from various levels of sea level rise. The following tables and graphs display the results for Lee and Collier Counties, which are the two counties with complete Lidar data at this time. There are currently gaps in the Lidar data for Charlotte and Sarasota Counties.

The elevations analyzed (0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 9.0 feet NGVD) correspond to the following climate change scenarios:

Elevation in NGVD	Rapid Stabilization Case	90% (least)	50% (moderate)	5% (worst)	Business as Usual
Half Foot	2084	2059	2030	2014	2011
One Foot	2222	2107	2063	2036	2027
Two Feet	2398	2214	2109	2075	2053
Three Feet	2575	2270	2158	2100	2079
Four Feet	2751	2327	2208	2109	2101
Nine Feet	3633	2610	2338	2174	2153

Table 2: Predicted year of different elevation levels (NGVD) of sea level rise for different future scenarios

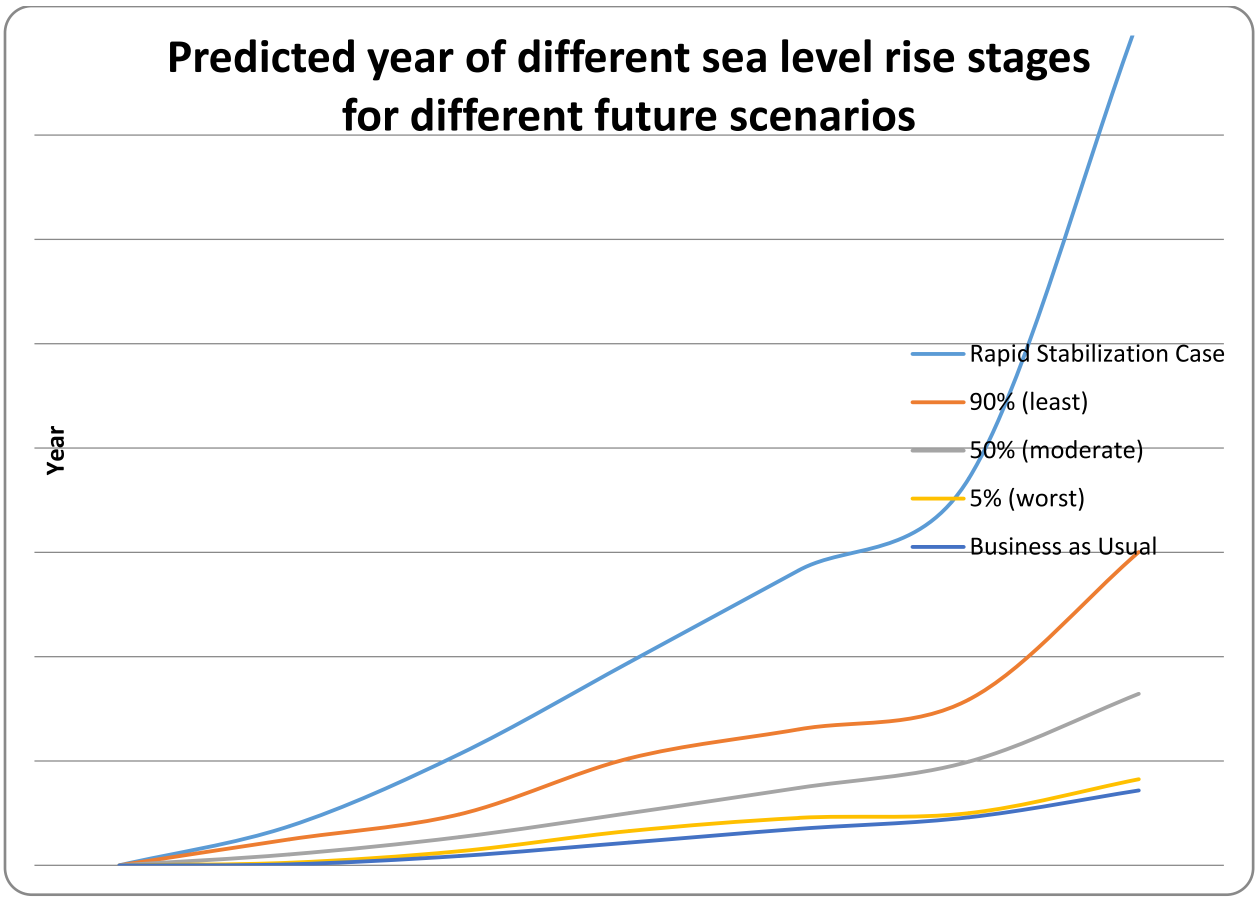
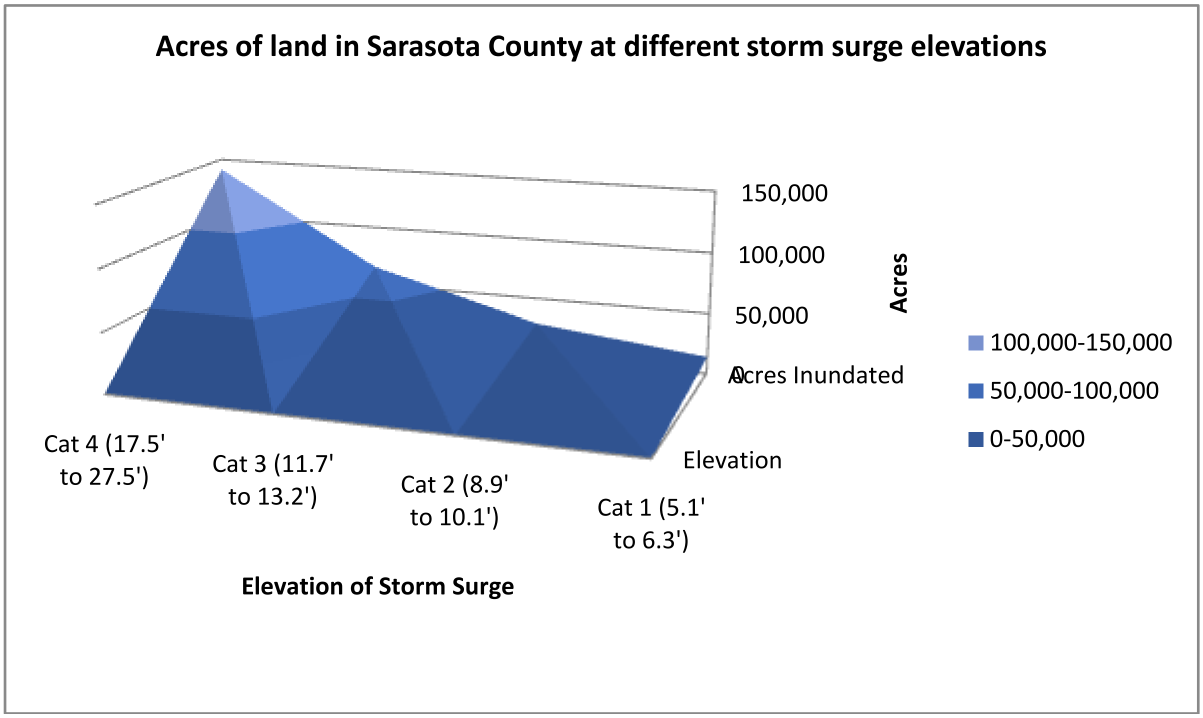


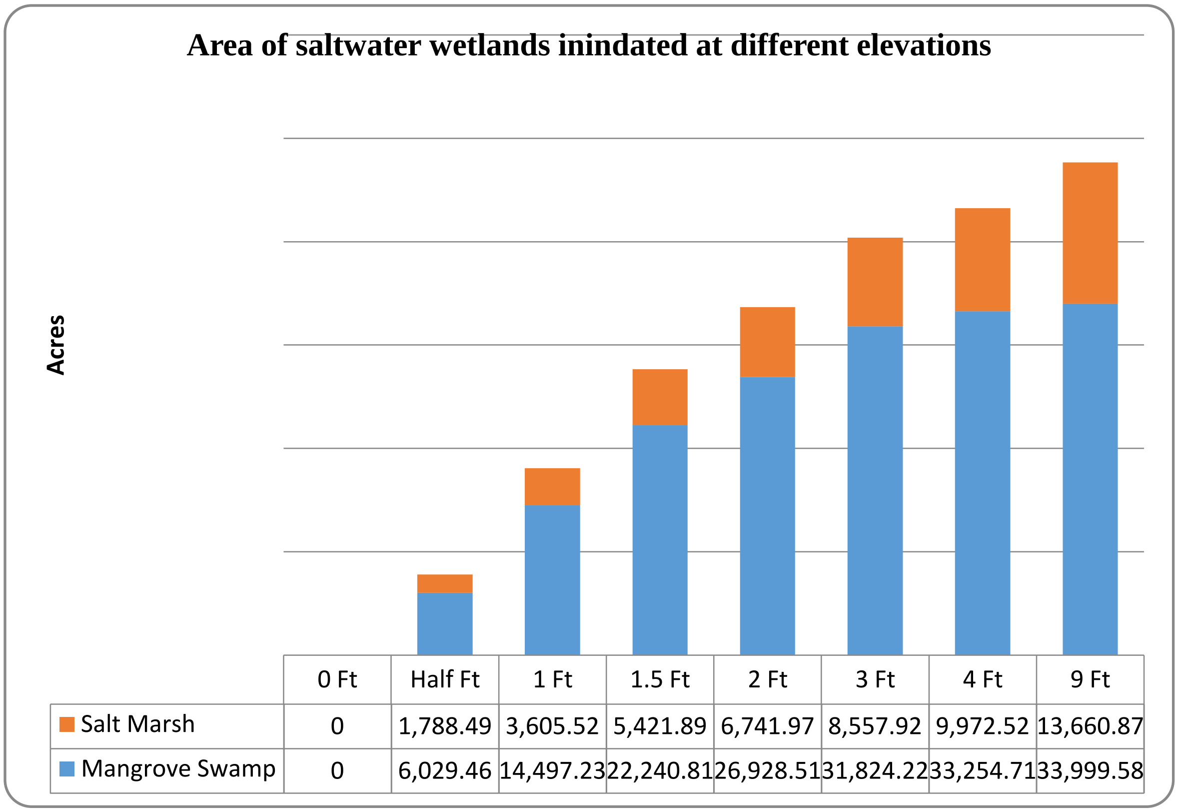
Figure 13: Approximate predicted year of different elevation levels (NGVD) of sea level rise for different future scenarios

Sarasota	Cat 1	Cat 2	Cat 3	Cat 4
	5.1' to 6.3'	8.9' to 10.1'	11.7' to 13.2'	17.5' to 27.5'
Coastal Strand	37.1	37.1	37.1	37.1
Sand/Beach	346.8	356.8	366.3	366.3
Xeric Oak Scrub	12.3	35.2	118.9	130.8
Sand Pine Scrub	6.3	10.0	17.0	26.7
Dry Prairie	308.8	2,706.1	11,135.2	20,995.3
Mixed Pine-Hardwood Forest	357.9	920.3	2,339.2	4,224.3
Hardwood Hammocks and Forest	535.6	1,381.4	3,384.6	5,809.0
Pinelands	1,397.1	3,898.7	8,803.4	16,759.2
Freshwater Marsh and Wet Prairie	159.6	1,121.9	2,870.8	7,705.7
Shrub Swamp	191.2	536.5	1,112.2	2,761.7
Bay Swamp	0.0	0.0	4.4	5.3
Cypress Swamp	153.1	274.8	536.9	1,070.5
Cypress/Pine/Cabbage Palm	0.7	0.7	0.7	0.7
Mixed Wetland Forest	285.4	453.7	780.4	1,255.1
Hardwood Swamp	454.5	1,041.4	2,368.7	4,419.5
Salt Marsh	1,198.7	1,283.3	1,300.1	1,319.9
Mangrove Swamp	665.9	695.2	699.7	701.1
Open Water	2,134.2	2,489.8	3,436.2	6,164.0
Shrub and Brushland	72.9	212.8	614.7	1,478.9
Grassland	3.4	12.1	86.3	239.4
Bare Soil/Clear-cut	100.8	143.0	352.1	685.1
Improved Pasture	6.7	186.2	1,399.9	8,614.8
Citrus	0.0	2.4	64.3	536.6
Row/Field Crops	0.0	0.0	58.4	216.4
Other Agriculture	1.2	7.2	97.8	244.0
High Impact Urban	4,649.6	8,722.6	17,695.0	41,594.7
Low Impact Urban	948.5	2,157.1	5,588.7	13,592.4
Extractive	0.0	0.0	5.9	379.7
Total	14,028.4	28,686.5	65,275.1	141,334.1

Table 3: Acres of habitat or land use at and below different storm surge elevations in Sarasota County 2009, Note number includes the prior acreage.

*F*igure 14: Acres of habitat or land at and below different storm surge elevations in Sarasota County 2009





	0 Ft	Half Ft	1 Ft	1.5 Ft	2 Ft	3 Ft	4 Ft	9 Ft
Salt Marsh	0	1,788.49	3,605.52	5,421.89	6,741.97	8,557.92	9,972.52	13,660.87
Mangrove Swamp	0	6,029.46	14,497.23	22,240.81	26,928.51	31,824.22	33,254.71	33,999.58

Figure 15: Acres of mangrove and salt marsh habitat at and below different elevations in Lee County 2009

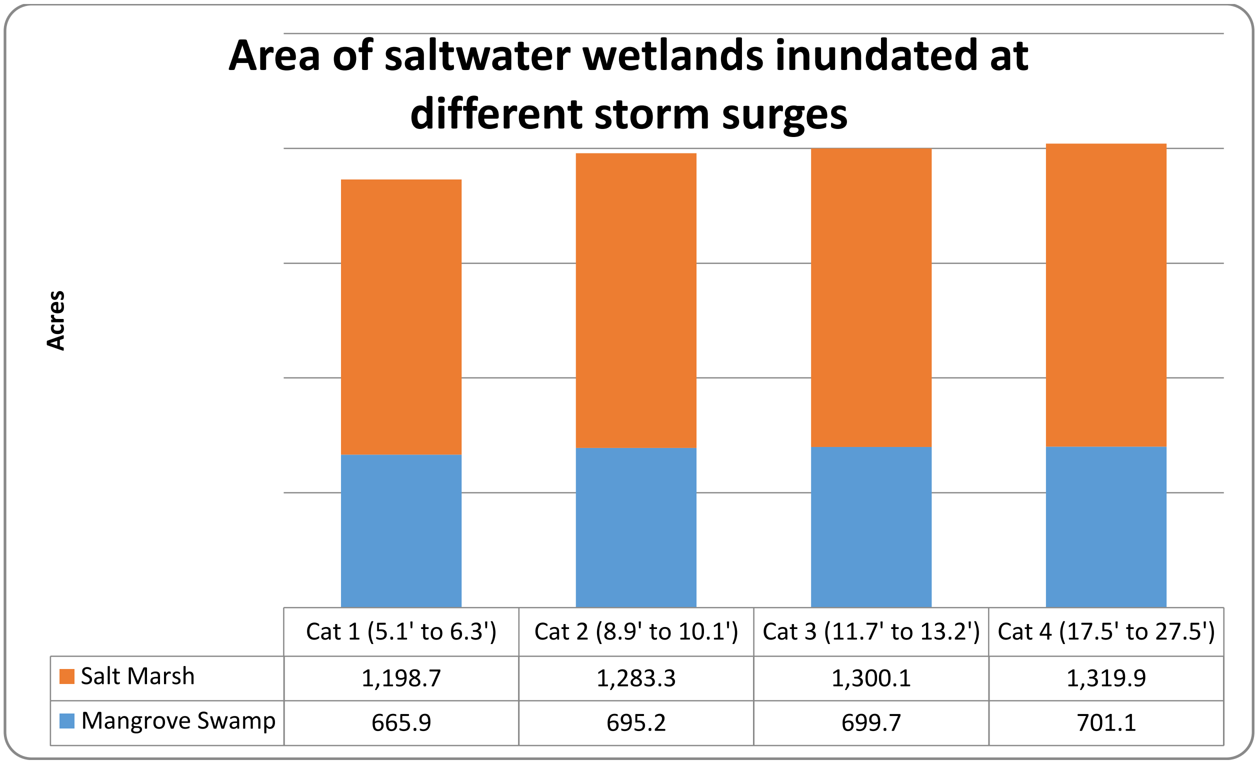


Figure 16: Acres of mangrove and salt marsh habitat at and below different storm surge elevations in Sarasota County 2009

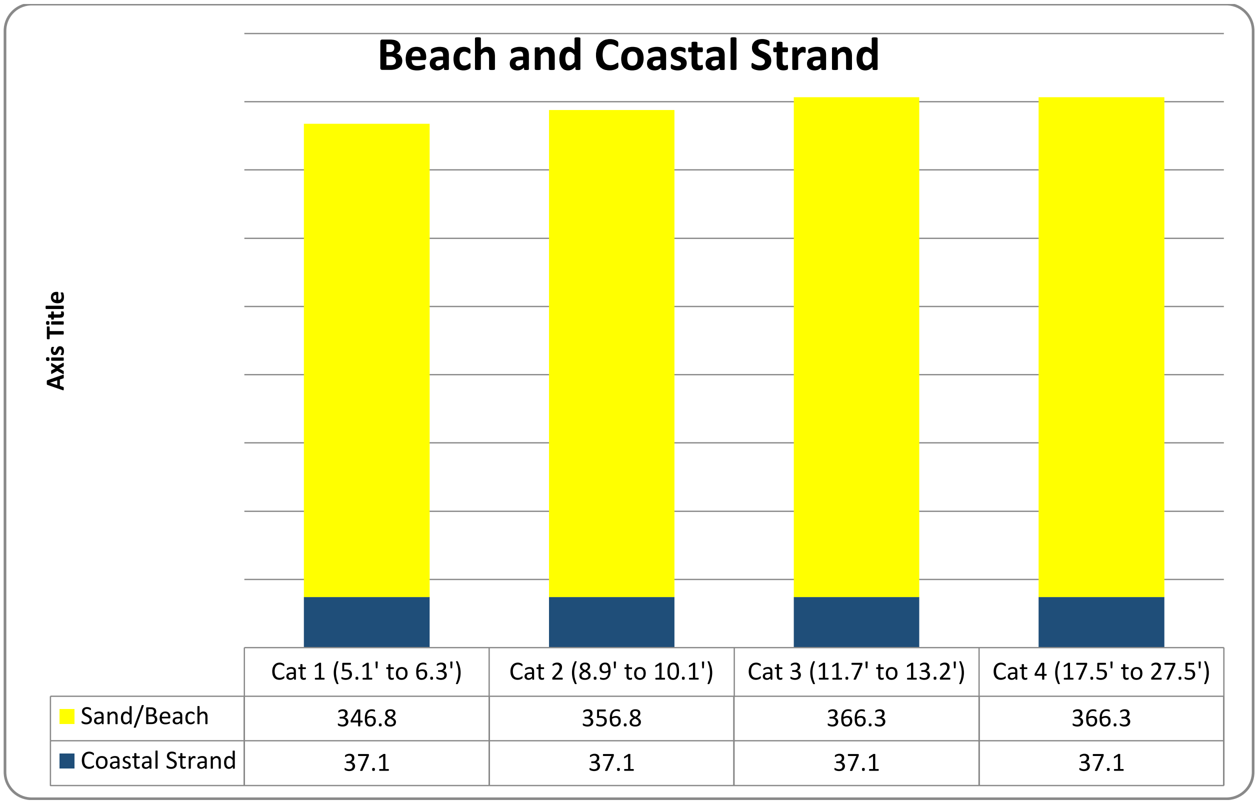


Figure 17: Acres of beaches and coastal strand habitat in Sarasota County at and below different storm surge elevations 2009

Future Land Use	Collier	Lee	Charlotte	Sarasota	Total	Sq. Miles	% of Region
Agriculture	7,766	467	1,247	1,188	10,669	16.7	0.28
Commercial	2,363	9,247	6,260	1,082	18,953	29.6	0.49
Estate	1,005	16,110	107	2,894	20,117	31.4	0.52
Industrial	653	2,597	1,321	382	4,952	7.7	0.13
Multi-Family	2,269	1,937	7,758	3,891	15,855	24.8	0.41
Preserve	615,177	247,286	108,897	22,737	994,098	1,553.3	25.79
Single Family	53,444	89,621	50,668	45,991	239,724	374.6	6.22
Total Acreage	682,677	367,266	176,259	78,165	1,304,368	2,038.1	33.84

Table 4: Southwest Florida Coastal Region Future Land Use Acreage Subject to 10 Feet NGVD Sea Level Rise *(equivalent to 9.2 feet above mean sea level or subject to daily tidal inundation with 8.2 feet of sea level rise)*

Protection Scenarios	Collier	Lee	Charlotte	Sarasota	Total	Sq. Miles	% of Region
0' to 10' NGVD Uplands, Not Protected	37,954	11,797	11,894	16,608	78,253	122.3	2.03
0' to 10' NGVD Uplands, Protection Likely But Wetland Migration Possible	41,887	85,430	49,963	17,979	195,258	305.1	5.07
0' to 5' NGVD Uplands, Protection Not Likely	467	346	796	0	1,609	2.5	0.04
Wetlands	485,074	57,168	34,449	8,807	585,499	914.8	15.19
Total Acreage	565,382	154,741	97,102	43,393	860,619	1,344.7	22.33

Table 5: Southwest Florida Coastal Region No Protection and Limited Protection Acreage Subject to 10 Feet **NGVD Sea Level Rise** (equivalent to 9.2 feet above mean sea level or subject to daily tidal inundation with 8.2 feet of sea level rise)

Wetland Types	Collier	Lee	Charlotte	Sarasota	Total	Sq. Miles	% of Region
Bay Swamps	0	8	8	21	38	0.1	0.001
Cypress	87,594	435	1	81	88,111	137.7	2.29
Cypress - Melaleuca Infested	2,232	131	0	0	2,363	3.7	0.06
Cypress - Pine - Cabbage Palm	72,970	197	0	0	73,167	114.3	1.90
Cypress - with Wet Prairies	56,705	91	0	0	56,797	88.7	1.47
Emergent Aquatic Vegetation	31	0	68	173	273	0.4	0.01
Freshwater Marshes	14,380	775	1,701	2,040	18,896	29.5	0.49
Intermittent ponds	0	0	15	1	16	0.0	0.0004
Gum Swamps	0	11	0	0	11	0.0	0.0003
Inland Ponds and Sloughs	28	3	0	0	31	0.0	0.001
Mangrove Swamps	82,813	42,341	18,162	777	144,093	225.1	3.74
Mixed Wetland Hardwoods	172	2,481	0	0	2,653	4.1	0.07
Mixed Wetland Hardwoods - Mixed Shrubs	30,903	4,613	0	0	35,516	55.5	0.92
Mixed Wetland Hardwoods – Willows	92	0	0	0	92	0.1	0.002
Saltwater Marshes	17,408	3,785	7,378	1,011	29,582	46.2	0.77
Stream and Lake Swamps (Bottomland)	19	71	1,560	2,834	4,484	7.0	0.12
Tidal Flats	736	1,179	0	0	1,914	3.0	0.05
Tidal Flats/Submerged Shallow Platform	0	0	1,207	396	1,603	2.5	0.04
Titi Swamps	0	5	0	0	5	0.0	0.0001
Wet Prairies	60,116	80	312	869	61,376	95.9	1.59
Wet Prairies - with Pine	5,856	65	0	0	5,921	9.3	0.15
Wetland Coniferous Forests	0	0	445	141	586	0.9	0.02
Wetland Forested Mixed	53,022	896	543	459	54,919	85.8	1.42
Wetland Hardwood Forests	0	0	3,049	4	3,053	4.8	0.08
Total Acreage	485,074	57,168	34,449	8,807	585,499	914.8	15.19

Table 6: Southwest Florida Region Wetland Acreage Subject to 10 Feet NGVD Sea Level Rise (equivalent to 9.2 feet above mean sea level) or subject to daily tidal inundation with 8.2 feet of sea level rise)

Development of Sea Level Response Maps

Current trends and policies regarding land use, conservation and shoreline protection provided a starting point for developing maps of the region's likely land use response to sea level rise. Nevertheless, because those policies do not precisely correspond to existing land use categories, and because those categories can change over time, some analysis and judgment is necessary to develop the maps. This section explains and documents the procedures used to create the maps.

SWFRPC staff first met with county officials to obtain any necessary data, explain the project, and obtain their understanding given current policies of the areas where shoreline protection is almost certainly precluded by environmental policies or is unlikely because the land will not be developed densely enough to justify shore protection. Originally, all other areas were considered likely candidates for protection measures. Areas where shoreline protection measures, such as seawalls, groins, levees and dikes, are precluded or unlikely are areas where wetlands present can potentially migrate inland. Areas where protection measures are likely or certain tend to be urbanized, built environments of human habitation, where wetlands would not be able to migrate.

During this initial phase, no concerted effort was made to distinguish those areas where protection is likely from the areas where it is virtually certain. Local officials had no trouble identifying conservation areas and those privately owned areas where land values are unlikely to justify protection. But they found it very difficult to specifically identify any areas that were certain to be protected. This preliminary set of maps was approved by the SWFRPC.

One objective of this process was to distinguish the areas where protection was likely from those where it is certain. USEPA's overall description of the project makes the point that such a distinction is important both for preserving the environment and encouraging efficient coastal investment. Indeed, the USEPA project manager reminded us that our initial decision to combine the likely and certain areas did not necessarily mean that wetland migration might occur across downtown Naples or Ft. Myers. It was just as reasonable to infer that if such areas are called "protection likely", then other areas that were less densely developed were equally likely to be protected. In an area where most of the coastal zone will be developed, the failure to distinguish urban areas that are certain to be protected or hardened from developed areas where wetland migration might be allowed eventually may imply that the only areas where wetlands will be allowed to migrate are the areas deemed to be precluded from or unlikely to be protected. We agreed with USEPA's assumption that part of our job, as planners, was to provide policy makers with options. By identifying those areas where protection is almost certain, the remaining areas where protection is likely would provide policy makers with the contours of an environmental-protection option which would allow more wetland migration than we currently expect. Conversely, hardening the areas where it currently is unlikely is an option that provides less environmental protection and more upland preservation than we currently expect.

This distinction might also be useful for those making long-term investments in the coastal zone. Why should a property owner or a unit of government make a permanent infrastructure investment when there is doubt about whether the land will be abandoned, and if there are similar areas where people are sure to hold back the sea? If in fact, Floridians will ultimately decide not protect all developed areas, it is all the more important to concentrate some types of development in the areas that are certain to be protected. Defining such areas was a first step.

The desirability of distinguishing areas for possible wetland migration from areas that are sure to be hardened, however, does not guarantee that doing so would be easy. Draft reports from the nationwide USEPA project became available for all of the Atlantic Coast states from Georgia to New York, as well as Rhode Island and parts of Massachusetts. We took a careful look at those reports to see how they made the distinctions and whether those approaches would be applicable to us. Some of the key methodological approaches from those reports included the following:

Within planning areas where development is expected and protection almost certain due to its low cost relative to land values, the land that was still undeveloped was categorized as likely to be protected in NY, MD, and GA, as well as parts of NC, NJ, and VA. The logic in those states was that as long as the land remains undeveloped, it may still be feasible for conservancies to purchase the land for wetland migration.

Along estuaries where the economics of protection may be marginal because elevations and land prices are low, development density was often the basis for protection, with the density cutoff tending to be county-specific.

Along ocean coasts with recreational real estate in jurisdictions that favor beach nourishment, Coastal Barrier Resource Act (CoBRA) areas tended to show up as “protection unlikely”. The distinction between certain and likely protection sometimes hinged on whether the public has access to the shore, the logic being that such areas are currently not eligible for federally funded beach nourishment.

Large farms and corporate farms in fertile areas were likely to be protected, while smaller farms were converting to wetland.

A few developed areas were already being abandoned due to flood vulnerability in North Carolina.

A few New England States already have prohibited shore protection in some areas.

None of the studies had considered environmental requirements for wetland migration as a basis for distinguishing likely to be protected from certain to be protected; several studies did consider environmental requirements in deciding whether public lands could be allowed to retreat or would likely be protected.

In a few rural areas in Virginia and Maryland, the existence of infrastructure such a sewer lines makes protection more likely than it would otherwise be.

The New York and New Jersey studies concluded that protection is almost certain for almost the entire New York metropolitan area. Baltimore, Washington DC, Wilmington (DE and NC), and Charleston, are also certain to be protected, but they each have land within the suburbs that may not be protected.

All of the studies except for South Carolina and parts of Virginia had decision-making rules based on planning and land use data, using recommendations of local officials, with site-specific adjustments to the maps as directed by county reviewers.

With the insights from those efforts, we developed decision-making rules as described below. Recognizing, however, that those rules seemed unlikely to identify enough land for wetland migration, we also decided to identify one or more wetland migration corridors within areas that would otherwise be certain to be protected. Our reasoning for identifying such a corridor was twofold. First, as previously mentioned, a key aspect of our mission as planners is to provide policy makers with as wide an array of feasible policy options as possible. Second, the published literature on wetland migration has demonstrated that, given a lead time of 100 years, it would be economically feasible to gradually remove development in a designated corridor to accommodate wetland migration. Our designation of such a corridor in no way implies endorsement for such a corridor—indeed the corridors are still considered “protection likely.” But given the possible environmental requirement for wetland migration, it is most accurate for the maps to acknowledge that we cannot characterize all privately owned areas as certain to be protected. We then went back to the counties for their reactions to the revised maps, and made changes accordingly.

Although sea level is very unlikely to rise more than one meter in the next century, the overall study area for this exercise is all land that is either below the 10-foot (NGVD) contour or within 1,000 feet of the shore. Given the likelihood that sea level will only rise two feet in the next century, the 10-foot contour may seem overly inclusive. However, the only complete and comprehensive sets of elevation information in Florida have 5-foot contours, which required a choice between using the 5-foot and 10-foot contours. We chose the latter for several reasons.

First, although the impacts of rising seas in the ‘near term’ are most relevant to current decision-making processes, this study does not focus on a defined time horizon, nor does it address a specific amount of sea level rise. Because the results may be put to a variety of different uses, it is better to be over-inclusive than under-inclusive. The 5-foot contour is only 4.25 feet above the mean tide level and three to four feet above the mean diurnal high tide. The National Ocean Service (NOS) web page reports the following elevations relative to mean low water at Fort Myers, Caloosahatchee River: NGVD (1929) = -0.11 ft; NAVD (1988) = 1.05 ft; mean tide level = 0.63 ft; mean high water = 1.1 feet; mean high high water = 1.3 feet. The diurnal tide range is approximately 2.9 feet along the Gulf at Naples but only 1.3 feet along the Caloosahatchee River at Ft. Myers. (NOS 2003) Tidal wetlands are generally found up to one foot above the diurnal mean high tide, due to the frequent higher tides caused by winds and full and new moons. Thus, the 5-foot contour could become the landward boundary of wetlands if sea level rises two feet, and the 10-foot contour could become the landward boundary with a rise of seven feet. Clearly, the prospect of a rise greater than two feet is sufficiently plausible that we would constrain the usefulness of the study if we only considered the 5-foot contour.

Second, the 5- and 10-foot contours approximately represent the extents of storm surge from a tropical storm and a category 2 hurricane, respectively, under current conditions. Thus, the entire study area would be affected by even a small rise in sea level. With a five foot rise in sea level over the next two centuries, the land between the 5- and 10-foot contours would become vulnerable to a tropical storm.

Finally, the vertical and horizontal resolution of existing contour data is poor. Not only does the data have a wide contour interval, but under National Mapping Standards, those contours can have a vertical error of 2.5 feet, i.e., the mapped 10-foot contour may really be as low as 7.5 feet in some places. Data that is available does not always have good horizontal accuracy either. Thus, a margin of error is required to ensure that our analysis includes all the lands that might be affected by rising seas.

The source for the five and ten-foot contour lines is the South or Southwest Florida Water Management Districts (SFWMD and SWFWMD) or the U. S. Geological Survey (USGS) Quadrangles. Sarasota County provided us elevation lines using GRID GIS. Additional elevations were determined using the original subdivision construction plans for large, antiquated platted land areas that were dredged and filled below the five-foot elevation level. Examples of this are in Cape Coral, Punta Gorda, Port Charlotte and the Cape Haze Peninsula. The City of Sanibel's elevations were determined using a special elevation study on the island. The latter two-elevation work was previously digitized and then converted into the Geographic Information System (GIS) when the 1991 Southwest Florida Hurricane Storm Tide Atlases were developed. Staff at the Big Cypress National Preserve provided the elevations for the Preserve area in Collier County.

Existing land uses (ELU) as defined in the Florida Land Use Cover Classification System (FLUCCS) were used to determine wetlands, water and uplands. Staff at the Big Cypress Preserve also provided ELU in this area. The FLUCCS maps were also kept current by the SFWMD and SWFWMD and were available in GIS shape file coverage. Once wetlands and water were mapped, everything else was considered uplands.

A determination of future land use was necessary in order to define development rights assumptions for the protection scenarios discussed below. Local government comprehensive plans for the year 2020 were generalized to create a standard format for land uses throughout the region. These generalized land uses are as follows: Agriculture, Residential Estate, Multi-Family, Single Family Residential, Commercial/Office, Mining, Industrial, Water, Military, and Preserve.

Critical facilities, as defined and mapped in the local mitigation strategy plans of the four coastal counties, were used to further assign protection scenario status and to also bring long-term sea level rise response planning into the more current local mitigation strategy planning. The critical facilities considered in this study are as follows:

County	Charlotte	Collier	Lee	Sarasota	Total
Facility					
Airport	1	3	3	0	7
Boat Locks	3	0	2	0	5
Clinic	2	8	2		12
Communication Tower	19	8	9	5	41
Community Centers	14	0	0	0	14
Community College	1	1	1	2	5
Drinking Water Facilities	0	9	13	25	47
Electrical Facilities	15	6	14	0	35
Elementary Schools	6	8	11	0	25
Emergency Medical Services	10	2	3	1	16
Fire Stations	0	12	19	14	45
Government Facilities	18	33	27	14	92
High School	3	2	2	0	7
Hospital	1	0	1	1	3
Hurricane Shelters	0	17	12	0	29
Landfills	0	2	2	1	5
Middle School	1	3	3	0	7
Nursing & Convalescent Facilities	0	0	26	1	27
Police-sheriff Facilities	4	9	3	6	22
Port	0	0	1	0	1
Private College	0	0	1	1	2
Private School	2	3	1	0	6
Sewage Treatment Facilities	0	6	43	21	70
Telephone Remote Building	1	0	0	0	1
Telephone Switching Stations	12	0	0	0	12
U.S. Post Office	0	1	0	0	1
Total	113	133	199	92	537

Table 7: Critical facilities in the CHNEP/SWFRPC study area vulnerable to tropical storm and hurricane flooding and sea level rise

For military bases, the USEPA's nationwide convention has been to not speculate on the fate of secured installations, which may involve sensitive security considerations in some cases and is—in any event—outside the planning authority and expertise of local government. USEPA's general convention is therefore to treat secured installations as likely to protect", except for those installations in urban areas where all the surrounding land is almost certain to be protected. In the latter case, the reasoning is that the land would be protected if it was not a base, and there is no basis for assuming that the military would ever retreat while civilians defended territory against the sea.

Incorporating critical facilities into sea level response planning is probably the best way to begin encouraging local governments to implement the sea level rise protection scenarios. For example, when the SWFRPC approved the maps, staff sensed frustration from elected officials as to what they could do to address this problem in their constituents' short-term outlooks. The SWFRPC concluded that this study would be used to work with local government staffs to consider sea level increases when planning for public facility expansions and reconstruction after hurricane damage or due to old age. Therefore, the intent of the study is being met by facilitating local government decision makers and staffs' efforts to begin considering sea level rise impacts on land uses and the supporting public critical facilities.

In Sarasota County there are five communication facilities, one EMS, 14 fire stations, 14 government facilities, one hospital, landfills, nursing/convalescent centers, six police- sheriff facilities, a private college, and two community college facilities, 21 sewage treatment facilities or transfers, one hurricane shelter, and 25 drinking water facilities in hazard of maximum five-10 foot hurricane storm surge.

A listing of all identified critical facilities for Sarasota County is found in Appendix 1 at the end of this document.

Seven colors are used to define the map in each county. First, all water areas in the Gulf of Mexico, bays, rivers, canals or lakes are shown in the color light blue. Second and third, all wetlands either fresh or saltwater are shown in the color dark green with the tidal wetlands shown as purple. Fourth, uplands where no shore protection from sea level rise is assumed are shown in the color light green. Fifth, uplands where shore protection from sea level rise is assumed unlikely are shown in the color blue. Sixth, uplands where shore protection is assumed to be likely are shown in the color red. The seventh color is brown where shore protection is almost certain. Finally, the non-color white is everything above 10' in elevation and is outside the study area.

Assumptions regarding the protection scenarios were made according to elevation and generalized land uses and are defined as follows. The counties agreed with SWFRPC staff that agriculture, mining and upland preserves would not protect their property from sea level rise and therefore would be colored light green. Commercial, estate, industrial, military, multi-family and single family would “almost certainly” protect their property from sea level rise and therefore would be colored brown. Dark blue areas would be land uses between zero and five feet in elevation that is not likely to be protected from sea level rise and might be areas such as unbridged barrier island, low income housing, low value property not on central water and sewer or repetitive flood loss properties. In this phase of the process only critical facilities between the elevation of five and 10 feet were colored brown, but the land itself was colored red. Critical facilities below five feet in elevation were shown as blue and protection was not recommended. Planners from all the counties agreed that we should assume that government owned critical facilities in this area should relocate these facilities to higher ground (see Appendix 1 for critical facilities subject to sea level rise by county).

We completed the maps in GIS shape files or coverage. JPGs and PDFs for each map have been created for easy distribution through the Internet and for display on the SWFRPC website and Environmental Protection Agency website. The SWFRPC provided a readme file on CD for further explanation on the GIS development of these maps to assist the most interested user in this GIS mapping effort.

Once other regional planning councils started to implement the SWFRPC staff initial methodology, it became clear that other data sources were becoming available, such as the Florida Land Use Cover Classification System for existing and future land uses in GIS format, and that even more up-to-date land use information was needed to better determine how to assign the shore protection colors. The table below was subsequently developed.

State-wide approach for identifying the likelihood of human land use protection from the consequences of 10 feet of sea level rise		
Likelihood of Protection[2]	Land-Use Category	Source Used to Identify Land Area
Shore Protection Almost Certain (brown)	Existing developed land (FLUCCS Level 1-100 Urban and Built-up) within extensively developed areas and/or designated growth areas.	Developed Lands identified from Water Management Districts (WMD) existing Florida Land Use, Cover and Forms Classification System (FLUCCS) as defined by Florida Department of Transportation Handbook (January 1999); Growth areas identified from planner input and local comprehensive plans.
	Future development within extensively developed areas and/or designated growth areas (residential/office/commercial/industrial).	Generalized Future Land Use Maps from local comprehensive plans, local planner input and Water Management Districts.
	Extensively-used parks operated for purposes other than conservation and have current protection [3] or are surrounded by brown colored land uses.	County-Owned, State-Owned, and Federally-Owned Lands (based on local knowledge) or lands defined as 180 Recreational on the Level 1 FLUCCS, local planner input and Florida Marine Research Info System (FMRIS) for current protection measures.
	Mobile home developments outside of coastal high hazard[4], expected to gentrify, or connected to central sewer and water.	Local planner input and current regional hurricane evacuation studies.
Shore Protection Likely (red)	Existing development within less densely developed areas, outside of growth areas.	Developed Lands identified from WMD existing FLUCCS; Growth areas identified from local planner input, local comprehensive plans and current regional hurricane evacuation studies.
	Mobile home development neither within a coastal high hazard area that is neither anticipated to gentrify nor on central water and sewer.	Local comprehensive plans and current regional hurricane evacuation studies.
	Projected future development outside of growth areas could be estate land use on Future Land Use Map.	Local planner input
	Moderately-used parks operated for purposes other than conservation and have no current protection or are surrounded by red colored land uses.	County-Owned, State-Owned, and Federally-Owned Lands (based on local knowledge) or lands defined as 180 Recreational on the Level 1 FLUCCS, local planner input and FMRIS.

	Coastal areas that are extensively developed but are ineligible for beach nourishment funding due to CoBRA (or possibly private beaches unless case can be made that they will convert to public)	Flood Insurance Rate Maps for CoBRA, local knowledge for beach nourishment.
	Undeveloped areas where most of the land will be developed, but a park or refuge is also planned, and the boundaries have not yet been defined so we are unable to designate which areas are brown and which are green; so red is a compromise between.	Local planner input
	Agricultural areas where development is not expected, but where there is a history of erecting shore protection structures to protect farmland.	Local planner input
	Dredge Spoil Areas likely to continue to receive spoils or be developed, and hence unlikely to convert to tidal wetland as sea level rises	Local planner input
	Military Lands in areas where protection is not certain.	FLUCCS Level 173
Shore Protection Unlikely (blue)	Undeveloped privately-owned that are in areas expected to remain sparsely developed (i.e., not in a designated growth area and not expected to be developed) and there is no history of erecting shore protection structures to protect farms and forests.	Undeveloped Lands identified from WMD existing FLUCCS Level 1- 160 mining, 200 Agriculture, 300 Rangeland, 400 Upland Forest, 700 barren land ; Non-growth areas identified from planner input, local comprehensive plans, Flood Insurance Rate Maps for CoBRA and current regional hurricane evacuation studies.
	Unbridged barrier island and CoBRA areas or within a coastal high hazard area that are not likely to become developed enough to justify private beach nourishment.	Flood Insurance Rate Maps for CoBRA, local knowledge for beach nourishment and local planner input.
	Minimally-used parks operated partly for conservation, have no current protection or are surrounded by blue colored land uses, but for which we can articulate a reason for expecting that the shore might be protected.	County-Owned, State-Owned, and Federally-Owned Lands (based on local knowledge) or lands defined as preserve on Future Land Use Map, local planner input and FMRIS.

	Undeveloped areas where most of the land will be part of a wildlife reserve, but where some of it will probably be developed; and the boundaries have not yet been defined so we are unable to designate which areas are brown and which are green; so blue is a compromise between red and green.	local planner input
	Dredge Spoil Areas unlikely to continue to receive spoils or be developed, and hence likely to convert to tidal wetland as sea level rises	local planner input
	Conservation Easements (unless they preclude shore protection)	local planner input
No Shore Protection (light green)	Private lands owned by conservation groups (when data available)	Private Conservation Lands
	Conservation Easements that preclude shore protection	local planner input
	Wildlife Refuges, Portions of Parks operated for conservation by agencies with a policy preference for allowing natural processes (e.g. National Park Service)	local planner input
	Publicly-owned natural lands or parks with little or no prospect for access for public use.	County-Owned, State-Owned, and Federally-Owned Lands (based on local knowledge) defined as preserve on the Future Land Use Map and local planner input.

Notes:
1. These generalized land use categories describe typical decisions applied in the county studies. County-specific differences in these decisions and site-specific departures from this approach are discussed in the county-specific sections of this report.
2. Colored line file should be used in areas where less than 10 ft. elevations exist within 1,000 feet of the rising sea or color can't be seen on ledger paper map.
3. Current protection may include sea walls, rock revetments, beach renourishment, levees, spreader swales or dikes.
4. Coastal High Hazard Area defined in Rule 9J-5 FAC as the Category 1 hurricane evacuation zone and/or storm surge zone.

Table 8: State-wide approach for identifying the likelihood of human land use protection from the consequences of 10 feet of sea level rise

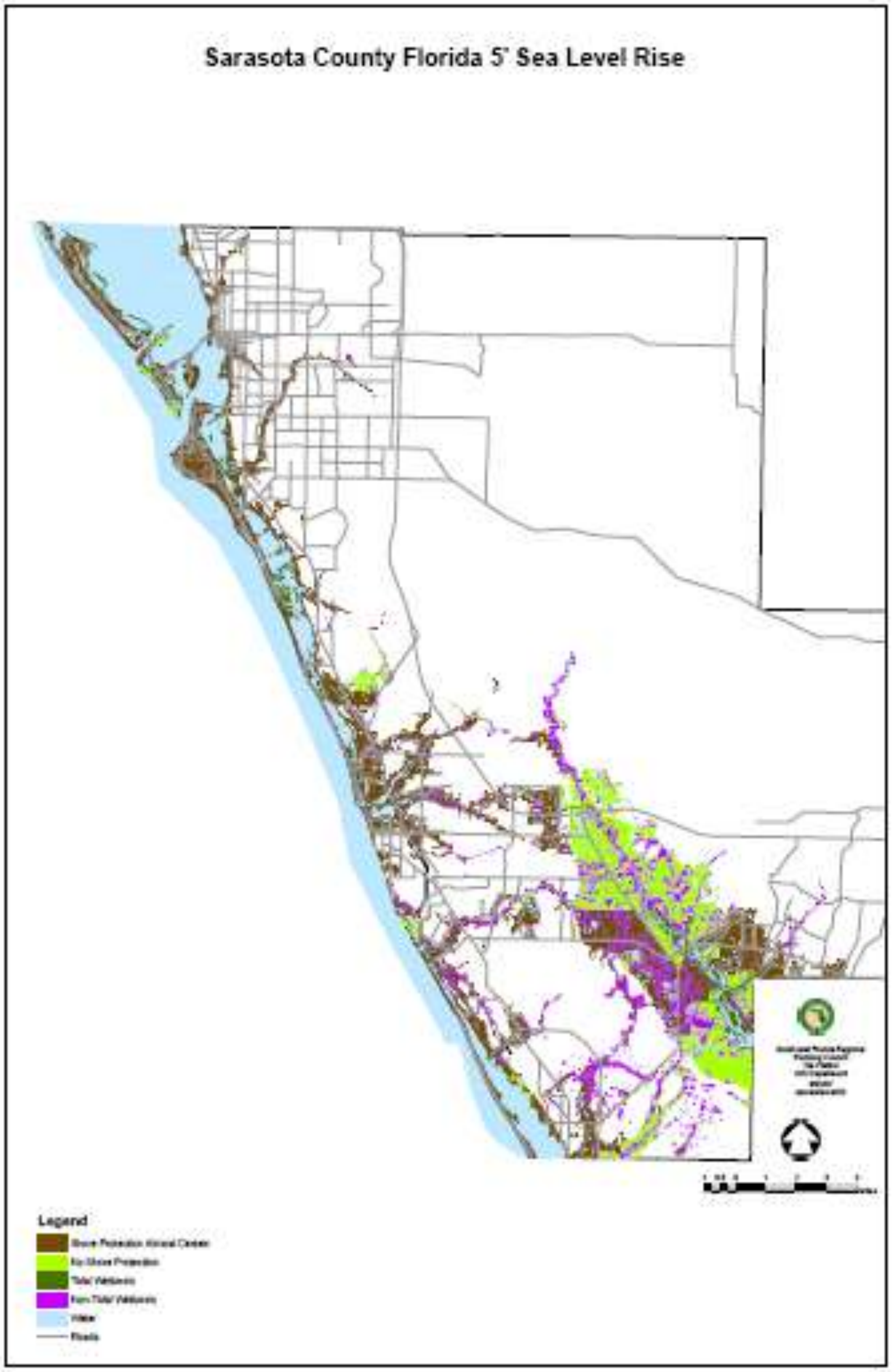


Figure 18: Land use projection map of Sarasota County at 5 foot sea level rise. From IPCC 2013

Global mean sea level budget (mm yr–1) over different time intervals from observations and from model-based contributions.

Source	1901–1990	1971–2010	1993–2010
Observed contributions to global mean sea level (GMSL) rise			
Thermal expansion	–	0.8 [0.5 to 1.1]	1.1 [0.8 to 1.4]
Glaciers except in Greenland and Antarctica *a*	0.54 [0.47 to 0.61]	0.62 [0.25 to 0.99]	0.76 [0.39 to 1.13]
Glaciers in Greenland *a*	0.15 [0.10 to 0.19]	0.06 [0.03 to 0.09]	0.10 [0.07 to 0.13] *b*
Greenland ice sheet	–	–	0.33 [0.25 to 0.41]
Antarctic ice sheet	–	–	0.27 [0.16 to 0.38]
Land water storage	–0.11 [–0.16 to –0.06]	0.12 [0.03 to 0.22]	0.38 [0.26 to 0.49]
Total of contributions	–	–	2.8 [2.3 to 3.4]
Observed GMSL rise	1.5 [1.3 to 1.7]	2.0 [1.7 to 2.3]	3.2 [2.8 to 3.6]
Modeled contributions to GMSL rise			
Thermal expansion	0.37 [0.06 to 0.67]	0.96 [0.51 to 1.41]	1.49 [0.97 to 2.02]
Glaciers except in Greenland and Antarctica	0.63 [0.37 to 0.89]	0.62 [0.41 to 0.84]	0.78 [0.43 to 1.13]
Glaciers in Greenland	0.07 [–0.02 to 0.16]	0.10 [0.05 to 0.15]	0.14 [0.06 to 0.23]
Total including land water storage	1.0 [0.5 to 1.4]	1.8 [1.3 to 2.3]	2.8 [2.1 to 3.5]
Residual *c*	0.5 [0.1 to 1.0]	0.2 [–0.4 to 0.8]	0.4 [–0.4 to 1.2]

Notes:

a Data for all glaciers extend to 2009, not 2010.

b This contribution is not included in the total because glaciers in Greenland are included in the observational assessment of the Greenland ice sheet.

c Observed GMSL rise – modeled thermal expansion – modeled glaciers – observed land water storage.

Source: IPCC 2016

This study initially considered three climate change “severity” scenarios: *least case* (90% probability of occurrence), *moderate case* (50% probability of occurrence), and *worst case* (5% probability of occurrence). These scenarios are based upon the USEPA Report "The Probability of Sea Level Rise." Basically, the formula multiplies the historic sea level rise (2.3 mm/yr) in southwest Florida (closest point used is St. Petersburg, Fl., Table 9-2) by the number of future years from 1990, plus the Normalized Sea Level Projections in Table 9-1.

Probability (%)	2025		2050		2075		2100		2150		2200	
	cm	inches	cm	inches	cm	inches	cm	inches	cm	inches	cm	inches
90 (best)	7	2.8	13	5.0	20	7.7	26	10.4	40	15.7	53	21.0
80	9	3.6	17	6.6	26	10.1	35	13.9	53	20.8	71	28.1
70	11	4.4	20	7.8	30	11.6	41	16.3	63	24.7	85	33.6
60	12	4.7	22	8.6	34	13.2	45	17.8	72	28.3	99	39.1
50 (moderate)	13	5.1	24	9.4	37	14.4	50	19.8	80	31.4	112	44.2
40	14	5.5	27	10.6	41	16.0	55	21.8	90	35.4	126	49.7
30	16	6.3	29	11.3	44	17.1	61	24.1	102	40.1	146	57.6
20	17	6.7	32	12.5	49	19.1	69	27.3	117	46.0	173	68.2
10	20	7.9	37	14.5	57	22.3	80	31.6	143	56.2	222	87.5
5 (worst)	22	8.7	41	16.1	63	24.6	91	35.9	171	67.2	279	110.0
2.5	25	9.9	45	17.6	70	27.4	103	40.7	204	80.2	344	135.6
1	27	10.6	49	19.2	77	30.1	117	46.2	247	97.2	450	177.3
Mean	13	5.1	25	9.8	38	14.8	52	20.6	88	34.6	129	50.9

*The results of this table are based on using Tables 9-1 and 9-2 of the USEPA Report "The Probability of Sea Level Rise".

Table 9: Sea level projection by year for southwest Florida
Source: IPCC 2007

While the IPCC (2007) has been a standard for current planning purposes, several researchers and scientists that express non-empirical opinions (Rahmstorf 2007) based on other methods of modeling consider the IPCC projections to be conservative and expect climate changes to be more severe. This is because the scenarios presented in IPCC’s Fourth Assessment Report (2007) exclude some of the feedback mechanisms that could accelerate the melting of the Greenland and Antarctic ice sheets.

During our literature review we found that Stanton and Ackerman (2007) foresee a different set of climate future extremes that include either a response to climate change by humans to reduce greenhouse gases, or inaction, a likely scenario at the time of their report’s publication.   Stanton and Ackerman (2007) compared the two scenarios: an optimistic *rapid stabilization case* and a pessimistic *business-as-usual case*. The scenarios represent extremes of what is expected to happen if the world succeeds in a robust program of climate mitigation, versus what is expected to happen if very little to nothing is done to address climate change. The difference between the two allows numerical calculation of climate change damage to Florida resources and economics. This calculation can be perceived as the benefits of mitigation, or, from an opposite perspective, the costs of inaction.

The r*apid stabilization case* (of greenhouse gas (GHG) emissions) includes the lowest levels of future emissions under discussion today including a 50% reduction in current global emissions and an 80% reduction in current U.S. emissions by 2050, where precipitation remains stable and hurricane intensity remains in the current ranges. The *business-as-usual case* or *no-action case* includes steadily increasing GHG emissions throughout this century modeled on the high end of the likely range of the IPCC's A2 scenario (2007). This includes climate instability impacts of less rain in Florida and increased hurricane intensity (IPCC 2007).

	2025	2050	2075	2100
Annual Average Temperature (in degrees F above year 2000 temperature)				
Rapid Stabilization Case	0.6	1.1	1.7	2.2
Business-as-Usual Case	2.4	4.9	7.3	9.7
Sea Level Rise in Florida (in inches above year 2000 elevation)				
Rapid Stabilization Case	1.8	3.5	5.3	7.1
Business-as-Usual Case	11.3	22.6	34	45.3

Table 10: Two other alternate future climate scenarios for Florida
Source: Stanton and Ackerman 2007 Table ES-2

The Stanton and Ackerman (2007) “Rapid Stabilization Case” is the scenario with the highest probability and least impact related to Table 10above, which shows the IPCC (2007) scenarios The more severe “Business-as-Usual Case” is the scenario with approximately 1% probability and greatest impact according to Table 10. So, one could consider the “Rapid Stabilization Case” as the very best and the “Business-as-Usual Case” as the very worst case scenarios.

New projections using the MIT Integrated Global Systems Model, Sokolov, et al. (2009) indicate a median probability of surface warming of 5.2 degrees Celsius by 2100, with a 90% probability range of 3.5 to 7.4 degrees. This falls between the IPCC worst case scenario and the Business-as Usual “worstest” case scenario of Stanton and Ackerman (2007). Therefore this extent of severity is accounted for in this project.

The level of sea level rise discussed for Florida in the recent report entitled "Global Climate Change Impacts in the United States" (Karl et al. 2009) falls between the moderate case and worst case scenarios predicted by the IPCC (2007) with a 30% probability of 24 inches of sea level rise by the year 2100.

Projecting future sea level rise presents special challenges (Karl et al. 2009). Scientists have a well-developed understanding of the contributions of thermal expansion and melting glaciers to sea level rise, so the models used to project sea level rise include these processes. However, the contributions to past and future sea level rise from ice sheets are less well understood. Recent observations of the polar ice sheets show that a number of complex processes control the movement of ice to the sea, and thus affect the contributions of ice sheets to sea level rise. Some of these processes are already producing substantial loss of ice mass. Because these processes are not well understood it is difficult to predict their future contributions to sea level rise. (Alley et al. 2005)

Because of this uncertainty, the 2007 assessment by the IPCC could not quantify the contributions to sea level rise due to changes in ice sheet dynamics, and thus projected a rise of the world's oceans from eight inches to two feet by the end of this century (Meehl et al, 2007). More recent research has attempted to quantify the potential contribution to sea level rise from the accelerated flow of ice sheets to the sea or to estimate future sea level based on its observed relationship to temperature (Rahmstorf 2007). The resulting estimates exceed those of the IPCC, and the average estimates under higher emissions scenarios are for sea level rise between three and four feet by the end of this century. An important question that is often asked is "What is the upper bound of sea level rise expected over this century?" Few analyses have focused on this question. There is some evidence to suggest that it would be virtually impossible to have a rise of sea level higher than about 6.5 feet by the end of this century (Pfeffer et al. 2008). The changes in sea level experienced at any particular location along the coast depend, not only on the increase in the global average sea level, but also on changes in regional currents and winds, proximity to the mass of melting ice sheets, and on the vertical movements of the land due to geological forces (Mitrovica et al. 2009). The consequences of sea level rise at any particular location depend on the amount of sea level rise relative to the adjoining land. Although some parts of the U.S. coast are undergoing uplift (rising), most shorelines are subsiding (sinking) to various degrees from a few inches to over two feet per century (Karl et al. 2009).

There is high confidence in projections of thermal expansion and Greenland surface mass balance, and medium confidence in projections of glacier mass loss and Antarctic surface mass balance. There has been substantial progress in ice-sheet modeling, particularly for Greenland. Process-based model calculations of contributions to past sea level change from ocean thermal expansion, glacier mass loss and Greenland ice-sheet surface mass balance are consistent with available observational estimates of these contributions over recent decades. Ice-sheet flow-line modeling is able to reproduce the observed acceleration of the main outlet glaciers in the Greenland ice sheet, thus allowing estimates of the 21st century dynamical response (medium confidence). Significant challenges remain in the process-based projections of the dynamical response of marine-terminating glaciers and marine-based sectors of the Antarctic ice sheet. Alternative means of projection of the Antarctic ice-sheet contribution (extrapolation within a statistical framework and informed judgment) provide medium confidence in a likely range. There is currently low confidence in projecting the onset of large-scale grounding line instability in the marine-based sectors of the Antarctic ice sheet. {IPCC 2013)

The sum of thermal expansion simulated by Coupled Model Intercomparison Project phase 5 (CMIP5) Atmosphere–Ocean General Circulation Models (AOGCMs), glacier mass loss computed by global glacier models using CMIP5 climate change simulations, and estimates of land water storage explain 65% of the observed global mean sea level rise for 1901–1990 and 90% for 1971–2010 and 1993–2010 (high confidence). When observed climate parameters are used, the glacier models indicate a larger Greenland peripheral glacier contribution in the first half of the 20th century such that the sum of thermal expansion, glacier mass loss and changes in land water storage and a small ongoing Antarctic ice-sheet contribution are within 20% of the observations throughout the 20th century. Model-based estimates of ocean thermal expansion and glacier contributions indicate that the greater rate of global mean sea level rise since 1993 is a response to radiative forcing (RF, both anthropogenic and natural) and increased loss of ice-sheet mass and not part of a natural oscillation (medium confidence).
Independent estimates of effective RF of the climate system, the observed heat storage, and surface warming combine to give an energy budget for the Earth that is closed within uncertainties (high confidence), and is consistent with the likely range of climate sensitivity. The largest increase in the storage of heat in the climate system over recent decades has been in the oceans; this is a powerful observation for the detection and attribution of climate change.

It is very likely that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971– 2010 for all Representative Concentration Pathway (RCP) scenarios due to increases in ocean warming and loss of mass from glaciers and ice sheets. Projections of sea level rise are larger than in the AR4, primarily because of improved modeling of land-ice contributions. For the period 2081–2100, compared to 1986–2005, global mean sea level rise is likely (medium confidence) to be in the 5 to 95% range of projections from process-based models, which give 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 0.45 to 0.82 m for RCP8.5. For RCP8.5, the rise by 2100 is 0.52 to 0.98 m with a rate during 2081–2100 of 8 to 16 mm yr**–1**. We have considered the evidence for higher projections and have concluded that there is currently insufficient evidence to evaluate the probability of specific levels above the assessed likely range. Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century. This potential additional contribution cannot be precisely quantified but there is medium confidence that it would not exceed several tenths of a meter of sea level rise during the 21st century.

Some semi-empirical models project a range that overlaps the process-based likely range while others project a median and 95th percentile that are about twice as large as the process-based models. In nearly every case, the semi-empirical model 95th percentile is higher than the process-based likely range. Despite the successful calibration and evaluation of semi-empirical models against the observed 20th century sea level record, there is no consensus in the scientific community about their reliability, and consequently low confidence in projections based on them.

It is virtually certain that global mean sea level rise will continue beyond 2100, with sea level rise due to thermal expansion to continue for many centuries. The amount of longer term sea level rise depends on future emissions. The few available process-based models that go beyond 2100 indicate global mean sea level rise above the pre-industrial level to be less than 1 m by 2300 for greenhouse gas concentrations that peak and decline and remain below 500 ppm CO_2-eq, as in scenario RCP2.6. For a radiative forcing that corresponds to above 700 ppm CO_2-eq but below 1500 ppm, as in the scenario RCP8.5, the projected rise is 1 m to more than 3 m (medium confidence). This assessment is based on medium confidence in the modeled contribution from thermal expansion and low confidence in the modeled contribution from ice sheets. The amount of ocean thermal expansion increases with global warming (0.2 to 0.6 m °C–1) but the rate of the glacier contribution decreases over time as their volume (currently 0.41 m sea level equivalent) decreases. Sea level rise of several meters could result from long-term mass loss by ice sheets (consistent with Paleo data observations of higher sea levels during periods of warmer temperatures), but there is low confidence in these projections. Sea level rise of 1 to 3 m per degree of warming is projected if the warming is sustained for several millennia (low confidence).

The available evidence indicates that sustained global warming greater than a certain threshold above pre-industrial would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of about 7 m. Studies with fixed ice-sheet topography indicate the threshold is greater than 2°C but less than 4°C (medium confidence) of global mean surface temperature rise with respect to pre-industrial. The one study with a dynamical ice sheet suggests the threshold is greater than about 1°C (low confidence) global mean warming with respect to pre-industrial. We are unable to quantify a likely range. Whether or not a decrease in the Greenland ice sheet mass loss is irreversible depends on the duration and degree of exceedance of the threshold. Abrupt and irreversible ice loss from a potential instability of marine-based sectors of the Antarctic ice sheet in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment.

It is very likely that in the 21st century and beyond, sea level change will have a strong regional pattern, with some places experiencing significant deviations of local and regional sea level change from the global mean change. Over decadal periods, the rates of regional sea level change as a result of climate variability can differ from the global average rate by more than 100% of the global average rate. By the end of the 21st century, it is very likely that over about 95% of the world ocean, regional sea level rise will be positive, and most regions that will experience a sea level fall are located near current and former glaciers and ice sheets. About 70% of the global coastlines are projected to experience a relative sea level change within 20% of the global mean sea level change.

It is very likely that there will be a significant increase in the occurrence of future sea level extremes in some regions by 2100, with a likely increase in the early 21st century. This increase will primarily be the result of an increase in mean sea level (high confidence), with the frequency of a particular sea level extreme increasing by an order of magnitude or more in some regions by the end of the 21st century. There is low confidence in region-specific projections of storminess and associated storm surges. It is likely (medium confidence) that annual mean significant wave heights will increase in the Southern Ocean as a result of enhanced wind speeds. Southern Ocean generated swells are likely to affect heights, periods, and directions of waves in adjacent basins. It is very likely that wave heights and the duration of the wave season will increase in the Arctic Ocean as a result of reduced sea-ice extent. In general, there is low confidence in region-specific projections due to the low confidence in tropical and extratropical storm projections, and to the challenge of downscaling future wind fields from coarse-resolution climate models.

Shifting surface winds, the expansion of warming ocean water, and the addition of melting ice can alter ocean currents which, in turn, lead to changes in sea level that vary from place to place. Past and present variations in the distribution of land ice affect the shape and gravitational field of the Earth, which also cause regional fluctuations in sea level. Additional variations in sea level are caused by the influence of more localized processes such as sediment compaction and tectonics.

Along any coast, vertical motion of either the sea or land surface can cause changes in sea level relative to the land (known as relative sea level). For example, a local change can be caused by an increase in sea surface height, or by a decrease in land height. Over relatively short time spans (hours to years), the influence of tides, storms and climatic variability—such as El Niño—dominates sea level variations. Earthquakes and landslides can also have an effect by causing changes in land height and, sometimes, tsunamis. Over longer time spans (decades to centuries), the influence of climate change—with consequent changes in volume of ocean water and land ice—is the main contributor to sea level change in most regions. Over these longer time scales, various processes may also cause vertical motion of the land surface, which can also result in substantial changes in relative sea level.

Since the late 20th century, satellite measurements of the height of the ocean surface relative to the center of the Earth (known as geocentric sea level) show differing rates of geocentric sea level change around the world. For example, in the western Pacific Ocean, rates were about three times greater than the global mean value of about 3 mm per year from 1993 to 2012. In contrast, those in the eastern Pacific Ocean are lower than the global mean value, with much of the west coast of the Americas experiencing a fall in sea surface height over the same period.

Much of the spatial variation is a result of natural climate variability—such as El Niño and the Pacific Decadal Oscillation—over time scales from about a year to several decades. These climate variations alter surface winds, ocean currents, temperature and salinity, and hence affect sea level. The influence of these processes will continue during the 21st century, and will be superimposed on the spatial pattern of sea level change associated with longer term climate change, which also arises through changes in surface winds, ocean currents, temperature and salinity, as well as ocean volume. However, in contrast to the natural variability, the longer term trends accumulate over time and so are expected to dominate over the 21st century. The resulting rates of geocentric sea level change over this longer period may therefore exhibit a very different pattern.

Tide gauges measure relative sea level, and so they include changes resulting from vertical motion of both the land and the sea surface. Over many coastal regions, vertical land motion is small, and so the long-term rate of sea level change recorded by coastal and island tide gauges is similar to the global mean value. In some regions, vertical land motion has had an important influence. For example, the steady fall in sea level recorded at Stockholm is caused by uplift of this region after the melting of a large (>1 km thick) continental ice sheet at the end of the last Ice Age, between ~20,000 and ~9000 years ago. Such ongoing land deformation as a response to the melting of ancient ice sheets is a significant contributor to regional sea level changes in North America and northwest Eurasia, which were covered by large continental ice sheets during the peak of the last Ice Age.

In other regions, this process can also lead to land subsidence, which elevates relative sea levels, as it has at Charlottetown, where a relatively large increase has been observed, compared to the global mean rate. Vertical land motion due to movement of the Earth's tectonic plates can also cause departures from the global mean sea level trend in some areas—most significantly, those located near active subduction zones, where one tectonic plate slips beneath another. For the case of Antofagasta this appears to result in steady land uplift and therefore relative sea level fall.

In addition to regional influences of vertical land motion on relative sea level change, some processes lead to land motion that is rapid but highly localized. For example, the greater rate of rise relative to the global mean at Manila is dominated by land subsidence caused by intensive groundwater pumping. Land subsidence due to natural and anthropogenic processes, such as the extraction of groundwater or hydrocarbons, is common in many coastal regions, particularly in large river deltas.

It is commonly assumed that melting ice from glaciers or the Greenland and Antarctic ice sheets would cause globally uniform sea level rise, much like filling a bath tub with water. In fact, such melting results in regional variations in sea level due to a variety of processes, including changes in ocean currents, winds, the Earth's gravity field and land height. For example, computer models that simulate these latter two processes predict a regional fall in relative sea level around the melting ice sheets, because the gravitational attraction between ice and ocean water is reduced, and the land tends to rise as the ice melts .However, further away from the ice sheet melting, sea level rise is enhanced, compared to the global average value.

In summary, a variety of processes drive height changes of the ocean surface and ocean floor, resulting in distinct spatial patterns of sea level change at local to regional scales. The combination of these processes produces a complex pattern of total sea level change, which varies through time as the relative contribution of each process changes. The global average change is a useful single value that reflects the contribution of climatic processes (e.g., land-ice melting and ocean warming), and represents a good estimate of sea level change at many coastal locations. At the same time, however, where the various regional processes result in a strong signal, there can be large departures from the global average value.

It is very likely that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971– 2010 for all Representative Concentration Pathway (RCP) scenarios due to increases in ocean warming and loss of mass from glaciers and ice sheets. Projections of sea level rise are larger than in the AR4, primarily because of improved modeling of land-ice contributions. For the period 2081–2100, compared to 1986–2005, global mean sea level rise is likely (medium confidence) to be in the 5 to 95% range of projections from process-based models, which give 0.26 to 0.55 m for RCP2.6, 0.32 to 0.63 m for RCP4.5, 0.33 to 0.63 m for RCP6.0, and 0.45 to 0.82 m for RCP8.5. For RCP8.5, the rise by 2100 is 0.52 to 0.98 m with a rate during 2081–2100 of 8 to 16 mm yr^{-1}.

We have considered the evidence for higher projections and have concluded that there is currently insufficient evidence to evaluate the probability of specific levels above the assessed likely range. Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century. This potential additional contribution cannot be precisely quantified but there is medium confidence that it would not exceed several tenths of a meter of sea level rise during the 21st century.

Table 11 | Surface mass balance (SMB) and rates of change of SMB of the Greenland ice sheet, calculated from ice-sheet SMB models using meteorological observations and re-analyses as input, expressed as sea level equivalent (SLE). A negative SLE number for SMB indicates that accumulation exceeds runoff. A positive SLE for SMB anomaly indicates that accumulation has decreased, or runoff has increased, or both. Uncertainties are one standard deviation. Uncertainty in individual model results reflects temporal variability (1 standard deviations of annual mean values indicated); the uncertainty in the model average is 1 standard deviation of variation across models.

Reference and Models	Time-Mean SMB 1961–1990 mm yr–1 SLE	Rate of Change of SMB 1991–2010 mm yr–2 SLE	Time-Mean SMB Anomaly (With Respect to 1961–1990 Time-Mean SMB)b mm yr–1 SLE		
			1971–2010	1993–2010	2005–2010
RACMO2, Van Angelen et al. (2012), 11 km RCM	–1.13 ± 0.30	0.04 ± 0.01	0.07 ± 0.33	0.23 ± 0.30	0.47 ± 0.24
MAR, Fettweis et al. (2011), 25 km RCM	–1.17 ± 0.31	0.05 ± 0.01	0.12 ± 0.38	0.36 ± 0.33	0.64 ± 0.22
PMM5, Box et al. (2009), 25 km RCM	–0.98 ± 0.18	0.02 ± 0.01	0.00 ± 0.19	0.10 ± 0.22	0.23 ± 0.21
ECMWFd, Hanna et al. (2011), 5 km PDD	–0.77 ± 0.27	0.02 ± 0.01	0.02 ± 0.28	0.12 ± 0.27	0.24 ± 0.19
Snow Model , Mernild and Liston (2012), 5 km EBM	–0.54 ± 0.21	0.03 ± 0.01	0.09 ± 0.25	0.19 ± 0.24	0.36 ± 0.23
Model Average	–0.92 ± 0.26	0.03 ± 0.01	0.06 ± 0.05	0.20 ± 0.10	0.39 ± 0.17

Table 12: Actual Measured Rates of Sea Level Rise in Southwest Florida

Last Year's Measured Sea Level Rise Rates

Location	Rate in MM/YR	Years to 1 foot	Years to 2 feet	Years to 3 feet
Fort Myers	2.73	112	223	335
Sarasota	2.66	115	229	344
St. Petersburg	2.59	118	235	353
Worst Case Scenario	8.8	35	69	104

Location	Rate in MM/YR	Year at 1 foot	Year at 2 feet	Year at 3 feet
Fort Myers	2.73	2128	2239	2351
Sarasota	2.66	2131	2245	2360
St. Petersburg	2.59	2134	2251	2369
Worst Case Scenario	8.8	2051	2085	2120

Figure 19: Elevation in meters at Pelican Cove from LIDAR

Photo 1: Mostly red mangrove hedge on Bayhouse Area shoreline facing northwest from the Wilbanks Area.

Photograph 2: Grassy swale system typical of stormwater conveyance in Bayhouse Area, Building #1.

Photograph 3: Areas of mangrove hedge with black mangrove and silver buttonwood uplift trimming at the western point of the Bayhouse Area, Building #8.

Photograph 4: Rip-rap behind mangrove hedge along Clower Creek, Building #9 in Bayhouse Area

Photograph 5: View from dock below Buildings #17 Harborhouse looking west across Yacht Basin

Photograph 6: Large rip-rap on the south Yacht Basin shoreline backed by vertical concrete wall in the Harborhouse area.

Photograph 7: View east up Clower Creek showing convergence of the Creek and the Yacht Basin channel with Bayhouse Building #10 shoreline on south and Harborhouse shoreline, Building #19 on north.

Photograph 8: Mouth of Clower Creek as it enters Little Sarasota Bay

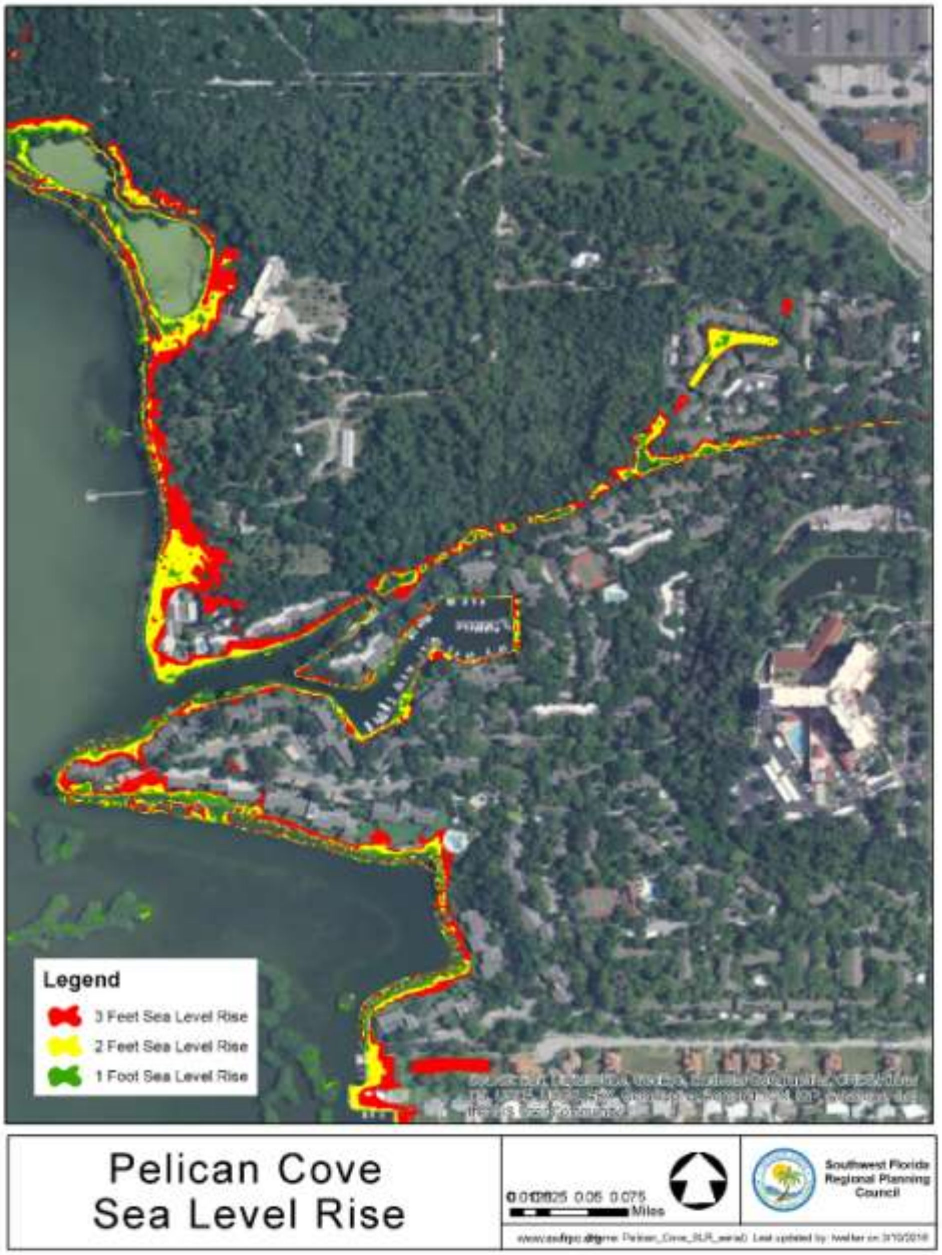


Figure 20: Sea Level Rise locations at 1 (green), 2 (yellow), and 3 feet (red) Elevations at Pelican Cove from LIDAR base.

Figure 21: Sea Level Rise locations at 1 (green), 2 (yellow), and 3 feet (red) Elevations at Pelican Cove from LIDAR base with street map and boundary reference.

Summary

At the current measured rates of sea level rise for Litter Sarasota Bay, Pelican Cove can expect 1 foot of eustatic sea level rise above the current mean tide by the year 2131; 2 feet of eustatic sea level rise above the current mean tide by the year 2245; and 3 feet of eustatic sea level rise above the current mean tide by the year 2341. Many climate change models with strong scientific bases anticipate a rapid acceleration of sea level rise above the current measured rate, caused by more rapid melting of land based ice in glaciers and the polar zones, increased releases of Green House Gases from human activities, agricultural practices, and natural sources released from melting . This set of models predict faster sea level rise such that Pelican Cove can expect 1 foot of eustatic sea level rise above the current mean tide by the year 2051; 2 feet of eustatic sea level rise above the current mean tide by the year 2085; and 3 feet of eustatic sea level rise above the current mean tide by the year 2120.

From site inspection the area of Bayhouse Buildings #7, #6, #5B and Bayhouse Buildings #2 and #1 have approximately 8 feet of elevation above the high tide mark. The Bayhouse Buildings #8, #9, and #10 appear to have 5 feet of elevation above current high tide.

II. Runoff caused by potential sea level rise and increased rain fall and storm activities including how these risks may negatively impact the environment in the Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay, as well as structures, grounds, and infrastructure at Pelican Cove

The potential sea level rise and increased rainfall and storm activities that will increase runoff and negatively impact Little Sarasota Bay Watershed and the water quality in Clower Creek and Little Sarasota Bay, as well as structures, grounds, and infrastructure at Pelican Cove are the result of change in air temperature and chemistry and changes in water temperature and chemistry that generates a climate instability that alters hydrology, results in geomorphic changes and impacts to the habitats and species of Little Sarasota Bay and the Clower Creek system. This section of the reports examines the changes in these drivers of climate change and the resultant effects.

Air Temperature and Chemistry
Known Air Temperature and Air Chemistry Changes and Events

Over the last 650,000 years, levels of atmospheric carbon dioxide have both increased and decreased. The rate of change in increases in carbon dioxide has been about 100 times faster in recent decades than over the past 650,000 years. Concentrations of other gases, such as methane and nitrous oxide, have also increased significantly. Concentrations of greenhouse gases, especially carbon dioxide, have increased. Since the Industrial Revolution, atmospheric carbon dioxide (CO_2) levels have increased by more than 30 percent, reaching concentrations higher than any observed in the last 420,000 years (Petit et al. 1999). These increasing levels of CO_2 and other greenhouse gases have contributed to a rise in global temperatures of about 0.7 to 1.4 degrees Fahrenheit since 1900, with the warmest temperatures occurring in the past 20 years (Houghton et al. 2001). Carbon dioxide emissions grew by 80 percent between 1970 and 2004. Eleven of the last 12 years have seen the warmest temperatures since 1850 (FOCC 2009). Mean global atmospheric temperature has increased by more than 0.6 degrees Celsius since 1901 (IPPC 2007b). Since the 1980s, the atmospheric column average water vapor concentration has increased by 1.2 percent (IPPC 2007b). All this being said, coastal air temperature observations around Florida since the 1830s do not show any statistically significant trend (Maul and Sims 2007).

Potential Future Climate Changes

Florida's future climate depends on overall emissions of greenhouse gases today and in the decades to come, and, because carbon dioxide persists in the atmosphere for a century or more, on the impacts of accumulated past emissions (Stanton and Ackerman 2007). If the world fails to achieve reductions in GHG emissions, the business-as-usual case assumes steadily *increasing* emissions, along with uncertain extreme weather, in which atmospheric concentrations of carbon dioxide exceed the critical 450 parts per million (ppm) threshold by 2030 and reach 850 ppm by 2100. Reaching this threshold is considered “likely” by the IPCC, so understanding that air temperature and air chemistry are interrelated is critical. Ocean acidity, global average temperatures, smog formation, heat waves, humidity (water vapor) and other conditions are affected by air chemistry and air temperature.

	2025	2050	2075	2100
Best Rapid Stabilization Case	0.6	1.1	1.7	2.2
Worst Case	2.4	4.9	7.3	9.7

Table 13: Two future climate scenarios for Florida annual average temperature in degrees F above year 2000 temperature
Source: Stanton and Ackerman 2007

Elevated atmospheric carbon dioxide will increase dissolved carbon dioxide in the oceans and waters associated with coastal areas and wetlands. This can be expected to acidify these waters and increase the frequency of algal blooms (Holman 2008; Ebi et al. 2007; Uhland 2007; Lee County Visitor and Convention Bureau 2008). Carbonate deposition in marine shell-forming taxa will be reduced, causing reductions in the health of and populations of animals ranging from conchs to barnacles to corals. Increased coral reef die-off should be expected, along with changes in plant growth and plant biomass turnover with a near-term increase in vegetative biomass at early stages (Holman 2008; Ebi et al. 2007; Uhland 2007; LCVCB 2008).

Temperature Predictions	Climate Scenario	Pre-development	1891-1995	2009	2025	2050	2100
Mean Annual Air Temperature	With Mitigation	73.6	73.8	74	74.6	75.1	76.2
	Least	73.6	73.8	74	75.1	74.5	77.1
	Moderate	73.6	73.8	74	75.5	77	80.4
	Worst	73.6	73.8	74	76	78.9	83.7
	“Worstest”	73.6	73.8	74	76.4	78.9	84.4

Table 14: Mean annual temperature changes for southwest Florida

Derived from Intergovernmental Panel on Climate Change (IPCC) (2007b), Florida Oceans and Coastal Council (FOCC) 2009, Stanton, E.A., and F. Ackerman 2007

Water vapor, the most abundant greenhouse gas, is an important factor causing uncertainty in climate prediction models. As air temperature increases, the capacity of the air to hold water vapor increases. However, clouds can have a cooling or heating effect, and cloud processes are one of the largest sources of uncertainty in climate change projections. Correctly characterizing the effects of water vapor greatly complicates climate forecasts (FOCC 2008).

Higher air temperatures and changing air chemistry are expected to increase the rate of smog formation in locations adjacent to and within denser urban areas (Fiedler et al. 2001; Southeast Climate Change Partnership (SCCP) 2005), and increased unhealthful levels of ozone pollution are expected (Holman 2008; Ebi et al. 2007; Uhland 2007; Lee County Visitor and Convention Bureau (LCVCB) 2008).

In the case outlined above, Florida's average annual temperatures will be 5° F higher in 2050 than today, and 10°F higher in 2100. Sea level rise will reach 23 inches above mean sea level by 2050, and 45 inches by 2100. The timing of seasonal temperature changes is expected to be disrupted with earlier springs, shorter winters, unseasonable freezes, and extended droughts (Peterson et al. 2007).

Increased air temperatures will affect hydrology, water quality and habitats in saltwater and freshwater wetlands with surface water supplies decreasing and drought in some portions of the region. Altered salinity gradients, altered species distributions, negative species interactions and increased metabolic activity; increased risk of disease and parasitism; creation of opened niches for invasive species; and increased evaporation of surface water are all expected to occur (USEPA CRE 2008; Holman 2008; FOCC 2009).

Warming effects will likely be greatest in the northern parts of this study area (FOCC 2009). Air temperature in south Florida may also increase because of changes in land use and land cover, such as urbanization and the reduction of wetlands (Pielke et al. 1999; Marshall et. al. 2003), multiplying the effect of climate change. Heat waves will become more severe and more common, with new record temperatures and a gradual decline in nighttime cooling. The average "heat index" (temperature combined with humidity) in summer will be 15–20 percent higher in much of the state. South Florida is estimated to become several degrees hotter than today's Bangkok (probably the world's hottest, most humid major city at present), and daily highs in many Florida cities will exceed 90 degrees F nearly two-thirds of the year (Stanton and Ackerman 2007).

Increases in surface temperatures will affect coastlines, wetlands species, water supplies; and power supplies in population centers by a reduction in water quality due to increased growth of nuisance algae and lower oxygen levels. Extirpation of cooler-water species, altered reproductive rates and maturation leading to declining fish and animal populations, increased evaporation of surface water, increased demand for electricity for cooling indoors and increased demand for power plants can be expected (USEPA CRE 2008, Rubinoff et al. 2008; Holman 2008; USNOAA 2008)

Timing of seasonal temperature changes will disrupt the flora and fauna of estuaries resulting in disturbance of predator/prey availability, food and reproductive cycles, life-cycles and upstream migration, temperature-driven behavior, photoperiod-driven behavior and, biological ocean-estuary exchanges (Peterson et al. 2007).

Water Temperature and Chemistry

Known Water Temperature and Water Chemistry Changes and Events

Florida, situated between the Gulf of Mexico and Atlantic Ocean, is subject to contrasting environmental effects because each body of water has its own characteristic temperature regimes and patterns of change (FOCC 2009), but there has been a cyclical rise in sea level and global ocean temperatures (Wang and Enfield et al. 1998). As well, ocean chemistry is changing at least 100 times more rapidly today than at any time during the 650,000 years prior to the industrial era (Kleypas et al. 2006).

As oceanic carbon dioxide has increased in recent decades, the world's oceans have become more acidic, with pH decreasing by 0.1 standard units since 1750 (Archer 2005). This represents a 30 percent increase in ocean acidity.

Additionally, global average sea-surface temperature has risen 1.1 degrees Fahrenheit (0.6 degrees Celsius) over the past 100 years (IPCC 2007b). Water temperatures at the sea surface rose by an average of 0.3 degrees Celsius between the 1950s and 1990s in tropical and subtropical waters (Wilkinson and Souter 2008; Florida Oceans and Coastal Council (FOCC) 2009). The year 2005 was the warmest in the wider Caribbean than any in the last 100 years, and coincided with the area of sea surface temperatures known as the Western Hemisphere Warm Pool being in an expanded state (Wang and Enfield et al. 1998; Wilkinson and Souter 2008).

Warm water holds less dissolved oxygen than cold water, thus, hypoxia, or low oxygen, occurs when the levels of oxygen dissolved in water fall with rising water temperatures to levels injurious to ocean and coastal life. This can lead to what is called a "dead zone." Excess nutrients can cause or exacerbate hypoxic conditions by causing certain organisms to proliferate, leading to further decreased dissolved oxygen as they die and decay. Terrestrial nutrients are introduced into the marine environment through precipitation and runoff, thus, hypoxia can occur as a natural phenomenon and also as a human-induced or exacerbated event (Turner et al. 2006). Precipitation and runoff amounts and distribution have changed over recent years and will continue to change as climate change progresses (UNEP 2006). Over the past 30 years, increased sea surface

temperatures have led to episodic die-offs of sponges, seagrasses, and other important components of coastal and marine ecosystems (FOCC 2009).
Clower Creek Condition Report for 2015

Figure 22 Clower Creek and its Watershed.

CAUTION 3 out of 4 indicators were rated as PASS.
All four indicators must pass for the creek to be rated as PASS.

Figure 23: Outline of Clower Creek

Water Chemistry Ratings Freshwater Portion of the Creek

Total nitrogen, total phosphorus, chlorophyll *a*, and dissolved oxygen levels are monitored carefully by water resource managers and used by regulatory authorities to determine whether a creek meets the water quality standards mandated byte Clean Water Act. Shown below are water quality data for each freshwater stream segment. Florida law defines a threshold for the maximum allowable concentration of nitrogen, phosphorus, and chlorophyll *a*, and the minimum required concentration of dissolved oxygen in these streams. Water quality data are not available for the freshwater portion of Clower Creek

Photograph 9 Upstream freshwater past of Clover Creek with red mangroves growing across it. This may be indicative of past tidal surges that exceeded the control elevations of the weir structures.

Water Chemistry Ratings Tidal Portion of the Creek

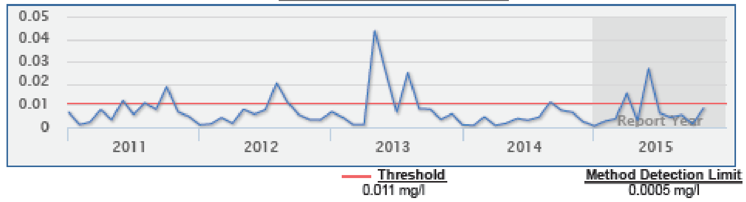
As is the case for predominantly freshwater streams, total nitrogen, total phosphorus, and chlorophyll *a* levels are monitored carefully by water resource managers and used by regulatory authorities to determine whether a tidally influenced stream meets the water quality standards mandated by the Clean Water Act. Shown below are water quality data for each saltwater water body within this basin. Florida law defines a threshold for the maximum allowable concentration of chlorophyll *a* and the minimum required concentration of dissolved oxygen in these streams. No thresholds have been established for the allowable concentration of nitrogen or phosphorus trend information is provided for these nutrients, to determine whether a statistically significant trend exists and if so, whether levels are rising (bad) or falling (good).

Chlorophyll a

Score: Pass

Units: mg/l	Year 2015	Historical period of record
High	0.0	0.2
Mean	0.0047	n/a
Low	0.0007	0.0001
No. of Samples	13	329

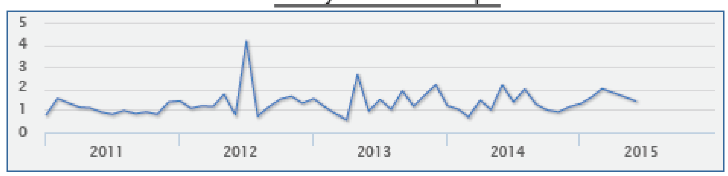
Five-year Trend Graph



Nitrogen, Total

Units: mg/l	Year 2015	Historical period of record
High	2.0	14.1
Mean	1.5884	n/a
Low	1.325	0.363
No. of Samples	4	266

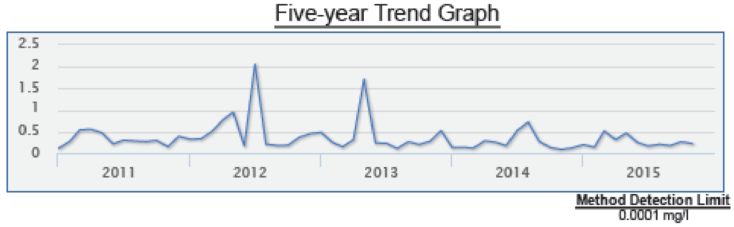
Five-year Trend Graph



Phosphorus, Total

Units: mg/l	Year 2015	Historical period of record
High	0.5	3.1
Mean	0.2507	n/a
Low	0.145	0.067
No. of Samples	13	350

Five-year Trend Graph



Dissolved Oxygen Saturation

Note: Low DO saturation also may be naturally influenced by inflows from nearby wetlands or groundwater sources

Score: Caution

Units: percent (%)	Year 2015	Historical period of record
High	81.2	147.7
Mean	34.14	n/a
Low	23.70	2.20
No. of Samples	8	421

Five-year Trend Graph

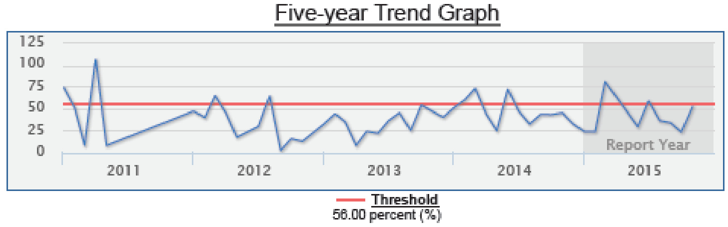


Figure 27: Water Quality Five-Year Trend in Tidal Clower Creek

Photograph 10: Tidal side of Clower Creek begins below the second weir.

The Watershed Size of Clower Creek is 284 acres. The surface water system in the Clower Creek Basin has undergone major alterations over the past 100 years. Historical survey does not identify Clower Creek by name, but aerial photographs and survey from the mid1900sconfirm the presence of agriculture and the extent of the creek, which meandered northeast through the entire basin and terminated at a wetland near the east basin boundary. The entirety of Clower Creek is predominantly marine. Development in the basin was well under way by the 1970s. The basin is about 85% developed, with over 40% commercial development. Stormwater from these commercial areas flows through a network of pipes and ditches to Clower Creek. *For basin details see: Little Sarasota Bay Water Quality Management Plan (2012).*

Figure 25: Watershed of Clower Creek. Note large amount of impervious surface and urbanization in the upper watershed.

Impervious Features

Rain that falls on land that is in a natural state is absorbed and filtered by soils and vegetation as it makes its way into underground aquifers. However, in developed areas, "impervious surfaces" impede this process and contribute to polluted urban runoff entering surface waters. These surfaces include human infrastructure like roads, sidewalks, driveways and parking lots that are covered by impenetrable materials such as asphalt, concrete, brick and stone, as well as buildings another permanent structures. Soils that have been disturbed and compacted by urban development are often impervious aswell.52% of the land area within the Clower Creek Basin is covered by impervious surfaces.

Land Use / Land Cover

Land use within a creek's watershed has a major effect on its water quality. In general, less development means better water quality. Land Cover/Land Use classifications categorize land in terms of its observed physical surface characteristics (e.g. upland or wetland), and also reflect the types of activity that are taking place on it (agriculture, urban/built-up, utilities, etc.).Florida uses as its standard a set of statewide classifications which were developed by the Florida Department of Transportation.

Photograph 11: Siltation in Clower Creek from sediment run-off in the watershed.

Potential Future Climate Changes

Sea-surface temperatures will continue to rise at least at the rate at which they have been rising for the past 100 years (IPCC 2007b). It is probable that water temperatures at the sea's surface will continue to increase at the average rate of 0.3 degrees Celsius over 40 years in tropical and subtropical waters (FOCC 2009). If Florida's ocean temperatures increase at the same rate that the IPCC models predict for the Gulf of Mexico and Atlantic as a whole, they would increase by 2 degrees Celsius over the next 100 years (IPCC 2007b).

As sea-surface temperatures continue to rise, the coastal and marine environments most stressed by nutrients from land-based sources of pollution will be most adversely affected (Wilkinson and Souter 2008). Increased stormwater runoff in some parts of the state, coupled with human population increases, will increase the transport of nutrients to coastal waters, contributing to hypoxia (low oxygen) and eutrophication (FOCC 2009).

More oxygen-poor (hypoxic) waters in areas like Charlotte Harbor may occur as a result of human development depending on the amount of nitrate-laden freshwater discharged by the Peace River. The complex interaction of nutrient load and amount of runoff will make future projections challenging. A 20 percent increase in river discharge, as some climate models project, could increase the risk of hypoxia and expand the oxygen-poor "dead zone" (Twilley et al. 2001; Ebi et al. 2007; USNOAA 2008; FOCC 2009; USEPA CRE 2008).

Increased sea surface temperatures will lead to increased temperature stratification and changed water current circulation with reduced dissolved oxygen (USEPA CRE 2008; NOAA 2008; FOCC 2009). Gulf of Mexico currents may shift (Wilkinson and Souter 2008).

Winter lake temperatures may increase (USEPA CRE 2008), interfering with the life cycle of species that require cooler temperatures for behaviors like aestivation and torpor.

The average pH of the world's oceans may decrease by as much as 0.1 to 0.4 pH units over the next 90 years, due to increasing absorption and solution of carbon dioxide into warmer ocean waters (Royal Society 2005: 29; Kuffner et al. 2008; Ishimatsu et al. 2005). Evidence from studies in the waters surrounding volcanic vents shows that, around the vents, pH fell as low as 7.4, the number of species was 30% less than neighboring areas, coral was absent, and species of algae that use calcium carbonate were displaced in favor of species that do not use it. Snails showed signs of dissolving shells. There were no snails at all in zones with a pH of 7.4. Meanwhile, seagrasses thrived, perhaps because they benefit from the extra carbon in the water (Martin et al. 2009).

Increased acidification of marine waters will cause increased trace metal toxicity and dissolution of carbonate structures, like marine animal shells (Peterson et al. 2007, SCCP 2008, Florida Oceans and Coastal Council (FOCC) 2009, USEPA CRE 2008, Orr et al. 2005).

Higher numbers indicate alkalis, lower values signify acidic liquids	
13	Bleach
10	Soap
8.2	Pre-1750 oceans (average)
8.1	Current oceans (average)
7.8	Oceans in 2100 (projected average)
7	Pure water
3	Vinegar
0	Battery acid

Table 15: The pH Scale
Source: NMEA

In inland areas, lakes, rivers and streams will show water quality climate change effects. Although sea level rise itself is generally not thought of as becoming a significant effect of climate change in inland areas, modeling shows that rising sea level will intrude far inland, extending past Interstate 75, via canals, creeks, and rivers (SWFRPC 2009). Another effect will be more severe and longer lasting droughts. This could result in lower lake levels, concentrating pollutants and nutrients. More intense rain storms and tropical systems may also result in increased urban and suburban stormwater runoff into lakes, increasing their pollutant and nutrient loads. The effects of increased water and air temperatures, reduced pH (from increased amounts of atmospheric CO_2 dissolved into water bodies and falling in rain), droughts and flooding will take many forms in Florida's inland lakes.

Dissolved oxygen levels are reduced with increased water temperatures in inland lakes as well as in coastal water bodies. Hypoxia is a regular natural event in the upper part of Charlotte Harbor occurring seasonally and following some hurricane events, and occurs in the Caloosahatchee River from excessive polluted lake water discharges. In lakes, when DO drops to 0, during both natural and human-induced anoxic events, pH changes. This frees heavy metals from the substrate and redistributes them into the water column. This could result in absorption of these metals into fish tissue, perhaps leading to fish kills and increased toxicity in fish consumed by vertebrates, including humans. Lower water levels resulting from drought may serve to concentrate these effects, increasing toxic levels even further. Care should be taken to prevent polluted waters such as these from being drawn upon for irrigation or consumption.

Chlorophyll-a is used as a measure of water quality because it indicates the amount of phytoplankton and/or algae present in a water body. These organisms take up carbon dioxide and produce oxygen, but an overabundance leads to eutrophication. Increases in temperatures are often accompanied by increases in biological process rates (Day 1989). This would indicate an increase in photosynthesis in phytoplankton, encouraging growth and reproduction, and further increasing amounts of chlorophyll-a. This cycle would continue up to an optimal temperature. Subsequent temperature increases beyond the optimal result in a decrease in phytoplankton growth (Day 1989). Lower pH serves to increase concentrations of CO_2 in the water available for metabolism through photosynthesis. This will increase growth of phytoplankton, adding to the chlorophyll-a load in the lake.

Nutrients such as nitrogen and phosphorus are taken up by algae, phytoplankton and other plants and used in growth processes. The characteristics and availability of these substances do not appear to be affected by climate change (once present in the water column), but nitrogen and phosphorus in lakes will magnify other responses. Increased algal/phytoplankton growth resulting from increased air and water temperatures will utilize nitrogen and phosphorus, fueling expansion, possibly to the point of eutrophication. In intense rain events, stormwater runoff could be expected to increase, introducing higher loads of these nutrients from excess fertilizer from urban and suburban landscapes.

Salts, or dissolved solids, will become more soluble with increasing water temperature, allowing higher concentrations to be maintained in lakes. Decreased pH in lakes, resulting from more CO_2 in the atmosphere, will affect different dissolved solids differently. Some suspended and dissolved solids will come out of solution, while others will be able to increase their concentration in solution. Drought accompanied by lower water levels, will increase concentrations, which may, in turn, force some solids out of suspension or solution. Flood conditions, with higher water levels, may reduce concentrations.

Depending on the content of shoreline soils, there could be increased turbidity from destabilized soil particles, increased total suspended solids, and increased nutrient levels. (Titus 1998; Florida Center for Environmental Studies 2007; Peterson et al. 2007; USNOAA 2008; Volk 2008; USEPA CRE 2008).

Finally, increased temperature increases metabolic rates, increasing growth and reproduction of bacteria. pH tolerance varies from species to species in bacteria and can affect maximum growth rates in varying ways. Bacteria should not be affected directly by drought or flood, but may respond to other limiting factors that are altered by changing water levels and concentrations.

Climate Instability
Known Climate Instability Changes and Events

Precipitation in Florida varies naturally and under human influence in many ways. Annual rainfall is affected by decadal-scale variability in tropical storms, such as the

Atlantic Multidecadal Oscillation and the El Niño-Southern Oscillation warming phenomenon in the Pacific Ocean (Enfield et al. 2001; Jones et al. 1999; Shepherd et al. 2007). Summer rainfall varies over periods of a few decades (Jones et al. 1999). Human alterations to freshwater inflow into estuaries, such as increased overland flow due to urbanization or decreased flow caused by dams and water withdrawals, have changed estuarine circulation patterns, salinity regimes, and patterns of animal use (Scavia et al. 2002).

While studies have shown that there is no clear, long-term trend in the number of tropical storms (IPCC 2007b; FOCC 2009; Webster et al. 2005), there have been changes in storm frequency over periods of a few decades. Although southwest Florida is currently in an active period, it may eventually enter a less active period (Goldenberg et al. 2001). Intense hurricanes and active seasons have occurred regardless of trends in sea-surface temperatures (Virmani et al. 2006). And, while storms can occur at any time of year, over 97 percent of North Atlantic tropical storm activity occurs from June to November (Landsea et al. 1994).

The power of Atlantic tropical cyclones, a function of wind speed, is rising rather dramatically and the increase is correlated with an increase in the late summer/early fall sea surface temperature over the North Atlantic. There is debate concerning the nature of these increases. Some studies attribute them to a natural climate fluctuation known as the Atlantic Multidecadal Oscillation (AMO), and others suggest climate change related to anthropogenic increases in radiative forcing from greenhouse-gases. Tests for causality using the global mean near-surface air temperature and the Atlantic sea surface temperature records during the Atlantic hurricane season have been applied. Results show that global mean near-surface air temperature is useful in predicting Atlantic sea surface temperature, but not the other way around (Enfield et al. 2001; Jones et al. 1999; Elsner 2006; Shepherd et al. 2007). This has provided additional evidence in support of the climate change hypothesis (Elsner 2006).

Potential Future Climate Changes

The development of tropical storms and hurricanes depends not only on sea-surface temperature and water vapor content, but also on factors such as wind shear, which plays a significant role. Wind shear appears to have an inverse relationship with storm intensity. Recent examples of rapid storm intensification are associated with storms passing over deep, warm ocean pools and through regions of low wind shear (Shay et al. 2000). Storm frequency and intensity may, therefore, decrease with increasing sea-surface temperatures (Knutson et al. 2008) because wind shear will increase in a warming planet (Vecchi and Soden. 2007; Wang and Lee 2008.). Other studies indicate that severe hurricanes (Category 3 or higher) may become more frequent with increasing sea-surface temperatures (Webster et al. 2005), and that rising sea temperatures are expected to causes a 5 to 10% increase in hurricane wind speeds (USNOAA 2008; FOCC 2009; USEPA CRE 2008).

Higher water temperatures in the Gulf of Mexico and Atlantic Ocean may cause more intense hurricanes, which will cause more damage to coastal and inland habitations, infrastructure and human economy (Elsner 2006; Peterson et al. 2007; USNOAA 2008; USEPA CRE 2008). Damage will multiply as the effects from more intense hurricanes are added to more severe storm surges resulting from higher sea levels. More intense hurricanes will cause more damage to both coastal and inland habitations and will increase the devastating effects of hurricanes to infrastructure and human economy (Elsner 2006; Peterson et al. 2007; USNOAA 2008; USEPA CRE 2008). Damage will multiply as the effects from more intense hurricanes are added to more severe storm surges resulting from higher sea levels. This increased magnitude of coastal storms will cause geomorphic shifts in barrier islands and habitats at coastlines through coastal erosion and inundation. There will be habitat loss/migration due to erosion/inundation (University of Washington Center for Science in the Earth System 2007; Peterson 2007; FOCC 2009; USEPA CRE 2008; USEPA 2008; USNOAA 2008). Clearly, climate change effects will magnify the effects of hurricanes and tropical storms.

Each of the coastal counties in this study have developed Local Mitigation Strategies (LMS) for anticipated natural disasters including flooding and the impacts of tropical storms and hurricanes. Each LMS estimates the effects of different levels of tropical storm impacts on the infrastructures and properties of their jurisdictions and estimates potential financial losses/damages from such events. The last updates are from 2005. Unfortunately, there is not a consistent reporting method or format for the different jurisdictions so, for example, Sarasota County does not provide estimates for tropical storms as an individual category, but includes it with Category 1 hurricanes. For some statistics there is full reporting. The following figures indicate the magnitude of the vulnerability of the region to these extreme weather events that are considered likely to impact southwest Florida within the time period of the projected futures analyzed in this study.

With climate change, higher, stronger coastal storm surges will reach farther inland. This may lead to saltwater intrusion in zones not tolerant of higher salinity, causing plant and animal mortality and contamination of surface and aquifer drinking water supplies. The higher waves, wave action, and hydrodynamic pressure will lead to deeper flooding. A 20 to 25% increase in the 100-year floodplain area is expected. Salt deposition from such surges and flooding can lead to physical and chemical destruction of habitats and infrastructure. Larger floating debris and increased beach erosion will have negative impacts on human infrastructure. Shorter storm evacuation time windows prior to storms may be expected (USCCSP 2008; Fiedler et al. 2001; Peterson et al. 2007; USNOAA 2008; USEPA CRE 2008).

Rainfall over the Florida peninsula depends on the winds (e.g., sea breezes), especially in the summer, and on hurricanes and tropical storms. Rainfall variations are highly cyclical (Enfield et al. 2001). Climate change, land use, and other factors may result in greater variations in observed patterns, conflicting trends, and regional differences within the state. Distinguishing Florida-specific rainfall and runoff trends from future global trends is a critical research need (FOCC 2009).

Since 1979, there has been a change in the type of rainfall in the tropics, with more frequent heavy and light rains, and less frequent moderate rains (Lau and Wu 2007). Air pollution also may cause more rainfall during weekdays (Bell et al. 2008). An increase in precipitation of 5-10% over the levels of the 20th century, including heavy and extreme precipitation events could be expected, affecting all land surfaces and receiving waterbodies in the entire area of southwest Florida (UWCES 2007; USNOAA 2008; SECCP SDRT LCCP 2005, FOCC 2009, USEPA CRE 2008). If the frequency of extreme rainfall events increases, or if river volume increases and the timing of freshwater flows to estuaries changes, it will exacerbate already altered conditions in estuaries such as increased nutrient delivery and eutrophication (Alber 2002; Peterson et al. 2008; Easterling et al. 2000). However, as mentioned previously, rainfall in south Florida also may be decreasing from changes in land use and land cover, such as urbanization and the reduction of wetlands (Pielke et al**.** 1999). Climate change effects will be variable, and in some cases, will combine to create even more complex and/or extreme outcomes.

Higher maximum temperatures should be expected, with more hot days and heat waves over nearly all land areas. This will negatively affect wetlands, freshwater bodies, and human communities and activities. Due to increased evaporation and evapotranspiration, the volume of bodies of freshwater will be reduced. This will concentrate the solutes in same waters increasing toxic effects (Ebi et al. 2007; USNOAA 2008; SCCP 2005; FOCC 2009; USEPA CRE 2008). Increases in hot extremes will be associated with heavier precipitation (FOCC 2009); storm intensity, even when not associated with tropical systems, will likely increase (FOCC 2009); and periods of drought between these rain systems may be longer (FOCC 2009).

Higher humidity will result from increased atmospheric/aquatic temperatures, allowing more water vapor to exist in the air column. This will result in increased heat stress for people, plants and animals; growth of harmful molds leading to increased negative health consequences; and more bacterial infections (FOCC 2009).

Wildfires, resulting from higher atmospheric temperatures in combination with increased drought, will destroy habitat and allow increased erosion from a lack of vegetative cover. Decreased air quality from particulates and other air pollutants released by the fires (USNOAA 2008; USEPA CRE 2008) can also be expected. Rising air temperatures increase evaporation, contributing to dry conditions, especially when accompanied by decreased precipitation. Even where total annual precipitation does not decrease, precipitation is projected to become less *frequent* in many parts of the country (Gutowski et al. 2008).

Drought is expected to be an increasing problem in southwest Florida and will have impacts on transportation. For example, wildfires during droughts could threaten roads and other transportation infrastructure directly, or cause road closures due to fire threat or reduced visibility, as has occurred in south Florida along Alligator Alley (Interstate 75) in the spring of 2009. Airports could also be affected by decreased visibility due to wildfires. River transport is seriously affected by drought, since lower water levels cause reductions in the routes available, shipping season, and cargo carrying capacity (Karl et al. 2009).

Sustained climate change instability threatens advanced computer technology and human dependency on computers and wireless communication systems. Storage media could be damaged by sustained heat, humidity, extreme storm disasters, flooding, and electromagnetic surges (USEPA CRE 2008).

Figure 26: FEMA Flood Zones at Pelican Cove

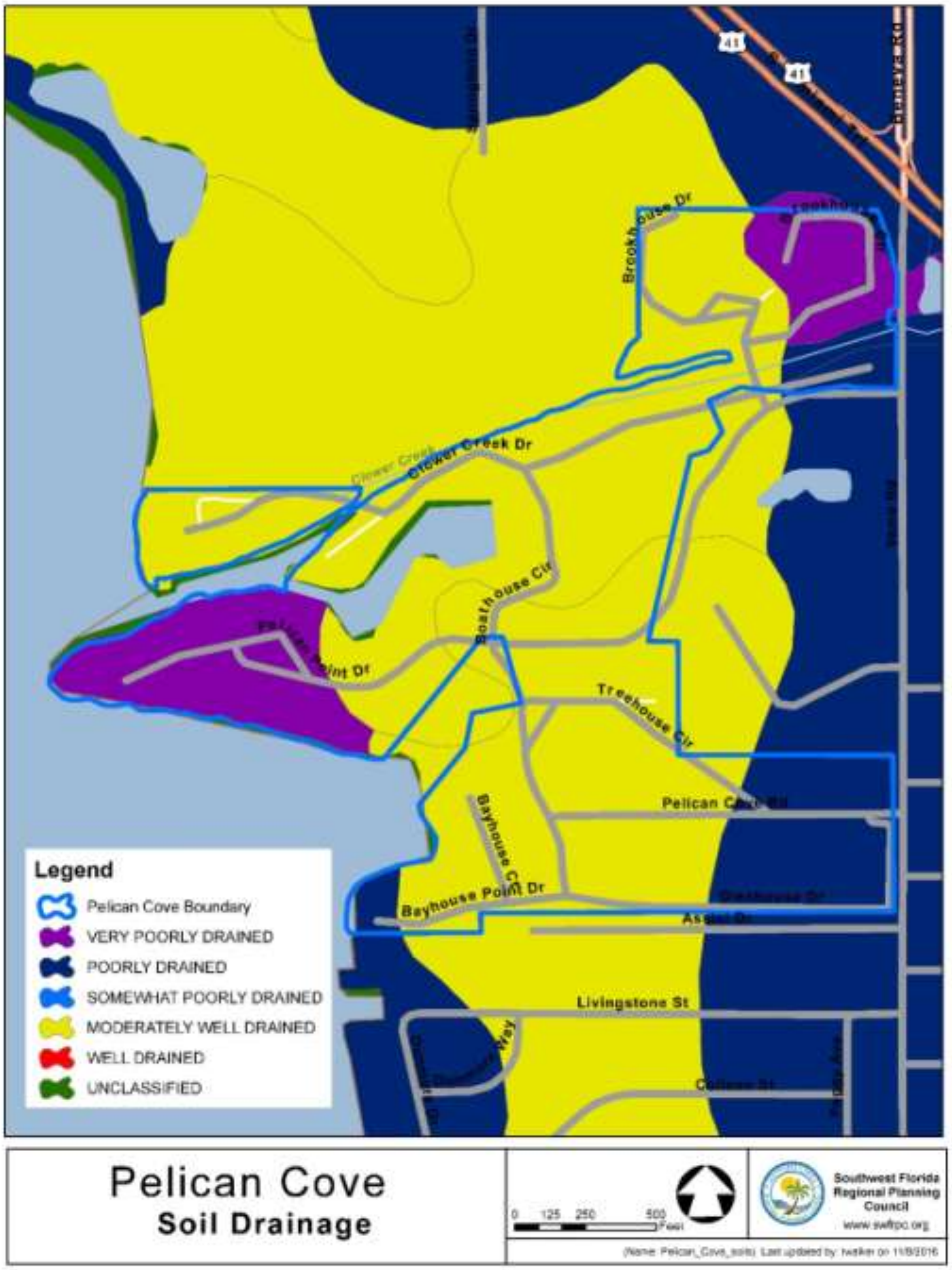


Figure 27: Soil Drainage Characteristics at Pelican Cove

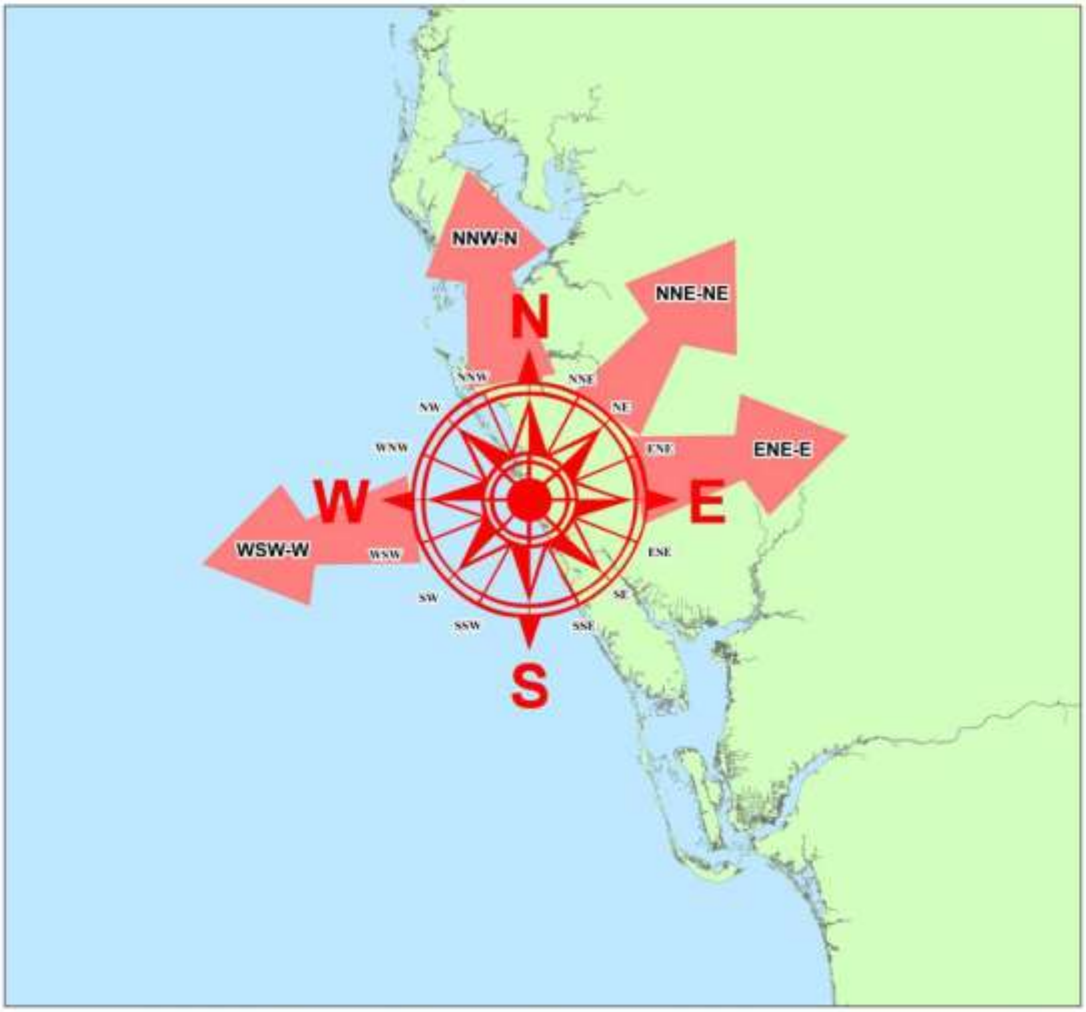


Figure 28: Key to the Directional Tropical Storm and Hurricane Path Storm Surge Maps

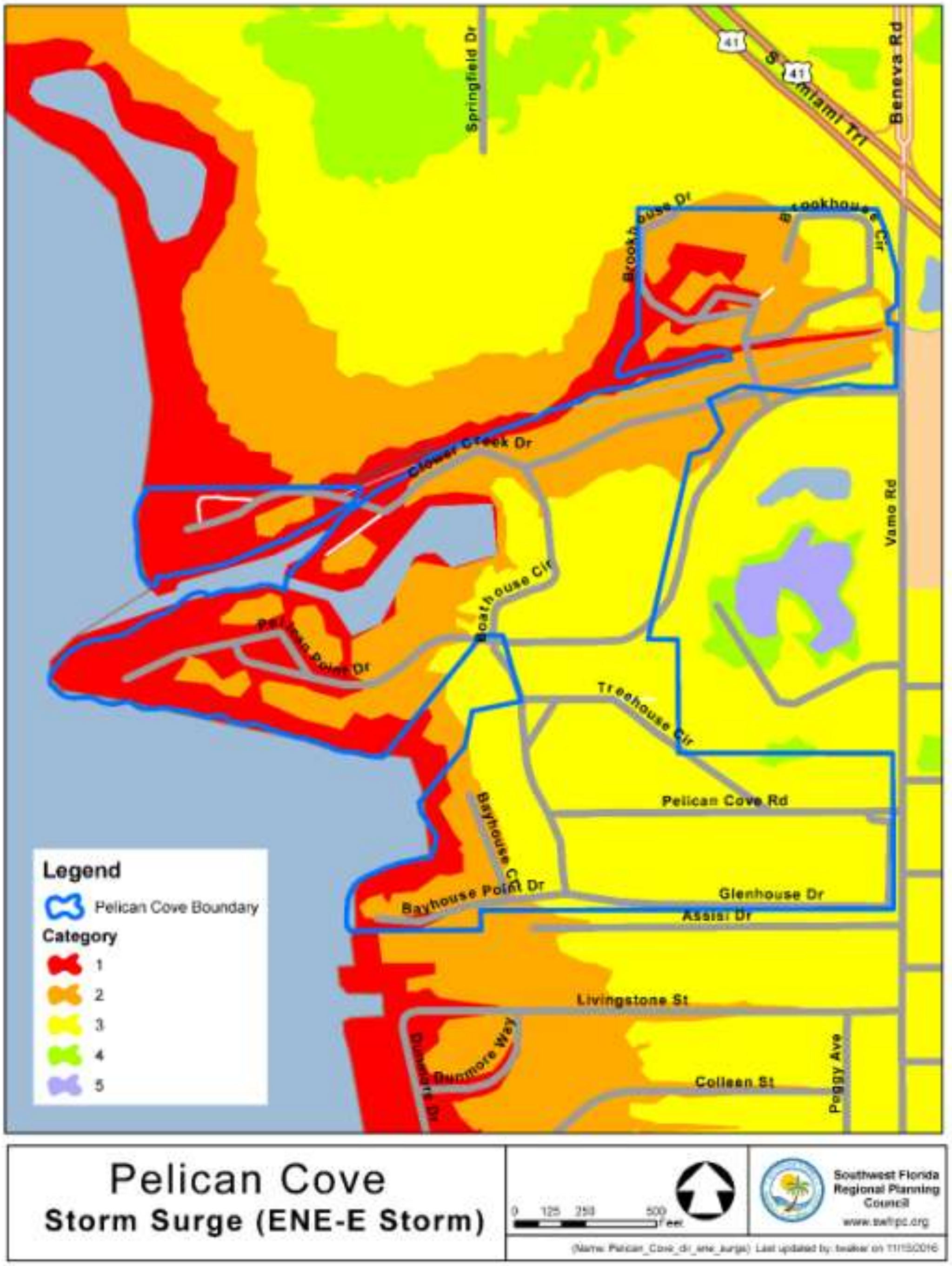


Figure 29: Storm Surge of an East-North-East Directional Tropical Storm and Hurricane Path Storm

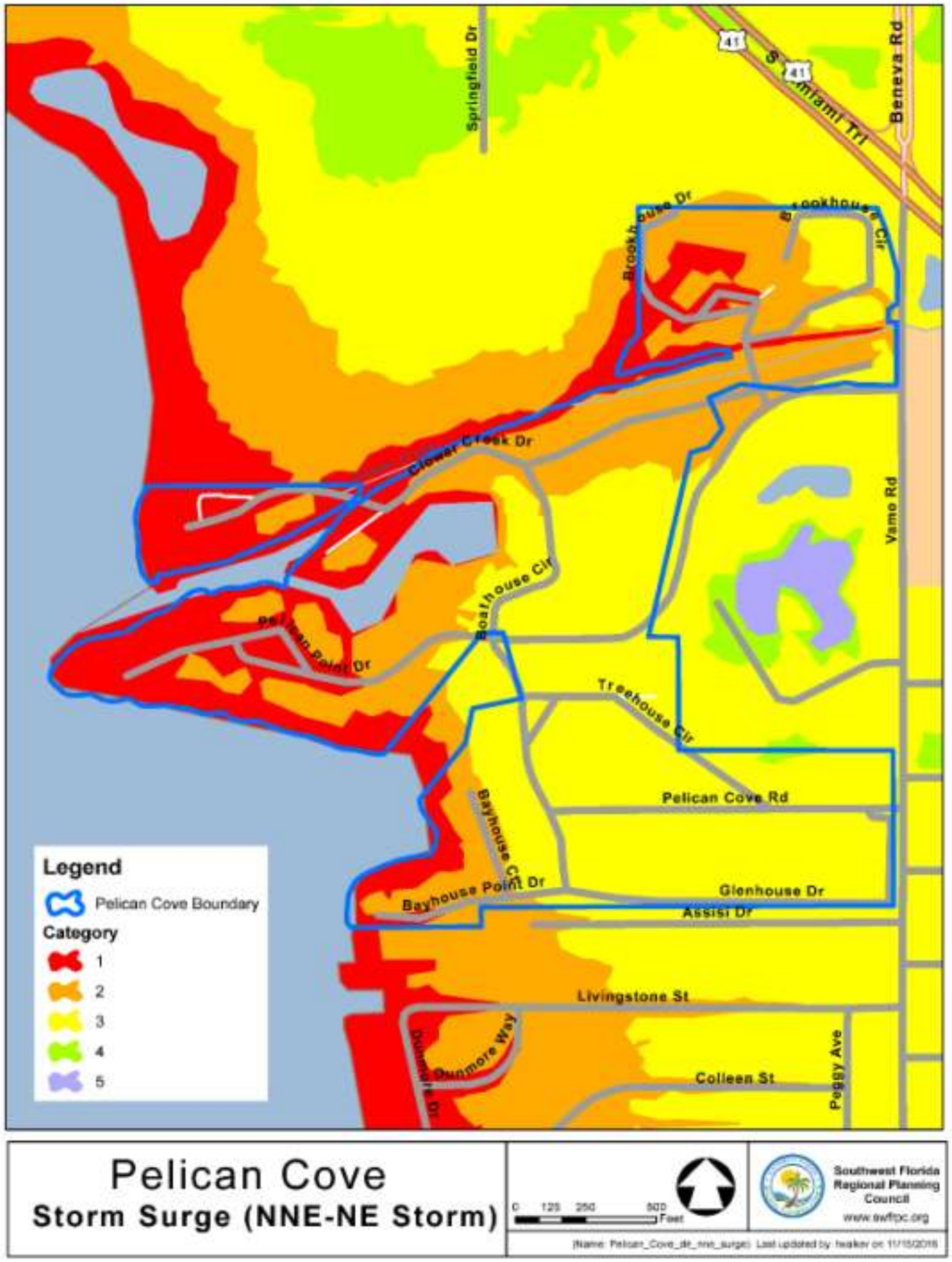


Figure 30: Storm Surge of a North-North-East / North-East Directional Tropical Storm and Hurricane Path Storm

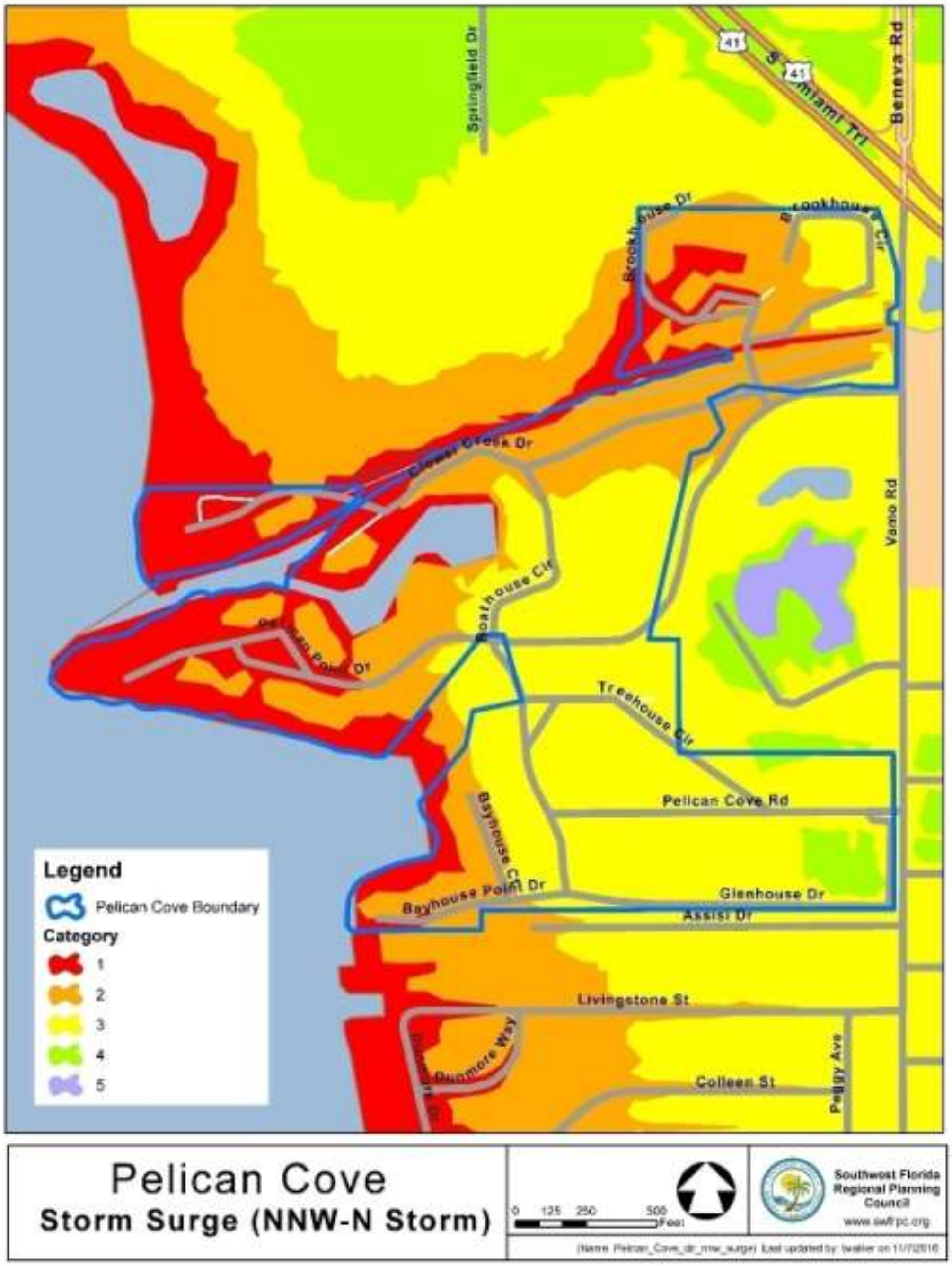


Figure 31: Storm Surge of a North-North-West / North Directional Tropical Storm and Hurricane Path Storm

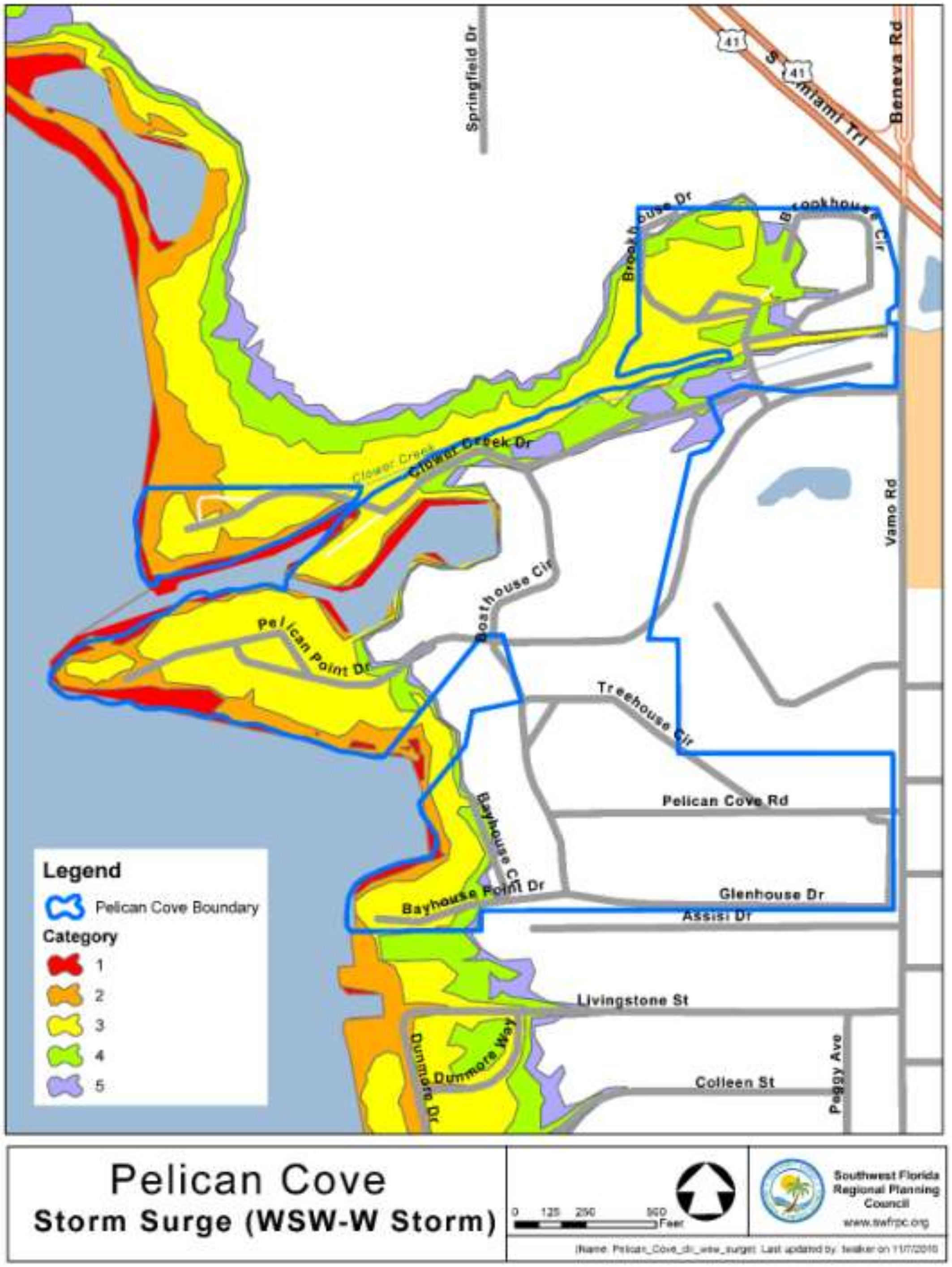


Figure 32: Storm Surge of a West-Southwest/West Directional Tropical Storm and Hurricane Path Storm

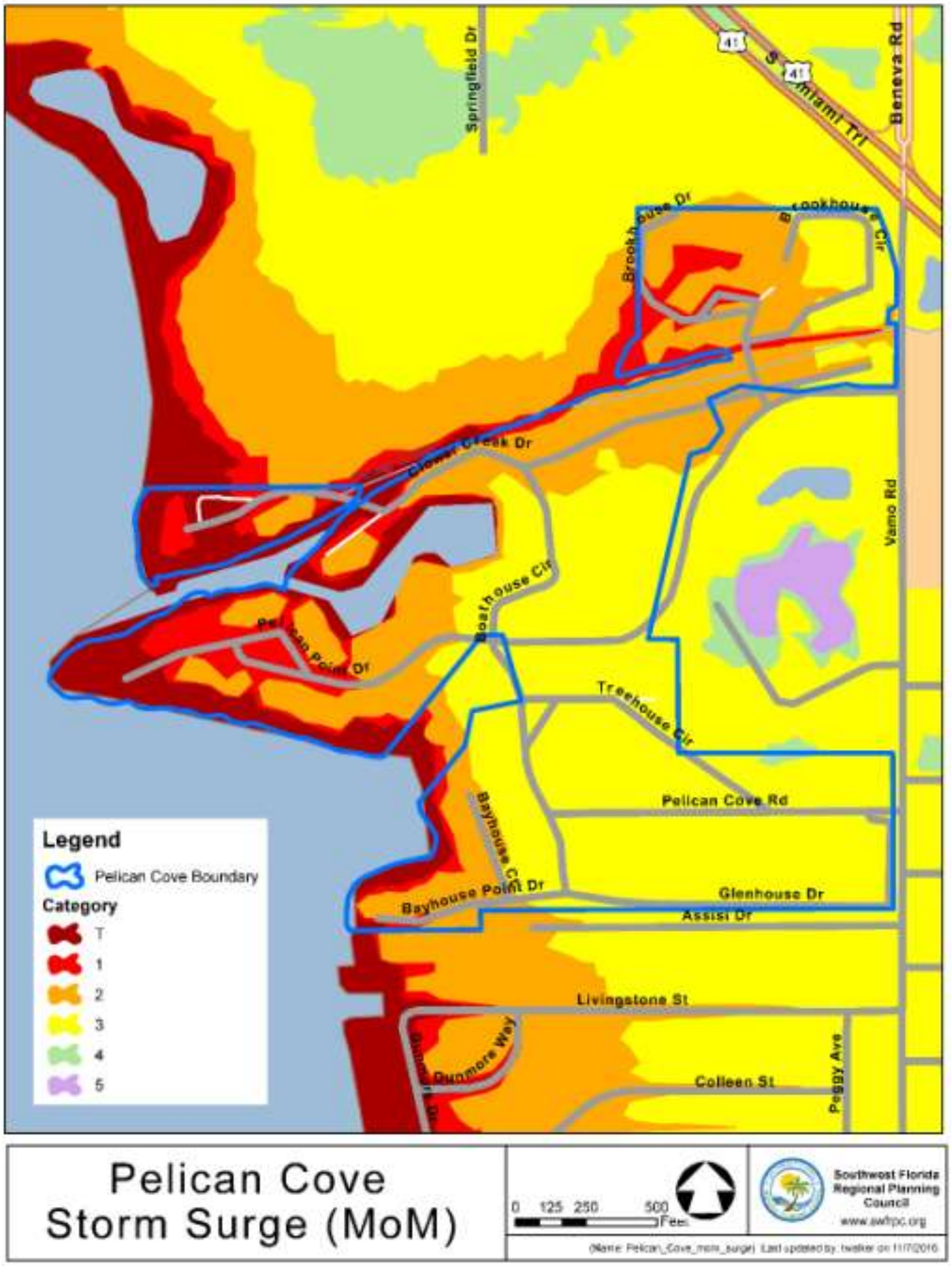


Figure 33: Storm Surge of a Worst Case Tropical Storm and Hurricane Path Storm

Number of Acres of Pelican Cove in Each Storm Surge Zone for a landing storm coming from the west.			
Category of storm	Sum of acres	Cumulative Acres	% of community
1	18.20	18.20	24.27%
2	20.06	38.26	51.01%
3	31.05	69.31	92.41%
4	0.12	69.43	92.57%

Table 16a: Number of Acres of Pelican Cove in Each Storm Surge Zone for a landing storm coming from the west.

Potential Storm Surge Heights (In feet above NAVD88)	
Storm Strength	Height in Feet above Current Sea Level
Tropical Storm	3.3 to5.6
1	3.9 to 6.9
2	9.1 to 15.4
3	13.2 to 26
4	16.8 to 33.2
5	20.8 to 35.4

Table 16b: Strom Surge Heights in Each Storm Surge Zone

Altered Hydrology
Known Hydrologic Changes and Events that Have Occurred

Sea levels in Florida are expected to eventually rise to the degree that saltwater intrusion will threaten the aquifers that currently supply much of Florida's drinking water in low-lying areas. This problem will be exacerbated by increased withdrawals of water for the anticipated increase in Florida's population.

Shallow coastal aquifers are already experiencing saltwater intrusion. The freshwater Everglades recharge Florida's Biscayne aquifer, the primary water supply to the Florida Keys. As rising water levels submerge the land, the low-lying portions of the coastal Everglades will become more saline, decreasing the recharge area and increasing saltwater intrusion (IPCC 2007c). The South Florida Water Management District (SFWMD) already spends millions of dollars per year to prevent Miami's Biscayne aquifer from becoming brackish (Miller et al. 1989).

Gulf Coast ecosystems are linked by the flow of water from the uplands through freshwater lakes, rivers, and wetlands to the coastal and marine systems downstream. Vast wetland areas of the region require periods of flooding to maintain healthy habitats and sustain food webs. While there remains uncertainty about how global warming will affect rainfall, stream flow, soil moisture, and overall water availability, human consumption of water resources is almost certain to increase as a result of the region's population growth.

Water resources are affected by changes in precipitation as well as by temperature, humidity, wind, and sunshine. Thus, changes in streamflow tend not just to reflect, but to magnify changes in precipitation. Water resources in drier climates tend to be more sensitive to climate changes, and, because evaporation is likely to increase with warmer climate, lower river flows and lower lake levels could be expected, particularly in the summer. If streamflow and lake levels drop, groundwater also could be reduced.

A critical factor in Florida's development, especially in southern Florida, has been availability of freshwater. Although south Florida receives an annual average of 54 inches of rain, annual evaporation sometimes can exceed this amount. Rainfall variability from year to year is also high, resulting in periodic droughts and floods. Competing demands for water — for residences, agriculture, industry, and for the Everglades and other natural areas — are placing stress on south Florida's water resources.

Potential Future Climate Changes

Rising air and sea temperatures combined with a rising sea level will change future hydrology. By 2200, the mean sea level is estimated to rise over 177 inches (14.74 feet), inundating most of Monroe County and two-thirds of Miami-Dade County. The Everglades south of I-75, including the Everglades National Park, will no longer be a freshwater ecosystem, causing a catastrophic environmental change for the species inhabiting that area. The incalculable effects on freshwater flows put surface water supplies throughout southern Florida at risk but three main changes can be expected (Stanton and Ackerman 2007). Flooding will result from changes in the intensity of precipitation and will cause stream bank erosion. Changes in the frequency of precipitation and increases in evaporation will cause drought. The sea level rise, lower water levels in the surface and groundwater result in salt water intrusion.

Increases in precipitation, including heavy and extreme precipitation events, affects all land surfaces and receiving water bodies. Precipitation is expected to increase five to 10% over the levels of the 20^{th} century. The altered timing of seasonal hydrologic changes will affect coastlines and wetlands. An increase of freshwater in rivers and estuaries will lead to more severe sediment-loading and flash flooding that results in damage to fish and wildlife resources, human infrastructure, and human safety. Changes in timing of the dry and wet seasons change the flow of pollutants and will affect river discharge balance (University of Washington 2007; USNOAA 2008; SCCP 2005; FOCC 2009; USEPA CRE 2008).

Rising sea temperatures are also expected to increase the frequency of droughts and floods, causing changes to hydroperiod and to water quantity especially during dry periods. The changing timing of seasonal temperature cycles may also disrupt the hydrologic run-off cycle (Peterson et al. 2007). Changes in the volume and intensity of precipitation contribute to erosion, flooding, and run-off at coastlines. Drought from decreased precipitation will cause lower stream flows and result in erosion and subsidence of stream banks (UWCSES 2007; USNOAA 2008; USEPA CRE 2008).

Water constraints are a major threat to the future of Florida's agriculture, by far the biggest user of water. Even the new proposals for sugar cane-based bioethanol will require continuing massive flows of water for irrigation. Changes, even slight ones, in rainfall patterns and amounts may change the agricultural yields of rain-irrigated crops and silviculture directly. Rainfall pattern deviation may alter the spread and severity of plant diseases, pests, and rates of decomposition. Groundwater-irrigated crops are affected as well, due to the variation in water recharge cycles. Changes in rainfall patterns change soil moisture levels which could result in increasing the need for irrigation from groundwater or alternative surface water sources in some areas (Mulkey 2007; Fiedler et al. 2007; USNOAA 2008; FOCC 2009; USEPA CRE 2008).

The agricultural, natural, and cultivated landscape will be negatively affected by the droughts caused by increased atmospheric temperatures. Plant, animal and human communities will suffer from the lowered water tables and deep aquifers. Less water in rivers and reservoirs increases the water supply demands. Subsequent water stress will result in a higher mortality rate for those plant, animal, and human communities from the lack of sufficient water resources (USNOAA 2008; USEPA CRE 2008).

The increased salinity of riverine and estuarine ecosystems is an effect of drought. Increased penetration of saltwater from upstream tidal movement of marine waters will truncate isohaline ecotones. Pollutants from urban runoff are expected to be more concentrated in freshwater systems due to lower water levels. Increased water temperatures and reduced dissolved oxygen will occur as a result of shallower streams. Marine exotics will spread and some freshwater exotics will be advantaged while native species suffer (University of Washington Center for Science in the Earth System 2007; USNOAA 2008; USEPA CRE 2008).

Rising sea levels will lead to increased saltwater infiltration into aquifers, particularly since water levels in the aquifers are dropping and freshwater recharge is diminishing. Groundwater supplies, which provide most of the state's drinking water, will tend to become brackish. Rising sea levels will also block the traditional water flow through the Everglades ecosystem, which is slowly being reconstructed at great expense. Eventually, if sea levels continue to rise, surficial aquifers throughout the state will be threatened with salt water intrusion into community water supplies (Freed et al. 2005; Dausman and Langevin 2005).

Conservation of water uses measures including grey-water recycling and cistern collection. While these measures may offset some of the future water use demand, they have their own environmental consequences, including discharge of nutrient laden waters for irrigation, increases in breeding loci for *Anopheles* mosquitoes, and more difficult accommodation for future population increase.

New water supplies will increasingly mean new investment in more expensive alternative sources. New reservoirs are being built wherever possible, including underground storage of freshwater in some cases. Wastewater treatment is becoming a growing industry in the state. Many areas have access to brackish groundwater but, while traditional ground and surface water supplies often cost less than $1 per 1,000 gallons, desalination of brackish water can cost up to $3 per 1,000 gallons (American Membrane Technology Association 2007). The drawbacks of desalination include creating large volumes of waste water and requiring large amounts of energy. With the reverse osmosis process, used in almost all existing plants, 100 gallons of brackish water is turned into about 75 gallons of useable water and 25 gallons of brine which is often pumped underground (Reeves 2007). The energy requirements of the process are great as well because such high pressure is require to properly force water through thousands of fine-mesh filters. A reliance on desalination would increase the demand for electricity, which in turn would increase the demand for cooling water in power plants, creating a loop. Despite this technology, it's still less expensive to pipe in freshwater from the mainland (Reid 2007).

The state's first large-scale ocean desalination plant was built for Tampa Bay Water, a regional authority in one of the most water-scarce regions. It has been plagued by technical problems, multi-year delays, and financial overruns, reaching a cost of $158 million by the time it began operation in 2003. The plant hoped to reach its design capacity of 25 MGD of freshwater, with water costs of a little over $3 per thousand gallon, by the end of 2007 (Barnett 2007; Reid 2007). In view of these problems, no one else in Florida is rushing to build a similar facility.

While the Tampa Bay plant is large compared to previous desalination efforts, it is small compared to Florida's water needs. To meet the growth in the demand for water through 2050 (as projected above), 186 Tampa-sized plants would be needed — more than one new plant coming on line every three months from now through 2050.
In short, there are no feasible supply-side options for providing this much water; most of the gap will have to be filled by conservation and reduction in demand.

Even under the best of circumstances — under the rapid stabilization scenario, with minimal damages due to climate change — Florida's racing economic and demographic growth is headed for a collision with the lack of additional water. The Florida Department of Environmental Protection (FDEP) projects an increase in water requirements of 22 percent by 2025 (FDEP 2007b). Looking farther ahead, if agricultural water use remains constant, since there is little land for agricultural expansion, and if all other water uses grow in proportion to population, then by 2050 the state would need 12,800 million gallons per day (MGD) of freshwater (Stratton and Ackerman 2007). This is a 57 percent increase over water use in 2000, a quantity that appears to be impossible to provide from existing freshwater sources. At the current cost of desalination, $3 per 1,000 gallons (see above), the additional water needed by 2050 would cost almost $6 billion per year — if it were available. Groundwater supplies are already encountering limits. The water level in the Floridan Aquifer has been dropping for decades (Marella and Berndt 2005); it can no longer meet the growing needs of many parts of the state. Meanwhile, the state has turned down Miami-Dade County's request for a big increase in its withdrawals from the Biscayne Aquifer, which is also under stress; the county will instead be forced to invest in expensive alternatives such as a high-tech wastewater disinfection plant (Goodnough 2007). Surface water supplies are limited in most areas, and will be further constrained in south Florida by the long-term effort to restore the Everglades ecosystem. Floridians, therefore, can look forward to more intensive conservation efforts, such as strict limits on lawn watering, combined with promotion of alternative vegetation that requires less water than a grassy lawn.

Meeting Florida's water needs will be challenging, even in the absence of climatic change. The business-as-usual climate scenario will make a bad situation much worse, with average temperatures rising by 10°F, rainfall decreasing from 54 to 49 inches per year, and sea levels rising by almost four feet over the course of the twenty-first century. Hotter, drier conditions will increase the demand for water for irrigation and other outdoor uses, while at the same time decreasing supplies. Surface water flows will be diminished by the decreased rainfall and increased evaporation. Groundwater supplies will also gradually diminish, as less rainfall and more evaporation means less water percolating down through the soil to recharge the aquifers. The decreased rainfall will not be uniform and predictable from year to year; rather, there will be more frequent droughts, resembling the conditions of 2001 and 2007. With water levels in Lake Okeechobee and elsewhere dropping under drought conditions, the water supplies for much of south Florida, and much of the state’s agriculture, are at risk.

Geomorphic Changes

Known Geomorphic Changes and Events that Have Occurred

Beaches and inlets are regional systems of sediment deposition, erosion, and transport. These processes are profoundly affected by changes in sea level and rates of sea level change, as well as storm events. Scientists and resource managers will be challenged to separate the effects of sea level changes from the effects of storms and the alterations resulting from beach and inlet management actions, such as dredging and beach renourishment.

Shoreline retreat due to erosion and overwash is already occurring (Sallenger et al. 2006, FOCC 2009). There has been an increase in the formation of barrier island inlets and in island dissection events, in which islands are eroded by wind and waves (Sallenger et al. 2006; Sallenger et al. 2005). Normal mangrove accretion in stable estuaries occurs at a rate of 7 mm/year (Cahoon et al. 1999) effectively increasing elevations. Under equilibrium conditions, the processes of erosion and deposition balance, and wetlands are not lost. However, even historic sea level rise coupled with local subsidence has upset coastal equilibrium in many parts of the world (Bird 1985; Bruun 1986).

According to the Florida Department of Environmental Protection (FDEP), beach erosion threatens the very resource that residents and visitors enjoy. In 1989, a first list of erosion areas was developed based upon an abbreviated definition of critical erosion. The list included 217.6 miles of critical erosion and another 114.8 miles of non-critical erosion statewide. Of the state’s 825 miles of sandy beaches, the 2006 list includes 385.3 miles of critically eroded beach, 8.6 miles of critically eroded inlet shoreline, 96.8 miles of non-critically eroded beach, and 3.2 miles of non-critically eroded inlet shoreline statewide (FDEP 2006). This data suggests a 20 percent increase in critically eroded beaches within 15 years of records. Over 409 miles, or approximately 50% of the state's beaches, are experiencing erosion. “Critical erosion", is defined as a level of erosion which threatens substantial development, recreational, cultural, or environmental interests.

While some of this erosion is due to natural forces and imprudent coastal development, a significant amount of coastal erosion in Florida is directly attributable to the construction and maintenance of navigation inlets. Florida has over 60 inlets around the state, and many have been artificially deepened to accommodate commercial and recreational vessels and employ jetties to prevent sand from filling in the channels. A by-product of this practice is that the jetties and the inlet channels have interrupted the natural flow of sand along the beach causing an accumulation of sand in the inlet channel and at the jetty on one side of the inlet, and a loss of sand to the beaches on the other side of the inlet (FDEP 2006).

Potential Future Climate Changes

Sea level rise will change coastlines in many ways (USEPA CRE 2008; Volk 2008; Bollman 2007; Titus 1998). There will be erosion with landward migration of coastlines, barrier island disintegration, saltwater intrusion into surface and subsurface waters, rising surface and groundwater tables. Where retreat is possible, there will be a migration of mangrove and marsh species, altered plant community structural diversity with potential changes in dominant or foundation species, and structural and functional habitat changes. As waters deepen, there will be less sunlight available to submerged aquatic vegetation (SAV) in current locations and light attenuation coefficients will be exceeded (USEPA CRE 2008). The ability of barrier islands to shield coastal areas from higher storm surges and the destructive effects of hurricanes will be reduced by sea level rise (Fiedler et al 2001; Titus 1998; USEPA CRE 2008).

Continued sea level rise will exacerbate erosion (Sallenger et al. 2009), reducing the elevation of barrier islands (Sallenger et al. 2009) and affecting coastal transportation infrastructure. Increased overwash and breaching of coastal roads will occur (Sallenger et al. 2006). Low barrier islands will vanish, exposing marshes and estuaries to open-coast; high fetch conditions (Sallenger et al. 2009).

A drier climate along the Gulf Coast combined with such activities as dredging, constructing reservoirs, diverting surface water, and pumping groundwater could accelerate local subsidence and sinkhole formation in areas underlain by limestone (Twilley et al. 2001). Carbonate sediment dissolution will accelerate as pH decreases (Orr et al. 2005). There is a potential for terrestrial ground subsidence with loss of terrestrial habitat for wildlife and humans and expansion of aquatic habitats (USCCSP 2008; USNOAA 2008; USEPA CRE 2008; SCCP 2008).

Sea level rise will add to the effects of relative surface elevation subsidence caused by changes in sediment transport from watersheds to the estuaries and coast. Dams, diversions, reservoirs, shoreline hardening, dredging of channels and passes with deep water or landward spoil disposal can starve the bed load sediment budget preventing the relative elevation of shallow subtidal and intertidal zones to retain a relative position to sea level to allow wetlands to retreat and re-zone . Some structural adaptations to sea level rise, such as vertical sea walls, tidal barriers, fetch barriers, channelization, etc., will restrict sediment transport and reduce the ability of wetlands to migrate inland with sea level rise. The balance between rainfall and evaporation modified by increased human consumption/drawdown of groundwater will reduce supplies for wetlands and estuaries.

When wetlands are "squeezed" and can't migrate, they do not create land fast enough to avoid drowning (Ebi et al. 2007; Titus 1998).

Specifically for southwest Florida coastal counties, the following erosion report discusses coastal segments mile-by-mile (FDEP 2006). This report also includes the segments that have beach restoration projects. (FFWI 2006). By examining these sources, locations of shore armoring can be used to determine where shore protection is almost certain to continue as sea level rises. The following are the areas identified by the FDEP as having critical coastal erosion problems in Sarasota County as of 2006

There are seven designated critically eroded beach areas (23.1 miles), one non-critically eroded beach area (0.4 mile), and two critically eroded inlet shoreline areas (1.1 miles) in Sarasota County.

The southern half of Longboat Key (R1 - R29) between Manatee County and New Pass has 5.4 miles of critically eroded beach that has threatened development interests in the Town of Longboat Key. This area has a beach restoration project, and terminal groins exist at New Pass.

The north end of Lido Key fronting on New Pass is a critically eroded inlet shoreline area (R31, east 1500 feet) for 0.3 miles. Nearly all of Lido Key (R31 - R44.5) has critically eroded beach that has threatened private development and recreational interests along 2.4 miles. Beach restoration has been conducted along the island and maintenance dredging material has been obtained from the federal navigation channel at New Pass.

The south shoreline of Big Sarasota Pass (R44A - R45) is critically eroded along 0.8 mile of Siesta Key. The threatened private properties along this inlet shoreline have bulkheads and rock revetments.

At the north end of Siesta Key, south of Sarasota Point (R46 - R48.4), is a critically eroded beach area that threatens private development and Beach Road. This 0.4-mile erosion area has rock revetments.

Along the southern half of Siesta Key south of the Point of Rocks headland is a 2.4-mile long critically eroded beach area (R64 - R77) that threatens private development. Some rock revetments exist in this area and a beach restoration project has been constructed. Along the northern half of Casey Key (R81 - R96) is a 2.9-mile long critically eroded beach area that threatens private development and the Casey Key Road. Almost all of this erosion area has rock revetments.

Extending 5.1 miles south of Venice Inlet is a critically eroded beach segment (R116 - R143) that has threatened development and recreational interests in the City of Venice, and to the south a sewage treatment plant, Harbor Drive, and Caspersen Beach. This area has a beach restoration project, and numerous concrete bulkheads exist at the north end of the City of Venice. To the south is a 0.4-mile segment of noncritical erosion (R143-R145).

The south end of Sarasota County (R160-R183.7) is critically eroded for 4.5 miles along Manasota Key threatening private development as well as Manasota Key Road. Some rock revetments have been constructed in this area.

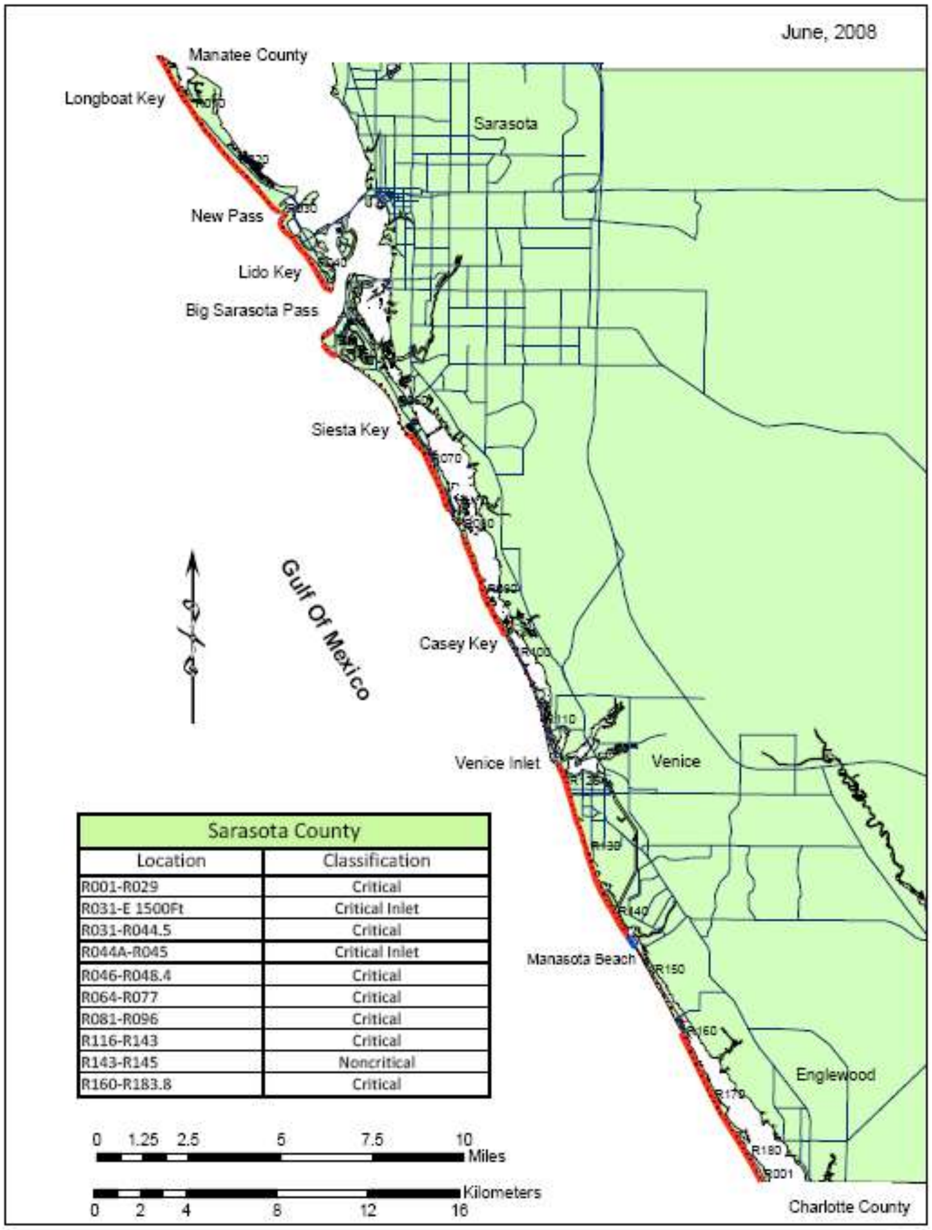


Figure 34: Identified areas of coastal erosion Sarasota County

Known Habitat and Species Changes and Events that Have Occurred

Increased sea-surface temperatures in coastal and marine environments, especially during slick, calm periods in shallow and semi-enclosed embayments, lead to episodic die-offs of sponges, seagrasses, and other important components of coastal and marine communities (FOCC 2009; USEPA CRE 2008). Massive die-offs of tropical reef fish, caused by infections of the organism *Brookynella*, a marine disease caused by a protozoan, or single-celled animal, that infects reef fish under stress, occurred in 1980 in the Florida Keys and from 1997 to 1998 in the Florida Keys and the Caribbean (Wilkinson and Souter 2008). Massive die-offs of sponges and blooms of cyanobacteria, a form of blue-green algae that can produce biological toxins, have also been documented during extended periods of elevated sea-surface temperatures (Wilkinson and Souter 2008) from Miami to the Dry Tortugas, and in Florida Bay during recent periods that coincided with elevated sea-surface temperatures and doldrum weather periods (Wilkinson and Souter 2008). An epidemic die-off of the long spine sea urchin (*Diadema antillarum*) began on the Caribbean side of Panama in 1983 (Lessios et al. 1984). A massive die-off of seagrasses occurred in Florida Bay in 1987, at the same time that a massive coral bleaching event was occurring throughout the Keys and around the Caribbean (Wilkinson and Souter 2008). Recent changes in the distribution and productivity of a number of fish species can, with high confidence, be ascribed to regional climate variability, such as the El Niño–Southern Oscillation warming phenomenon in the Pacific Ocean (Lessios et al. 1984).

Along with increasing sea temperatures, staghorn and elkhorn coral are now re-expanding their ranges northward along the Florida peninsula and into the northern Gulf of Mexico (Brander 2007). Abundant fossil evidence demonstrates that marine animals shifted towards the poles as sea surface temperatures rose—for example, during the Pleistocene–Holocene transition, which occurred about 11,000 years ago (Precht and Aronson 2004.). In addition to allowing natural range expansions, warming temperatures can facilitate the establishment and spread of deliberately or accidentally introduced animal and plant species (Carlton 2001; Stachowicz et al. 2002).

The metabolism of marine and coastal ecosystems is affected by water temperature, nutrient supply, and volume of freshwater inputs. How efficiently or inefficiently nutrients move through the food web can affect the diversity, number, and economic value of living marine resources (FOCC 2008).

Estuarine circulation, salinity, and faunal use patterns are changing (Peterson et al. 2008). Many tidal wetlands are keeping pace with sea level changes (Estevez 1988). Some are accreting vertically, migrating up-slope, or both (Williams et al. 1999; Raabe et al. 2004; Desantis et al. 2007). The rate of sea level rise will be critical for the continued presence of tidal wetlands.

Seagrass

The seagrass beds of Little Sarasota Bay consist predominantly of shoal grass (*Halodule wrightii*) and turtle grass (*Thalassia testudinum*). Some manatee grass (*Syringodium filiforme*) is distributed in patches within beds of the dominants. Primary feeders on seagrasses include sea turtles, manatees, sea urchins, blue crabs, fiddler crabs, and many fishes. The amount of direct grazing varies with location. In Lemon Bay many seagrass grazing fishes are at their northern limit. Many feeders, such as conch, scrape the seagrass blades for epiphytic algae and animals. If roots are undisturbed, seagrass beds respond well to grazing, regenerating easily. With optimal depths, water clarity, and temperature, seagrasses can grow as fast as 2.3 inches per day. In concert with mangroves, macrophytic algae, phytoplankton, benthic micro-algae and emergent marshes, the seagrass meadows provide the primary productive food base of the estuarine system.

The complex structure of seagrass bottoms provides living spaces for numerous periphytic and epifaunal organisms, topological structures for a rich invertebrate fauna, and cover from predation for large populations of small fishes, nektonic and benthic crustaceans, annelids, mollusks, and echinoderms. This combination of shelter and food source makes the seagrass bed a rich nursery and feeding ground for the juvenile and adult forms of many commercially and ecologically significant species of fish and other vertebrates. Many animals associated with mangroves, oyster bars and open unvegetated waters by day, such as pomadasyid fishes, forage in grassbeds at night. Many estuarine fishes spend their entire life cycle feeding in seagrass habitats while others are resident only during critical developmental periods (Ogden and Zieman 1977).

Macro-Algal Beds

The primary types of macro-algal growth of Little Sarasota Bay include: those that grow on the soft sediments; epiphytic species that utilize seagrasses, mangroves, or emergent marsh grasses; the algae that require a hard substrate to anchor such as oyster bars; and the unattached drift algae.

The only algae able to remain in the soft sand and mud substrates utilized by seagrass are mat-forming algae and the *Siphonales* green algae that have creeping rhizoid anchors, including *Halimeda, Penicillus, Caluerpa, Rhipocephalus* and *Udotea*. These algae have limited substrate stabilization capability when compared to seagrasses. They are able to survive in more shifting sediments, however, and are often considered as an early successional stage for seagrass establishment. These algae provide primary food production and deposit large quantities of calcium carbonate, or lime mud, from their skeletons upon seasonal die-back. Many of these species are also common in seagrass, mangrove, soft bottom, and hard substrate communities as well.

The epiphytic algae are a diverse assemblage. Red algae (*Rhodophyta*) make up approximately 45% of the common species of epiphytes. Blue-green (*Cyanophyta*) and green algae (*Chlorophyta*) constitute 21% each of this total and brown algae (*Phaenophyta*) represent the remaining 12%. At least 113 species of epiphytic algae are recorded from turtle grass alone. Sixty-six species are common and the others facultative. The turnover of the epiphytic community is rapid since a seagrass blade's lifetime is 30 to 60 days. The epiphytes increase the primary productivity of seagrass beds and can account for 18 to 33% of community metabolism. They are able to fix molecular nitrogen which is utilized by seagrass. Many animals feed directly on these epiphytes. Heavy growth of encrusting coralline algae, however, can damage seagrass blades by reducing photosynthesis (Goering and Parker 1972).

Hard substrate algae consist of hundreds of species from all of the major macroalgal phyla. Natural bottoms of the Lemon Bay Aquatic Preserve provide few hard abiotic surfaces. Old exposed shells (oysters, clams and whelks) and some areas of exposed bedrock constitute the principal natural areas of hard bottom. Mixed abundances of these plants occur where water quality and clarity is good.

The drift algae species begin growth attached to a firm substrate, plant or inorganic, and subsequently become detached by wave action, grazing, or mechanical disturbance. Large masses travel on the tides and currents like organic tumbleweeds, providing shelter and food for many small invertebrates and fishes, often where no other cover would be available. The drift algae of the Lemon Bay Aquatic Preserve are commonly the red algae, *Gracilaria* and *Laurencia* that seasonally peak in abundance and concentration from July to December.

The contribution of microalgae to estuarine productivity and the food chain is often overlooked because of their microscopic size and seasonality. Diatoms and armored flagellates, which comprise the major abundance and diversity of phytoplankton and benthic, epiphytic, and epifaunal microalgae, are essential to zooplankton, the larval life stages of crustaceans and fish species, and filter-feeding mollusks including clams and oysters. Productivity of the phytoplankton community is seasonal, with different species assemblages resulting from changes in temperature, day length, water quality and clarity, nutrient balance, and grazing pressures. Imbalances in these factors result in algal blooms, including the notorious red tide. Although phytoplankton productivity is, on the average, only one sixth of the system-wide macrophytic production, this productivity is directly available, often at critical periods in consumer life cycles. In combination with bacteria and saprophytes, the epiphytic microflora mediates the productivity of mangroves, seagrass, and salt marsh plants by converting their detrital biomass to nutritive forms digestible by animals.

Mud Flats and Sandbars

Regardless of their barren appearance, naturally occurring, undisturbed, unvegetated bottoms are rich in animal biomass and can display high diversities of invertebrates and fishes. The principal sand and mudflat community is buried beneath and within the unvegetated substrates. This includes a diverse assemblage of bivalve mollusks: hard shelled clams, angel wings, surf clams, razor clams, stout tagelus, donax clams, semele clams, macoma clams, tellins, Venus clams, cockels, lucines, and many others. Burrowing segmented worms, filter feeding segmented tube worms, burrowing flatworms, ribbon worms, burrowing crustaceans, brittle starfish, sand dollars, acorn worms, and lancelets filter feed, deposit feed, scavenge, and hunt within the unvegetated substrate. Numerous species of gastropods are also associated with seagrass and algal beds, living on and within sand and mudflats, often in amazing abundance, including Florida crown conchs, whelks, nassa mud snails, horse conchs, tulip conchs, moon snails, horn shells, and ceriths. Predatory, bottom-feeding fishes flourish in these areas of naturally diverse, often patchy bottom habitats. Many mobile invertebrates and fishes which avoid open, unvegetated areas during the day forage across these flats nocturnally.

The intertidal flats support abundant burrowing crab colonies that forage in coordination with tidal cycles. Wading and shore birds, including sandpipers, dowitchers, willets, plovers, egrets, herons, and ibis hunt the denizens of the flats by probing the substrates and snatching the exposed invertebrates.

Benthic microalgae are often present in more consolidated substrates providing a pale pink, green, brown, or black hue to surface sand/mud layers. The natural unvegetated bottom observed today is often the seagrass bed, algal bed, or oyster bar of tomorrow, given the proper conditions and freedom from disturbance. Frequently, when areas are observed in mid-winter, the vegetation component is not apparent. The same site examined in mid-summer can be a lush seagrass bed.

Oyster Bars

The oyster bars and reefs of Charlotte Harbor are located in the lagoonal estuaries near the confluence of estuarine streams with the bay. The intertidal oyster reefs range in size from small scattered clumps to large mounds of living oysters atop dead shells. Reefs are limited to the middle intertidal zone, where minimum inundation time determines the maximum reef height. Predation and siltation limit oyster populations in the subtidal zone to scattered individuals. During ebb tide exposure to the air, the living reefs are greenish-brown from a thin film of associated algae. In typical reefs the upper surface is level. Sides slope steeply at the edges, with the living portion of the reef thickest at the perimeter. Central areas tend to trap mud from sedimentation and biodeposition, which can smother the live oyster.

At least 50 species of macroinvertebrates are associated with oyster bars, including sponges, insects, barnacles, mud crabs, stone crabs, commensal crabs, clams, mussels, anemones, polychaetes, amphipods, and mollusks including oyster drills. Several bird species, many fishes, and an occasional raccoon hunt the oyster bars at appropriate tides for the reef dwellers and the oysters themselves. Many fish and swimming invertebrates take shelter in the rough topography of the reef to escape predators.

The filter feeding oysters, clams, mussels, sponges, and fan-worm polychaetes directly consume the plankton and suspended particulate material from the water column. In the process of concentrating biomass from this food source, filter feeders can also concentrate metals, red tide toxins, certain harvesting human pathogens, and exotic anthropogenic chemicals. For this reason shellfish harvesting is allowed only in areas with safe water quality. Most Charlotte Harbor oyster bars are in prohibited areas due to the pollution of the adjacent tributaries.

Oyster bars fill a major trophic role in the conversion of carbon and nutrients from phytoplankton and detritus to animal biomass available to higher order consumers, including blue crab, black drum, American oystercatchers, oyster drill, stone crab, and Herbst's mud crab. Concurrent with their metabolism, the oysters, their associated fauna, and aerobic bacteria mineralize organic carbon and release nitrogen and phosphorus in forms usable by primary producers such as phytoplankton, benthic algae, seagrasses, mangroves, and marsh grasses. Oyster reef communities have among the highest measured metabolic rate of any benthic community.

Oysters in reefs live close to their stress tolerance threshold. Further perturbation of conditions by man can easily destroy the entire reef community. Turbidity from dredging, man-made chemicals, heavy metals, artificial hydraulic changes, oxygen depletion by over nitrification, and sediment disturbance, all contribute to the continual loss of live oyster reefs in southwest Florida.

Mangroves

The mangrove forests of south Florida are a vital component of the estuarine and marine environment, providing a major detrital base to organic food chains, significant habitat for arboreal, intertidal and subtidal organisms, nesting sites, cover and foraging grounds for birds, and habitat for some reptiles and mammals. The relationship between mangroves and their associated marine life cannot be overemphasized. The mangrove forest provides protected nursery areas for fishes, crustaceans, and shellfish that are important to both commercial and sport fisheries. The value and central role of mangroves in the ecology of south Florida has been well established by numerous scientific investigations directed at primary productivity, food web interactions, listed species, and support of sport and commercial fisheries. Mangroves are important in recycling nutrients and maintaining the nutrient mass balance of the estuarine ecosystem. They are one of the most productive ecosystems in the world, in terms of primary or associated secondary biological productivity. Mangroves provide one of the basic food chain resources for arboreal life and nearshore marine life through their leaves, wood, roots, and detrital materials. This primary production forms a significant part of the base of the arboreal, estuarine, and marine food web. Mangroves have a significant ecological role as physical habitat and nursery grounds for a wide variety of marine/estuarine vertebrates and invertebrates. Many of these species have significant sport fishery and/or commercial fishery value. Approximately 554,515 acres (224,579 hectares) of mangroves remain in central and south Florida. This tropical ecosystem is a habitat unique in the continental United States. It deserves special protection because of this uniqueness and because of the multiple ecological functions it provides. Mangroves have a significant ecological role as habitat for endangered and threatened species, and many species of special concern. For several of these species, the habitat is critical and vital to their continued survival.

Mangroves also serve as storm buffers by functioning as wind breaks and by baffling wave action with prop roots. Mangrove roots stabilize shorelines and fine substrates, reducing turbidity, and enhancing water clarity. Mangroves improve water quality and clarity by filtering upland runoff and trapping waterborne sediments and debris. Unaltered mangroves contribute to the overall natural setting and visual aesthetics of Florida's estuarine waterbodies. Through a combination of the above functions, mangroves contribute significantly to the economy of the coastal counties of south Florida and the state as a whole.

Mangroves are tropical species restricted by frost and vegetative competition to intertidal regions in tropical and subtropical sheltered waterbodies. Mangroves in the subtropical regions of south Florida represent the northern limits of tropical species that have been able to colonize because of the warm ocean waters and warm currents along the Florida coastline and dependably warm winters (Tomlinson 1986). The distribution of mangroves in North America has changed through geologic time. When the red mangrove (*Rhizophora mangle*) evolved in the Cretaceous, Florida was a great coral reef in shallow seas. There may have been a few mangroves surrounding small islands and on the coastline in what is currently Georgia. In the Eocene, when black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangroves evolved, mangroves extended as far north as South Carolina. During the Pleistocene Ice Ages, mangroves were absent from the Florida coastline and *Spartina* marshes dominated the estuarine intertidal zones. During the past few centuries mangrove distribution has changed in response to short- and long-term climatic fluctuations.

Red and white mangroves have been reported as far north as Cedar Key on the west coast of Florida. Black mangroves occur further north than reds and whites and have been reported as far north as 30° N latitude on the east coast of Florida (Odum 1982). They are distributed as a shrub elsewhere around the Gulf of Mexico where vegetated shorelines have survived development. Over 90 percent of the mangroves in Florida occur in the four southern counties of Lee, Collier, Dade, and Monroe.

The availability of fresh water and nutrients influences the location, size, structure, and productivity of mangrove communities in south Florida. Mangroves reach their greatest abundance in southwest Florida where the positive interaction of fresh water and nutrient inputs with lower wave energy shorelines occurs. In southeast Florida, mangrove development has historically been limited by the lack of fresh water and nutrients combined with narrow intertidal zones and high wave energy. Along the central east cost (Indian River Lagoon) (IRLCCMP 1996) and parts of the west coast (Charlotte Harbor and Sarasota Bay), mangrove communities support the continued existence of barrier islands against tidal and wave forces (CHNEP CCMP 2008). The Everglades system changes from fresh water to an extensive mangrove community at its seaward margin of Florida Bay. Fluctuations in sea level rise along the Florida peninsula can limit the distribution of mangroves, particularly if the rate of sea level rise exceeds the rate of mangrove forest growth and substrate accretion, and if the landward slopes provide no suitable habitat for forest retreat as sea level rises (Wanless 1998). Areas with seawalls behind mangrove habitat prevent such shoreline adjustment. The local distribution of mangroves is affected primarily by a variety of interacting factors that include microclimate, substrate type, tidal fluctuation, terrestrial nutrients, wave energy, and salt water. Sea level rise, shore erosion, interspecific competition, and seed dispersal also affect local distribution to a lesser degree. The interrelations of these factors can alter the intertidal distribution of mangrove species. Mangroves are unique in that their morphological specialization, such as aerial roots, vivipary, and salt excretion or excluding abilities allows them to adapt to these different rigorous environmental factors.

Mangrove ecosystems are a mosaic of different types of forest, with each type providing different physical habitats, topology, niches, microclimates, and food sources for a diverse assemblage of animals. Mangroves have important structural properties including: the trapping and stabilization of intertidal sediments; the formation of organic soils and mucks; providing protection from wave and wind erosion; providing a dendritic vegetative reef surface in the subtidal and intertidal zones; and forming a structural complex of a multi-branched forest with a wide variety of surface habitats (Savage 1972).

Mangrove associates include up to 30 species of vascular plants occurring in transitional areas with mangroves, but are not restricted to mangrove communities. Several saltmarsh grasses (*Juncus*, *Sporobolus*, *Monanthachloe, and Distichlis*) and succulent herbs (*Salicornia*, *Sesuvium*, *and Batis*) occur with mangroves along transition zones of saline marshes. Smooth cordgrass (*Spartina alterniflora*) communities often colonize bare emergent areas near mangrove forests, but are eventually displaced by mangroves shading them.

Mangrove ecosystems are important habitat for at least 1,300 species of animals including 628 species of mammals, birds, reptiles, fish, and amphibians. They provide areas for breeding, nesting, foraging, and shelter (Odum *et al.* 1982, Beever 1989, Beever 1996, Day *et al.* 1989, Odum and McIvor 1990). The mangrove forest provides a multitude of habitats for resident, seasonal, and transient organisms from adjacent terrestrial and marine habitats. Many of the larger motile species are not restricted to mangroves, but are seasonal or opportunistic visitors. However, most invertebrate and some resident vertebrate species are totally dependent upon mangroves to survive and complete important life cycle functions (Tomlinson1986). Fish and invertebrates from the marine environment are frequent visitors to mangrove communities, as are birds and mammals from nearby terrestrial systems.

The prop roots of red mangroves support a specific microhabitat for resident species (*e.g.*, tunicates, crustaceans, mollusks, fishes) that spend their entire life cycle either on or among the root systems. Transient species are not dependent upon prop roots, but use them intermittently for shelter, feeding, and/or breeding. The prop root system also provides an important nursery for organisms (*e.g.*, crustaceans, mollusks, fishes) that develop here and spend their adult lives elsewhere (Odum and McIvor 1990).

Mangrove canopies provide habitat for some species of songbirds that occur only in this habitat type, such as the black-whiskered vireo (*Vireo altiloquus*), mangrove cuckoo (*Coccoyzus minor*), yellow warbler (*Dendroica petechia*), and Florida prairie warbler (*D. discolor*). The black-whiskered vireo nests primarily in red mangroves up to 5 m (15 ft) above the ground. Considered a rare bird species by the Florida Committee on Rare and Endangered Plants and Animals (FCREPA), the mangrove cuckoo requires large expanses of undisturbed forested mangrove and hardwood hammock habitat found primarily in the southernmost parts of Florida, from Charlotte Harbor to the Florida Keys (Smith 1996). The mangrove cuckoo nests on horizontal branches of mature mangrove trees. The yellow and Florida prairie warblers nest 3 to 6 m (10 to 20 ft) high in mangroves.

In addition to these mangrove endemic species, many estuarine birds utilize fringing mangrove forest as loafing areas and foraging perches. Included in this group are osprey (*Pandion haliaetus*), northern harrier (*Circus cyaneus*), sharp-shinned hawk (*Accipiter striatus*), Cooper’s hawk (*Accipiter cooperii*), red-shouldered hawk (*Buteo lineatus*), broad-winged hawk (*Buteo platypterus*), short-tailed hawk (*Buteo brachyurus*), red-tailed hawk (*Buteo jamaicensis*), American kestrel (*Falco sparverius*), peregrine falcon (*Falco peregrinus tundrius*), bald eagle (*Haliaeetus leucocephalus*), merlin (*Falco columbarius*), kingfisher (*Megaceryle alcyon*), eastern brown pelican (*Pelecanus occidentalis*), double-crested cormorant (*Phalacrocorax auritus*), anhinga (*Anhinga anhinga*), and a variety of wading birds. As loafing areas, this habitat provides resting areas near their food supplies. This allows the use of foraging habitat distant from nighttime roosts or nesting areas without the added energy cost of flight. For other species in this group, the height of the mangroves offers a better view of prey. This area is also an important foraging area during periods of low water because organisms become concentrated in small pools of water, making it easy for predators to capture prey. Juvenile endangered wood storks (*Mycteria americana)* are especially dependent on these conditions.

Twenty-four taxa of reptiles utilize the aquatic and arboreal habitats of the mangroves. Resident species include the mangrove water snake (*Nerodia fasciata compressicauda*), the threatened Atlantic salt marsh snake (*Nerodia fasciata taeniata*), rough green snake (*Opheodrys aestivus*), the threatened eastern indigo snake (*Drymarchon corais couperi*), yellow rat snake (*Elaphe obsoleta quadrivittata*), green anole (*Anolis carolinensis*), mangrove terrapin (*Malaclemys terrapin rhizophorarum*), American alligator (*Alligator mississippiensis*), and the endangered American crocodile (*Crocodylus acutus*). The threatened loggerhead sea turtle (*Caretta caretta*) and the endangered green sea turtle

(*Chelonia mydas*) are found in association with mangrove-lined shorelines along tidal passes and within estuarine embayments.

Five amphibian species utilize the mangrove habitat for feeding and/or breeding. The most frequently encountered and abundant amphibians are treefrogs (*Hyla* spp.) and, unfortunately, the exotic marine toad (*Bufo marinus*). No state listed amphibians are found in mangrove habitats. The amphibian life cycle is poorly adapted to the saline environment required by mangroves.

The value of the red mangrove as the basis of the detrital food chain of estuarine waters is well documented (Odum *et al.* 1982, Seaman 1985, Hutchings and Saenger 1987). It is recognized that over 90 percent of commercial fishery species and at least 70 percent of sport fishery species depend upon the natural mangrove forest for food and habitat as a critical part of their life cycles (Lewis *et al.* 1985). In concert with seagrass beds, macrophytic algae, phytoplankton, benthic microalgae, and emergent marshes, the mangroves provide the primary productive food base of the estuarine system. The detritus provided by decomposition of seasonally shed mangrove leaves is the food base for microcrustaceans and other detrital processors that are consumed by macrocrustaceans, small fishes, and other first order predators. These animals, in turn, are the prey of larger fish species such as snooks (*Centropomus* spp.), snappers (*Lutjanus* spp.), jacks (*Caranx* spp.), tarpon (*Megalops atlantica*), sheepshead (*Archosargus probatocephalus*), spotted seatrout (*Cynoscion nebulosus*), and redfish (*Sciaenops ocellatus*). Based on surveys performed during the preparation of the Charlotte Harbor Aquatic Preserve Management Plan, at least 230 species of fish utilize the mangrove ecosystem of Charlotte Harbor for food, shelter, breeding and/or nursery grounds (Beever 1988).

The dominant fish species of the basin mangrove forests are poeciliids, mosquitofish (*Gambusia* spp.), the least killifish (*Heterandria formosa*), and the sailfin molly (*Mollienesia latipinna*). These cyprinodont fish are a fundamental link between primary producers and higher trophic level fish and wildlife species. The typical cyprinodont diet consists of plant and animal tissue, including periphyton, insect larvae, and vascular plant detritus. They subsequently are food for sport fish and wading bird species. Fourteen of the 54 freshwater fish species found in south Florida (Kushlan and Lodge 1974) utilize the mangrove wetlands during the wet season, high-runoff flow events (Odum *et al.* 1982).

Most of the 350 species of marine invertebrates in Charlotte Harbor are found in or depend on mangroves for habitat or food. The arboreal canopy provides habitat to both aquatic and amphibious resident and transient species (Simberloff and Wilson 1969, Beever *et al.* 1979, Odum and McIvor 1990). Approximately 264 species of arboreal arthropods inhabit the mangrove canopy, branches, and wood (Beever *et al.* 1979). Aquatic organisms, such as crabs and snails, spend part of their time in the water, but can also migrate up into the canopy of mangroves.

The mangrove tree crab (*Aratus pisonii*) is found only in estuarine areas from the Indian River Lagoon and Tampa Bay south to the Florida Keys (Gore1994a). This species is restricted to mangroves for its adult life cycle, especially red mangroves. It is one of the few crabs that also use the arboreal canopy and can climb to the uppermost branches which it forages upon (Beever *et al.* 1979). The mangrove crab (*Goniopsis cruentata*) is restricted to mangrove forests in central and southern Florida mangrove areas (Gore1994b).

Landward from the shoreline, the mangrove forest intermixes with saltmarsh species and provides habitat to organisms that can withstand changing water levels. As water levels change with daily tides and seasonal influences, the organisms here migrate to adjacent permanent aquatic habitats.

Further inland, the mangrove forest mixes with tropical hardwood hammock species. Organisms rely on the arboreal and terrestrial components of this transition community. Commonly associated hardwood species include cabbage palms (*Sabal palmetto*), Jamaica dogwood (*Piscidia piscipula*), West Indian mahogany (*Swietenia mahogani*), stopper (*Myrtus verrucosa*), poisonwood (*Metopium toxiferum*), black bead (*Pithecellobium keyense*), and gumbo limbo (*Bursera simaruba*) (Schomer and Drew 1982). The transition between these two adjacent communities provides an important ecotone, where species can take advantage of resources from both communities. Mammals and reptiles move from the hardwood forests to feed in the mangrove community.

Creek Wetlands

The low tidal creek reaches display a mixture of mangrove and saltmarsh vegetation. Further upstream the less saline mixture of upland watershed drainage with bay waters provides a euryhaline zone which can support up to 29 species of halophytic plants. In this ecotone between mangroves/salt marsh and the freshwater wetlands, the dominant plant species change in response to seasonal variations in salinity, water volume, air and water temperature, nutrient loading, and grazing pressures. Diversion of fresh water by unnatural water control projects and activities shifts plant species composition in favor of more salt tolerant plants.

The gross productivity of riverine wetlands increases when surface freshwater input increases, however net production decreases because of osmoregulatory stress: thus productivity is optimal at medial salinity. In these moderate to low salinity waters, a wide variety of plant communities can develop, depending on sediment, elevation, and season.

Widgeon grass, a submerged grass tolerant of wide salinity changes, vegetates sandy shallow channels, providing habitat for fishes and invertebrates in similar fashion to seagrasses. Creek banks support a variety of emergents, including three-squares (*Scirpus* *spp.*), bulrushes (*Scirpus spp.*), fringerushes (*Fimbristylis spp.*), *Juncus* rushes, spikerushes (*Eleocharis spp.*), cattails (*Typha spp.*), giant reed (*Arundo donax*), leather fern, saltgrass, knotgrass (*Paspalum distichum*), cordgrasses, asters (*Aster spp.*), pinks (*Sabatia spp.*), coast water hyssop (*Bacopa spp.*), and many of the salt marsh herbs.

The health of the estuary depends upon the health of its tributaries. If the riverine wetlands are destroyed, the creeks channelized, and the water quality degraded in the watershed external of the below the tide boundaries of water bodies, it will not be possible for those water bodies to retain fishery and wildlife habitat values.

Coastal Zonation

The standard zonation of southwest Florida consists of red mangroves in the lower and middle intertidal zone, black mangroves in the upper intertidal areas that are occasionally flooded and white mangroves in patches on higher elevations that is less frequently flooded. Buttonwoods are located further inland in areas that are within the limits of the highest tides (Tomlinson 1986).

Mangrove forests are different than other vegetative communities in that there is an absence of traditional plant succession. Instead, mangrove communities experience replacement succession primarily as a function of sea level rise, where mangroves must either keep up with the rise in sea level or retreat from rising water levels. On shorter time scales, the mangrove community can experience fluctuations in habitat type and species composition as a result of changes in such factors as hydrologic patterns. A typical zonation with adjacent uplands is shown in Figure 35.

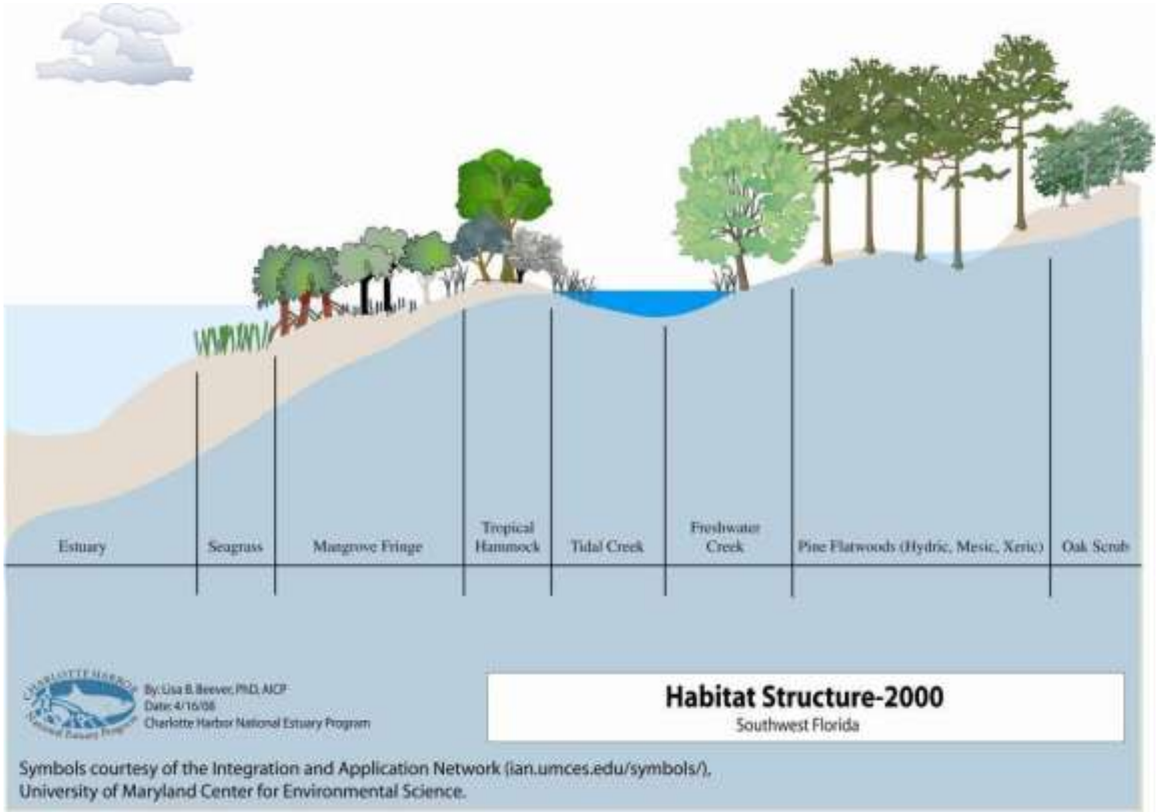


Figure 35: Typical coastal habitat zonation for Southwest Florida, Year 2000

Potential Future Climate Changes

Climate-related changes in freshwater runoff to coastal marine systems, coupled with changes in stratification (or layering) patterns linked to warming and altered salinity, will change the quantity and availability of nutrients in estuarine systems (Boyd and Doney 2002). Changes in the absolute and relative availability of nutrients will lead to changes in microscopic plants (phytoplankton) and microbial activity in the marine food web (Arrigo 2005). Induced changes may result in food webs that are less efficient in transferring energy to higher levels, thus affecting the productivity of economically important fish and other plant and animal life (Arrigo 2005).

Increased runoff in some areas, coupled with human population increases in Florida, will lead to the increased transport of nutrients to coastal waters, contributing to hypoxia (IPPC 2007b) and leading to adverse impacts on bottom-feeding fish and sessile (attached to the bottom) organisms (IPPC 2007b). Locations that have experienced hypoxia may experience longer hypoxic episodes or more frequent recurrence of hypoxia (Osterman et al. 2007). Increased density stratification within estuaries could also occur with increased precipitation and runoff. New locations with hypoxia may develop in coastal areas where they previously have not appeared (Osterman et al. 2007).

As sea-surface temperatures continue to rise, die-offs of marine fauna incapable of moving to cooler water are likely to become more frequent. Other factors, such as low levels of dissolved oxygen, the addition of nutrients and other land-based sources of pollution, and harmful algal blooms, will exacerbate these die-offs. The conditions that have contributed to fish diseases and various die-offs in the Florida Keys may move to more northern latitudes. As sea-surface temperatures continue to increase, the impacts may begin to affect more northerly coastal and marine environments that have thus far escaped these problems (FOCC 2009).

Marine thermal stratification will change dissolved oxygen levels at different water depths. This will result in changes to zonation for animal and plant life and increase the probability of fish and other marine life kills (Coastal States Organization Climate Change Work Group 2007; Holman 2008; FOCC 2009; USEPA CRE 2008)

The range of potential impacts on species and ecosystems include the following:

Corals and Calcifying Organisms

Increased atmospheric concentrations of carbon dioxide are expected to contribute to increased acidity (lower pH) of sea water. Marine organisms with calcium carbonate shells or skeletons, such as corals, clams, and plankton at the base of the food chain may be adversely affected by decreases in pH and carbonate saturation state (IPPC 2007b; Bates 2007). A higher carbonate saturation state favors the precipitation of calcium carbonate, a mineral, while a lower state supports its dissolution into the water.

Carbonate-depositing organisms will have to expend more energy to maintain shell construction and structural integrity in a lower pH environment (Peterson et al. 2007; SCCP 2008; FOCC 2009; USEPA CRE 2008).

With decreases in the pH of seawater, some marine plants may show increases in production until a particular threshold is met, and then will show a decline (FOCC 2009). Some marine organisms will not be able to tolerate decreases in pH (FOCC 2009). It is probable that the die-offs of sponges, seagrasses, and other important components of coastal and marine ecosystems from increased sea surface temperatures will become more frequent (FOCC 2009; USEPA CRE 2008). Ocean acidification may lead to shifts in marine ecosystem structure and dynamics that can alter the biological production and export from the ocean surface of organic carbon and calcium carbonate (Royal Society 2005). Important fisheries habitats, such as coral reefs, will markedly decline or disappear (Kleypas ET al.2006; Ishimatsu et. al. 2005).

The thermal tolerance limits of some coral species will be surpassed. The rates of sea-surface temperature change predicted by global climate models suggest that coral bleaching events will be more frequent and severe in the future (Wilkinson and Souter 2008; FOCC 2009; Ramsar 2002; USEPA CRE 2008). Current predictions of future coral bleaching events indicate that certain coral species will not be able to adapt to warmer water (Wilkinson and Souter 2008). Coral reef community structure will shift towards coral species with a higher tolerance of changing conditions, resulting in major shifts in coral reef communities and a decrease of biodiversity (FOCC 2009).

The geographic range of marine species, including corals, will shift northward as sea-surface temperatures continue to rise. The species composition of Florida’s native marine and estuarine communities will change, perhaps drastically. With further rises in water and atmospheric temperatures, conditions will probably become more favorable for certain exotic plant and animal species to invade Florida’s coastal waters (FOCC 2009). Some native species may be able to survive farther north than in current ranges, but interactions among communities with new species compositions cannot be predicted. Moreover, reproduction in some fishes decreases in warmer temperatures, potentially resulting in population decreases (Straile and Stenseth 2007).

Increased numbers and altered ranges of jellyfish are also expected with some invasion of exotic jellyfish species, and with increased predation on local prey species. Some highly vulnerable prey species may be significantly affected (Perry and Yeager 2006; FOCC 2009; USEPA CRE 2008).

Seagrass

Sea level rise is expected to cause migration of seagrass beds landward with subsequent depletion of existing beds at the deeper waterward edges due to less penetration of sunlight. This coupled with increased turbidity from erosion and breakup of coastlines, increased storm season runoff, and human activities will likely lead to die-off at deeper edges. Where natural shoreline exists, seagrass beds are expected to migrate into appropriate depths. Where opportunities for landward migration of the shallow subtidal zone is blocked by human bulkheads or other barriers, the seagrass beds will be reduced and then disappear if the water depths at the sea wall barriers exceeds the light extinction coefficient for the seagrasses (USCCSP 2008; USEPA CRE 2008).

Algae

Harmful blooms are caused by microscopic algae in the water column that can produce biological toxins, such as those generated by red tide in coastal marine waters, blue-green algae in estuarine waters., Larger species of marine and estuarine algae that grow on the bottom can smother corals and other native plants and animals. Environmental factors, including light, temperature, and nutrient availability, set the upper limit to the buildup of biomass in marine algae (Smyda 1997). The algae that cause harmful blooms in coastal marine and estuarine waters are favored over other algal species when water temperature is high and becomes thermally stratified (Paerl and Huisman 2008, Peperzak 2005, Van Dolah 2000; FOCC 2009; Twilley et al.2001; Coastal States Organization Climate Change Work Group 2007; Holman 2008; USEPA Office of Policy, Planning and Evaluation 1997; USEPA CRE 2008). The increased occurrence, intensity, and toxicity of harmful algal blooms may result in the disruption of coastal marine and estuarine food webs, more frequent fish kills, and adverse impacts to people in or near an affected coastal area (Smyda 1997; Paerl and Huisman 2008; Van Dolah 2000). Harmful algal blooms have been reported throughout Florida's coastal marine and estuarine waters (Carder and Steward 1985).

If climate change systematically increases nutrient availability and this alters the amount of available light and the stability of the water column, there may be substantive changes in the productivity, composition, and biomass of marine algae, including harmful species (Smetacek and Cloern 2008).

Coastal Wetlands

Although southwest Florida tide ranges are relatively small, tidal effects extend far inland because much of the state is so low in relative elevation and flat in topography. Because sea level change has been relatively constant and slow for a long time, tidal wetlands such as mangrove forests and salt marshes have been able to grow into expansive habitats for estuarine and marine life. However, these tidal wetlands are sensitive to the rate of sea level rise and can perish if that rate exceeds their capacity to adapt. With rising sea levels, sandbars and shoals, estuarine beaches, salt flats, and coastal forests will be altered, and changes in freshwater inflow from tidal rivers will affect salinity regimes in estuaries as well as patterns of animal use. Major redistributions of mainland and barrier island sediments may have compensatory or larger benefits for wetland, seagrass, or fish and wildlife communities, but these processes cannot be forecast with existing models.

Sea level change is an important long-term influence on all mangroves and salt marshes (Gilman et al. 2008). Based on available evidence, of all the climate change outcomes, relative sea level rise may be the greatest threat to mangroves. Most mangrove sediment surface elevations are not keeping pace with sea level rise, although longer term studies from a larger number of regions are needed. Rising sea level will have the greatest impact on mangroves experiencing net lowering in sediment elevation, where there is limited area for landward migration.

Depending on the rate and extent of local sea level change, mangrove and salt marsh systems will respond differently (Titus 1998, Wanless et al.1994). If rates of sea level rise are slow, some mangrove salt marsh vegetation will migrate upward and inland and grow without much change in composition. If rates are too high, the salt marsh may be overgrown by other species, particularly mangroves, or converted to open bodies of water. If there is no accretion of inorganic sediment or peat, the seaward portions of the salt marsh become flooded so that marsh grass drowns and marsh soils erode; portions of the high marsh become low marsh; and adjacent upland areas are flooded at spring tide, becoming high marsh.

Don Cahoon of the USGS has stated that if wetland plant communities are unable to keep vertical pace with sea level rise they will likely to also be unable to keep pace with lateral migration upslope. This can occur because on some soil types when saltwater inundates formerly unsubmerged uplands, sulfate reduction reactions can cause the land to sink up to six inches in micro-tidal areas that then shift from nontidal wetlands directly to open subtidal waters. (Titus 2009). This would be mediated by fetch and wave action as well as the emergent vegetation that is present, since both red mangroves and cordgrass can colonize low energy intertidal zones.

Extirpation of cooler water temperate fishes that seasonally visit the Charlotte Harbor estuaries and alteration of reproductive rates and maturation in invertebrate species leading to declining populations can be expected from increases in global surface water temperatures (USEPA CRE 2008; Rubinoff et al. 2008; Holman 2008; USNOAA 2008).

There will be changes associated with inundation of coastal wetlands and marshes including altered tidal ranges, tidal asymmetry leading to changes in tidal mixing, changes in sediment transport, migration of estuarine salinity gradients inland, migration inland of marsh species zonation, altered diversity of foundation dominant plant species, structural and functional habitat changes, and less sunlight available to submerged marsh plants (USEPA CRE 2008;USNOAA 2008; Titus 1998; Bollman 2007; Volk 2008a).

Higher maximum temperatures, with more hot days and heat waves over nearly all land areas will negatively affect wetlands and freshwater bodies. Fish and wildlife will experience increased heat stress, with increased mortality. Many invasive tropical species are likely to extend their ranges northward. Native plants and animals, already stressed and greatly reduced in their ranges, could be put at further risk by warmer temperatures and reduced availability of freshwater (Twilley et al.2001; USEPA CRE 2008).

Changes in precipitation will affect different wetlands differently with regional increases or decreases depending on the type and landscape position. Local extirpations of fish, amphibians, or water-dispersed plants are expected due to drought conditions that isolate and dry down tributaries and connected wetlands (USEPA CRE 2008; Holman 2008; FOCC 2009).

As rising sea temperatures causes a 5 to 10% increase in hurricane wind speeds, storm events will result in increased beach erosion and losses of mangroves, marshes, and other wildlife habitats (USCCSP 2008; USNOAA 2008; USEPA CRE 2008). With sea level rise there will be an increased inundation of low marsh dominated by *Spartina* and *Juncus.* Subsequently there will be a migration up-gradient and inland of low marsh habitat into the high marsh areas with a resultant expansion of low marsh and a depletion of high marsh if high marsh does not have adjacent native upland to migrate into (USCCSP 2008; USEPA CRE 2008). More frequent or longer lasting droughts and reduced freshwater inflows could increase the incidence of extreme salt concentrations in coastal ecosystems, resulting in a decline of valuable habitats such as the mangroves and seagrasses (Twilley et al. 2001).

Beach nourishment, or the addition of sand to an eroded beach, may be utilized as a mitigation factor to protect shorelines and human infrastructure. However, it disturbs indigenous biota living on and in the beach, and disrupts species that use the beach for nesting, nursing, and breeding. Wetlands elsewhere are perishing as estuarine and coastal forests and swamps are retreating and being replaced by marsh vegetation (Williams et al. 1999; Raabe et al. 2004; Desantis et al. 2007). Open estuarine waters, some brackish marshes, and mangroves in south Florida estuaries are expanding (Glick and Clough 2006; Hine and Belknap 1986). Even at constant rates of sea level rise, some tidal wetlands will eventually be “pinched out” where their upslope migration is prevented by upland defenses such as seawalls (Estevez 1988; Schleupner 2008).

Up-gradient wetland and upland habitats

Climate change is predicted to be one of the greatest drivers of ecological change in the coming century. Increases in temperature over the last century have clearly been linked to shifts in species distributions (Parmesan 2006). Given the magnitude of projected future climatic changes, Lawler et al. (2009) expects even larger range shifts over the next 100 years. These changes will, in turn, alter ecological communities and the functioning of ecosystems. Despite the seriousness of predicted climate change, the uncertainty in climate-change projections makes it difficult for conservation managers and planners to proactively respond to climate stresses. To address one aspect of this uncertainty, Lawler et al. (2009) identified predictions of faunal change for which a high level of consensus was exhibited by different climate models. Specifically, they assessed the potential effects of 30 coupled atmosphere-ocean general circulational model (AOGCM) future-climate simulations on the geographic ranges of 2,954 species of birds, mammals and amphibians in the Western Hemisphere. Eighty percent of the climate projections based on a relatively low greenhouse-gas emissions scenario result in the local loss of at least 10% of the vertebrate fauna over much of North America. The largest changes in fauna are not predicted for Florida.

Southwest Florida has national treasures in the Big Cypress Swamp, the Corkscrew Regional Ecosystem Watershed (CREW), and the barrier island chain (Stanton and Ackerman 2007). These three ecosystems are interlinked and have a common history. The Big Cypress Swamp is part of the broad, shallow sheet flow river moving fresh water south into Florida Bay. The CREW is the northernmost extent of the greater Big Cypress Swamp with major strands of cypress that form headwaters for Estero Bay, coastal Collier County estuaries, and the Picayune and Fakahatchee Strands. The barrier islands mark the last outposts of the tropical hardwood hammocks. Once hummocks of higher vegetation set in a prehistoric swamp, they have struggled against the rising sea. Mangroves on their perimeters collect silt and organic material, building a barricade secure against all but the most severe hurricane winds and tides.

Already stressed by water diversions, invading species of plants and animals, and the natural phenomena of drought, flood, and storms, these ecosystems will be stressed further by climate change. A 20-inch sea level rise would cause large losses of mangroves in southwest Florida. Increased salinity, resulting from saltwater rising into the Everglades from Florida Bay, would also damage freshwater slough ecosystems. Communities of wet prairie would also decline with the rise in sea level. Climatic conditions in central Florida may become suitable for subtropical species such as the gumbo-limbo tree, now confined to subtropical hummocks in the southern part of the peninsula and the Keys. Theoretically, such species could move as far north as Gainesville and Jacksonville, but agricultural and urban development could preclude such migration (USEPA OPPE 1997).

Upland plant communities along tidal rivers and estuaries will be replaced by low-lying, flood-prone lands. Changes in soil moisture could shift forest dynamics and composition. For instance, natural pine forests can tolerate lower soil moisture than oak-pine forests (Twilley et al. 2001). Extensive open grassland and forest areas in South Florida could become more vulnerable to damaging invasion by exotic species such as Chinese tallow, *Melaleuca* and *Casuarina* trees (Twilley et al. 2001). Increased saline flooding will strip adjacent upland soils of their organic content (Williams et al 1999; Raabe et al. 2007).

Increased air temperatures affecting wetland hydrology will alter salinity gradients. Subsequently there will be altered species distributions associated with salinity and the timing, depth, and duration of inundation. Species interactions will be altered and metabolic activity decreased with drought. Many species will experience increased risk of disease and parasitism. Changes in drought and salinity will open niches for invasive species (USEPA CRE 2008; Holman 2008; FOCC 2009, Peterson et al. 2007; Lee County Visitor and Convention Bureau 2008).

Climate changes such as warmer temperatures, fewer freezes, and changes in rainfall or storm frequency will tend to shift the ranges of plant and animals species and alter the makeup of biological communities (Twilley et al. 2001). Populations of amphibians, reptiles, birds and mammals may have major faunal shifts including elimination from current range, reduction in range, shift to alternate ranges, overuse of new ranges, and isolation or prevention from coastal or temperature retreat due to barriers to new ranges from land use changes and flooding (Lawler et al. 2009)

Listed species that are already endangered such as the Cape Sable seaside sparrow and Florida panther could become more vulnerable as their preferred habitats change or shift with global warming. Current water management practices and human development create additional challenges for species migration and adaptation (Twilley et al. 2001).

Shifts in behavior phenology of perching birds, seabirds, and farmland birds have been observed and are expected to continue. Perching birds will breed earlier in the calendar year. Seabird populations are expected to decline due to reduction in needed prey items at the right locations at the right time of the year. Farmland birds are expected to decline due to reduced food items being available at breeding time. This disjuncture between the breeding season and vital food or other resources availability is termed “mismatching” (Eaton et al. 2008; USEPA CRE 2008).

Climate change will affect the phenology of pest and beneficial insects by altering reproductive cycles, feeding and predation, and mismatching with host plants and pollinators (Backlund et al. 2008). For example, moth phenology will be shifted to earlier dates. This will affect birds and other animals that depend upon the moths for food, the host plant vegetation that moth larvae feed on, and the plants that depend upon the moths for pollination (Eaton et al. 2008; USEPA CRE 2008). There will be both positive and negative outcomes depending upon the phenological sequence and nature of the participants. In any case significant change could be expected.

Air temperature increases will affect soil temperatures in uplands and other areas where reptiles nest. The increased soil temperatures may affect nesting lizards, changing hatchling gender determination, fitness, and hatch date, which may expose hatchlings to different prey availability and predation potentials (Telemeco 2009). Amphibian populations' ranges, health, and phenology will also be affected (Backlund et al. 2008; FOCC 2009; USEPA CRE 2008). Increased air temperatures will also affect animal health, resulting in reduced feeding; reduced reproduction; reduced milk production (in mammals) for offspring; and increased pathogens and parasites (Backlund et al. 2008).

In freshwater streams, warmer water temperatures and a longer growing season could reduce habitat for cooler-water species, particularly fish, insects, snails, and shellfish. In very shallow water systems, higher temperatures could lead to oxygen depletion and cause potentially massive die-offs of fish and invertebrates (Twilley et al. 2001).

The altered timing of seasonal temperature changes is expected to disrupt predator/prey availability, food and reproductive cycles, patterns of upstream faunal migration, disruption of temperature-driven behavior including breeding and hibernation, and disruption of biological ocean-estuary exchanges of fishes and invertebrates (Peterson et al. 2007). Events occurring in spring or summer may occur later or have a longer "window". Events occurring in fall or winter may occur later or have a smaller "window". Events dependent on seasonal rainfall may occur differently with changes in rainfall patterns. Some animal and plant populations may migrate northward or inland to conditions supporting their required limiting life/reproductive cycles. There may be local extirpation of some plant and animal populations with replacement by exotic species tolerant of/or advantaged by the new climate conditions.

Increases in precipitation of five to 10% over levels of the 20th century, including more heavy and extreme precipitation events will result in increased flash flooding, affecting ground-dwelling species (UWCES 2007; USNOAA 2008; SECCP SDRT LCCP 2005, FOCC 2009, USEPA CRE 2008).

Habitat Migration

Conceptual diagrams are a technique developed by the University of Maryland Center for Environmental Science Integration and Application Network (IAN) to communicate science. The technique uses Adobe Illustrator and symbol libraries designed to communicate to an international audience. This conceptual diagramming technique was used to illustrate application of several principals of climate change as they related to southwest Florida native ecosystems.

"Figure 36: Habitat Structure 2000 Southwest Florida" is a conceptual diagram that identifies a typical cross-section of southwest Florida native ecosystems from the estuary to the high oak scrub. Such habitats include the estuary, seagrass, mangrove, tropical hardwood hammock, tidal and freshwater creeks, pine flatwoods, and oak scrub.

Several climate change processes were applied to the typical cross-section to observe potential impacts to create "Figure 37: Habitat Structure 2200 Southwest Florida". The processes include:

- Sea level rise
- Increasing water temperature
- Geomorphic changes related to
  - movement of the shoreline to maintain the coastal energy gradient, and
  - sediment accretion by mangroves

Effects of these processes include:

- Landward migration of the Gulf of Mexico,
- increasing evapotranspiration,
- changes in rainfall patterns,
- movement of tidal creeks up into the freshwater creek systems,
- water table changes as a result of sea level rise, shoreline movements, rainfall changes, and mangrove sediment accretion,
- compression of freshwater wetland and upland systems,
- compression of estuarine areas, and
- loss of suitable seagrass areas.

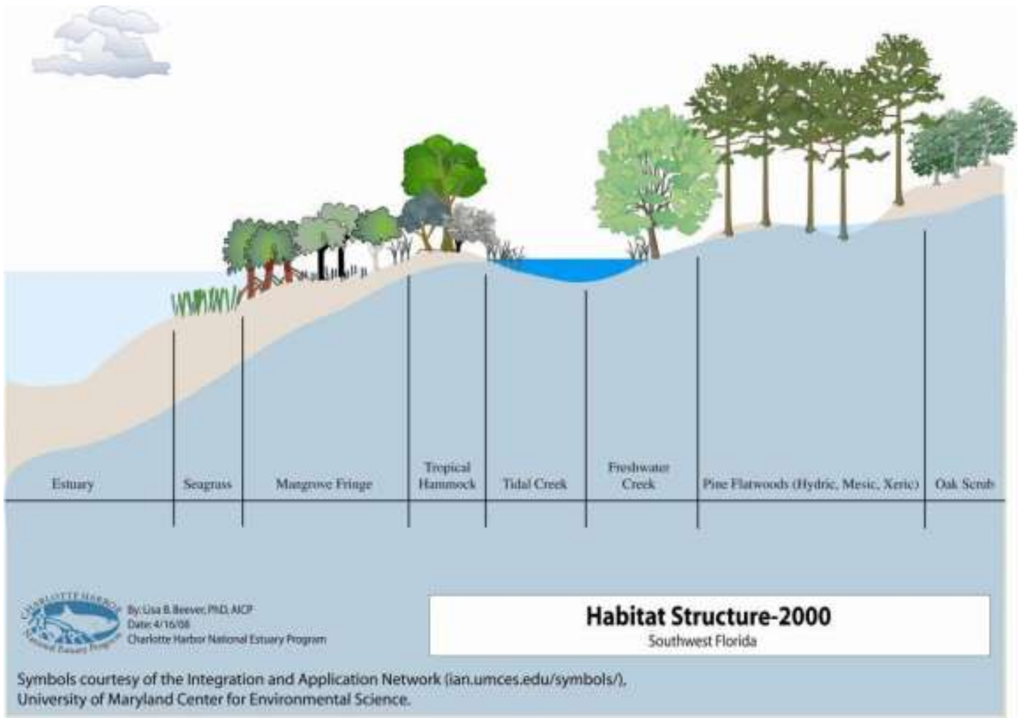


Figure 36: Habitat Structure 2000 Southwest Florida

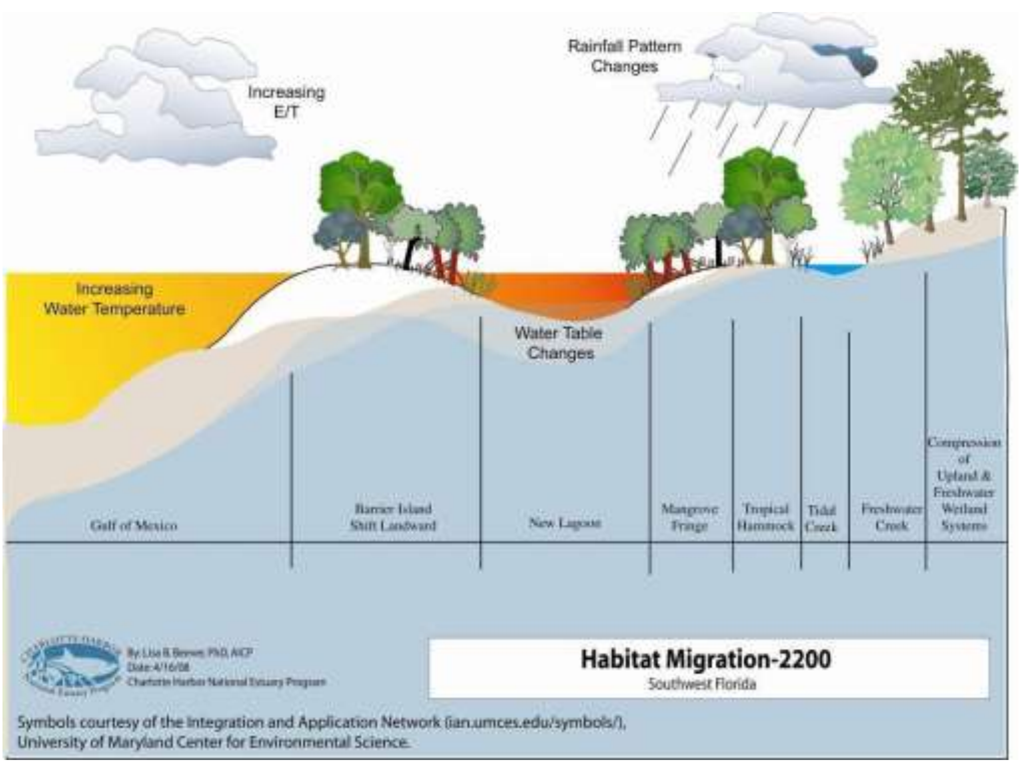


Figure 37: Habitat Structure 2200 Southwest Florida

III. The structures, grounds, and infrastructure from trees that are most susceptible to wet soils and high winds

The vegetation of Pelican Cove reflects a canopy that is composed of an original coastal oak hammock uplands flanked by a mangrove shoreline that has been invaded by the typical invasive exotics that move into disturbed areas and then landscaped intentionally as a form of botanical garden with a wide diversity of non-native species disperse among the residential and common areas. There are 82 species of trees at Pelican Cove at this time. There are 29 (35.37 %) native tree species on-site with oaks and cabbage palm the most common. There are 52 (63.41%) species of non-native tree species.

Twenty-one tree species have the highest wind resistance. Seventeen of the trees with the best wind resistance are natives, Of the non-native trees with high wind resistance all are palms naturally adapted to high winds of their original home environment.
Fourteen tree species have medium wind resistance, 30 species have medium to low wind resistance, and 17 have low wind resistance. Only 2 of the species with the lowest wind resistance are native, the red cedar and laurel oak. The other 15 include some of the worst invasive plant exotics in Florida including Australian pine, melaleuca, and carrotwood

The vegetation understory is principally exotic species ranging from sod grasses to typical nursery landscaping species like hibiscus and periwinkles and several invasive exotic species including Brazilian pepper, wedelia, and exotic ferns as well as some toxic species like cats-eye and Devil's trumpet.

There are pockets of coastal hammock shrubs with sea grape, inkberry, sea ox-eye daisey, silver buttonwood, and palmettos found shoreward of the mangrove fringes in the Bayhouse and lower Clower Creek areas.

The trees with low and medium to low wind resistance are potential dangers to buildings, property and human safety form wind through branch break and utility damages. Some are allopathic and prevent species other than their offspring from living or sprouting in their vicinity.
Hurricane-force winds can be extremely damaging to communities and urban forests. Without question, trees can become hazardous and pose risks to personal safety and property. As destructive as these storms are, it is important not to forget that trees provide many environmental benefits, such as providing shade and energy conservation, reducing the well-known “heat island” effect in cities caused by concrete and pavement, and increasing property values. Also, there are opportunities to better prepare for the next hurricane season by rebuilding a healthy urban forest. Valuable lessons can be learned from knowing more about how, when and why trees fail in storms. A key issue facing communities is how to manage the urban forest from an ecological standpoint so urban forests are healthier and more wind-resistant. A healthy urban forest is composed of trees

that maximize ecosystem benefits while being able to withstand natural and anthropogenic stresses and disturbances, such as wind from hurricanes and tropical storms, flooding, pollution, etc.

I

Hurricanes Ivan and Jeanne, research showed that trees growing in groups survived the winds better than individual trees (80% versus 70% in Hurricane Ivan, and 88% versus 78% in Hurricane Jeanne.) A group was defined as five or more trees, each growing within 10 feet of another tree, but not in a row. Research has also shown that the more rooting space trees have, the less likely they are to fail. Only if they have adequate soil space can trees develop a strong supporting root system.

In measurements of trees after ten hurricanes, show that some tree species are more resistant to wind than others (IFAS 2016). Wind resistance is defined as the ability or capacity of a tree to survive (remain standing and living) hurricane-force winds, which means that they do not easily uproot or break in the winds. One of the main objectives of this study was to develop lists of wind-resistant tree species. To complement the findings a survey of arborists, scientists and urban foresters ranked wind resistance of urban tree species they observed after hurricanes. The rankings were used with the field data collected and the available scientific literature to classify broad-leaved, conifer, palm, and fruit tree species into highest, medium-high, medium-low and lowest wind resistance. When comparing survival of sand live oak, live oak, and laurel oak in four panhandle Florida hurricanes(Erin, Dennis, Opal and Ivan), laurel oak had poorer overall survival than both live oak and sand live oak(Duryea *et al*. 2007).However, in two South Florida hurricanes (Jeanne and Charley), both survival and branch loss for these oaks were similar. Speculations about the reasons for this lack of difference include: (1) Laurel oak in South Florida may be a different cultivar or variety than those in North Florida and (2) Sandier soils in South Florida and their accompanying lower site quality may result in laurel oaks with shorter heights or lower height-to-diameter ratio (as occurs between the North Florida and South Florida varieties of slash pine (*Pinus elliottii* var. *elliottii* and var. *densa*). Still, many authors point to live oak as a tree with strong wood and little failure in hurricanes (Touliatos and Roth1971; Swain 1979; Hook *et al*. 1991; Barry *et al*. 1993).

When compared to broad-leaved and other conifer trees (such as pines), palms have often been observed to be more resistant to winds. Palms grow differently from other trees because they have one terminal bud. If that bud is not damaged, palms may lose all their fronds (leaves) and still survive. Our research shows that palms in the coastal plain and tropical and subtropical regions are often more resistant to winds. However, individual palm species do vary in their responses to wind like. Examples would be queen and Washington palms which have exhibited poor survival in south Florida during hurricanes.

Pines may show no immediate visible damage after hurricanes but may decline over time. In our study, IFAS measured pines looked green and healthy. However, IFAS went back three months after Hurricane Charley and found that 27% of the standing south Florida slash pines and 48% of the standing longleaf pines had died. Pines have been observed to be very sensitive to wind damage. They may show no immediate visible damage after high winds but may die sometime later. They can die slowly over a period of 6 months to 2 years after wind storms. Some may remain green for a year or more, and then suddenly turn yellow and quickly progress to brown needles in a very short period. The causes of yellowing of the needles and pine death are not completely understood. It is likely due to hidden damage produced by bending and twisting during hurricane-force winds. Prolonged winds may also rupture smaller roots without breaking the larger support roots. The injured stems and roots are unable then to supply the water and nutrients needed in the crown, resulting in pine decline and death.

Trees that lose all or some of their leaves in hurricanes are not necessarily dead. The greater the wind speed, the more leaves trees lose during hurricanes. Trees can lose all or some of their leaves in most hurricanes. However, leaf loss does not mean the tree is dead, rather it means the tree is temporarily unable to photosynthesize (produce food) and store energy. With time, the tree will produce new leaves which are a sign of recovery, since they restore the tree's ability to photosynthesize and bring the tree back to health. Some species defoliate (lose leaves) easily during winds. Losing leaves may be a good strategy, helping the tree to better resist winds. Our research in Hurricane Ivan found that trees that lost their leaves survived the winds better. Live oak (in north Florida) 13) and gumbo-limbo (in south Florida) are examples of trees which readily lose leaves and small branches and stand up well to winds.

Native tree species survived better in South Florida hurricanes (Jeanne, Andrew, and Charley). In our research, native trees survived better in south Florida hurricanes but not in north Florida (Hurricane Ivan). Native species also lost fewer branches than exotic species in Jeanne (36% versus 21%) and Charley (39% versus 36%) in south Florida. Some of the exotic species with low survival in south Florida were melaleuca, Australian pine and queen palm as compared to native species with high survival, such as live oak, gumbo limbo and sabal palm.

In tropical and subtropical areas, exotics represent a large proportion of the urban forest (for Hurricane Jeanne, exotics made up 38% of the trees in the urban forest, for Hurricane Charley, 42% and for Hurricane Andrew 64% were exotics). In the southeast coastal plains (Hurricane Ivan), exotic tree species make up 9%of the trees in the urban forest. The major exotic species were crape myrtle, Chinese tallow (a prohibited invasive species), camphor tree, (an invasive species), Bradford pear and palms such as Pindo and Washington palms. These differences in the composition of the urban forest may explain why, with fewer exotics in their population, natives did not survive better in the coastal plain during Hurricane Ivan. Native trees also survived winds better in south Florida hurricanes when compared to Puerto Rico (Hurricane Georges). Out of the 35 tree species measured in Puerto Rico, only 4 were native to the island. The lighter winds and conditions of Hurricane Georges showed no differences between native and exotic species.

Older trees are more likely to fail in hurricanes. As trees grow and age, they become more susceptible to insects and diseases, branches and parts of the tree begin to die, they become less flexible, and they may be more vulnerable to winds. Our research shows that larger and older trees lose more branches in hurricanes. Larger trees (40 to 79 inches in diameter) lost a greater percentage of their branches compared to small trees (less than 8 inches in diameter). Every tree species has an inherent life span. Some tree species live longer than others. It is important to keep in mind that risk of failure in wind increases with age. For example, the life span of laurel oak is 50years; it begins to decay and show signs of diseases as it reaches 40 years. The older a tree gets, the greater the likelihood of diseases and pathogens, breakage during winds, and the greater the risk of it causing damage when it fails.

Unhealthy trees are predisposed to damage. Old trees with decayed root systems, stem decay, or large dead branches are vulnerable to hurricanes. Decay, a major cause of tree failure, is caused by fungi that weaken wood. Cracks, seams, butt swell, dead branch stubs and large, older wounds suggest internal decay. They can be weak points on a trunk and increase the likelihood of tree failure. Mushrooms at the base of the tree trunk might also indicate root problems. They can be the sign of *Armillaria*or other fungi than can decay roots, creating unstable trees. Root rot can be diagnosed with careful, regular inspections by qualified arborists.

Trees with poor structure or included bark are more vulnerable in the wind. A tree with two or more trunks or stems of equal size originating from the same point on the tree is said to have co-dominant stems. Co-dominant stems may develop bark inclusions, which are weak unions between branches and are very susceptible to breakage. To develop strong structure, trees need to be managed with structural pruning.

Well-pruned trees survive hurricanes better than poorly pruned or unpruned trees. Poor pruning practices, such as topping or removing large branches, make trees more susceptible to wind failure. Old, large pruning cuts can become an entry point for fungi that begin the decay process .In our study of Master Gardeners after Hurricane Andrew in 1992 (Duryea *et al*. 1996), IFAS found that trees that had been pruned properly (not topped and with more open and well-distributed crowns) survived high winds better than unpruned trees. IFAS re-analyzed this data using more broad-leaved tree species—black olive, gumbo limbo, bottlebrush, royal Poinciana, live oak, West Indian mahogany, and white cedar. Survival for pruned trees was 73% compared to47% for unpruned trees, showing that overall, pruned trees are less likely to fail in hurricanes.

Trees with more rooting space survive better**.** The most important factor in designing a healthy urban landscape is also probably the one most often overlooked—that is providing enough soil space for tree roots to grow. In Hurricane Georges (Puerto Rico), IFAS measured rooting space for trees and found that with more rooting space, tree survival during winds was higher.

Soil should provide plenty of open space to allow growth of the trunk and development of the main flare roots. To provide anchorage for the tree, roots need to spread beyond the edge of the canopy and grow deep into the soil. Sidewalks, curbs, buildings, parking lots, driveways and other urban structures restrict root development. A strong supporting root system with adequate rooting space is the most critical factor to the ability of trees to withstand hurricane-force winds in urban landscapes.

Deep soil depth, a deep water table, and no compaction, help wind resistance. Trees without deep roots can become unstable and fall over in strong winds. Trees in shallow soils are more likely to blow over than trees rooted more deeply. Trees planted in compacted soil grow very poorly and are weak and unhealthy. This is especially true when the soil is poorly drained or the water table is high.

Damaged root systems make trees vulnerable in the wind. Roots anchor the tree. It is important that roots under the canopy are not cut because many roots are located just below the surface of the soil. Tree roots need to extend out from a treeing all directions in order to stabilize it against wind throw. When roots under the canopy are cut, trees are more predisposed to falling over.

Botanical Name	Common Name	Wind Resistance
Acer rubrum	Florida Red Maple	Medium-Low Wind Resistance
Acoelorrhaphe wrightii	Parrotis Palm	Medium-High Wind Resistance
Agave americana	Century Plant	Medium-High Wind Resistance
Araucaria excelsa	Norfolk Pine	Lowest Wind Resistance
Ardisia escalloruoides	Marlberry Tree	Medium-High Wind Resistance
Avicennia germinans	Black Mangrove	Highest Wind Resistance
Bambussa (spp.)	Bamboo	Medium-Low Wind Resistance to Lowest Wind Resistance
Bauhinia pinnata	Hong Kong Orchid	Medium-Low Wind Resistance
Beaucamea recurvata	Ponytail Palm	Medium-Low Wind Resistance
Bismarckia noblis	Bismarck Palm	Medium-Low Wind Resistance to Lowest Wind Resistance
Bougainvillea (spp.)	Bougainvillea	Medium-High Wind Resistance
Brassia actinophylla	Schemera	Lowest Wind Resistance
Bucida "Shady lady"	Shady Lady	Medium-Low Wind Resistance
Bursera simaruba	Gumbo Limbo	Highest Wind Resistance
Callistemon rigidus	Rigid Bottlebrush	Medium-Low Wind Resistance
Callistemon viminauis	Weeping Bottlebrush	Medium-Low Wind Resistance
Carissa macrocarpa	Natal Plum	Medium-Low Wind Resistance
Carya glabra	Hickory Nut Tree	Medium-High Wind Resistance
Caryota mitis	Fish Tail Palm	Medium-High Wind Resistance
Cassia fistula	Golden Shower Tree	Lowest Wind Resistance
Casuarina equisetifolia	Australian Pine	Lowest Wind Resistance
Chorisia speciosa	Floss-Silk Tree	Lowest Wind Resistance
Chrysalidocarpus luteseens	Areca Palm	Medium-High Wind Resistance
Chrysophyllum olivifonne	Satin Leaf Tree	Medium-High Wind

		Resistance
Cinnamomum camphora	Camphor Tree	Medium-High Wind Resistance
Citrofortunella mitis	Calamondin	Medium-Low Wind Resistance
Coccoloba uvifera	Sea Grape	Highest Wind Resistance
Cocos nucifera	Coconut Palm	Medium-High Wind Resistance
Conocarpus erectus var. sericeus	Silver Buttonwood	Highest Wind Resistance
Cupamopsis anacardioides	Carrotwood Tree	Lowest Wind Resistance
Cyeas circinalis	Queen Sago Palm	Medium-Low Wind Resistance
Dalbergia sisso	Indian Rosewood	Medium-Low Wind Resistance
Datura arborea	Angel Trumpet	Medium-Low Wind Resistance
Delonix regia	Royal Poinciana	Medium-Low Wind Resistance
Dipbolis salicfollia	Willow Bustic	Medium-High Wind Resistance
Eucalyptus torelliana	Eucalyptus Tree	Medium-Low Wind Resistance
Ficus benjamina	Weeping Fig	Lowest Wind Resistance
Ficus lyrata	Fiddle Leaf	Medium-Low Wind Resistance
Ficus reclusa	Cuban Laurel	Medium-Low Wind Resistance
Grevillea robusta	Silk Oak	Lowest Wind Resistance
Hibiscus rosa-senensis	Anderson Crepe Hibiscus	Medium-Low Wind Resistance
Ilex attenuate "East Palatka"	East Palatka Holly	Highest Wind Resistance
Jacaranda acutifolia	Jacaranda	Lowest Wind Resistance
Juniperus sillicicola	Red Cedar	Lowest Wind Resistance
Kigelia pinnata	African Sausage Tree	Medium-Low Wind Resistance
Koelreuteria formosana	Golden Rain Tree	Medium-Low Wind Resistance
Laguncularia racemosa	White Mangrove	Highest Wind Resistance
Ligustrum lucidum	Ligustrum Tree	Medium-Low Wind Resistance
Livistona chenensis	Chinese Fan Palm	Highest Wind Resistance
lllex attenuate	Eagleston Holly	Highest Wind Resistance

Magnolia grandiflora	Southern Magnolia	Highest Wind Resistance
Magnolia grandiflora "Bracken"	Brown Back Magnolia	Highest Wind Resistance
Mangifera indica	Mango Tree	Medium-Low Wind Resistance
Melaleuca leucadendron	Punk Tree	Lowest Wind Resistance
Myrica cerifera	Wax Myrtle	Medium-Low Wind Resistance
Neodypsis decaryi	Triangle Palm	Medium-High Wind Resistance
Peltaphorum pterocarpum	Yellow Poinciana	Lowest Wind Resistance
Phoenix canariensis	Canary Island Date Palm	Highest Wind Resistance
Phoenix reclinata	Reclinata Palm	Highest Wind Resistance
Phoenix roe elenii	Pygmy Date Palm	Highest Wind Resistance
Pinus elliottii	Slash Pine	Medium-Low Wind Resistance
Pinus palustris	Long Leaf Pine	Medium-Low Wind Resistance
Podocarpus gracilior	Weeping Podocarpus	Highest Wind Resistance
Psidium littorale	Cauley Guava	Medium-Low Wind Resistance
Quercus laurifolia	Laurel Oak	Lowest Wind Resistance
Quercus minima	Scrub Oak	Highest Wind Resistance
Quercus virginiana "QVTIA"	Highrise Oak	Highest Wind Resistance
Quercus virginiana	Live Oak	Highest Wind Resistance
Quercus virginiana "SDLN"	Cathedral Oak	Highest Wind Resistance
Ravenea rivularis	Majesty Palm	Medium-Low Wind Resistance
Rhapis excelsa	Lady Palm	Medium-Low Wind Resistance
Rhizophora mangle	Red Mangrove	Highest Wind Resistance
Sabal palmetto	Cabbage Palm	Highest Wind Resistance
Serenoa repens	Saw Palmetto	Highest Wind Resistance
Spathodea companulata	African Tulip Tree	Lowest Wind Resistance
Streelitzia uvifera	White Bird of Paradise	Medium-Low Wind Resistance
Swietenia mahagoni	Mahogany	Medium-High Wind Resistance
Syagrus romanzoffianna	Queen Palm-Cocos Plumossa	Lowest Wind Resistance
Syzigium cumini	Java Plum	Medium-Low Wind Resistance

Tabebuia argentea	Tree of Gold	Lowest Wind Resistance
Washington robusta	Washington Palm	Lowest Wind Resistance
Wodyetia bifurcate	Foxtail Palm	Medium-High Wind Resistance

Table 17: Tree species with wind resistance factor at the Pelican Cove Community

The most dangerous non-native trees with lowest wind resistance (Australian pines, melaleuca, Norfolk Pine) and therefore that have the highest potential for damage to buildings and infrastructure and to blocking road access safety and evacuation are located at the entrance road areas of Pelican Cove, at segments of the Bayhouse shoreline, portion of Clower Creek, and distributed as individual trees or tree copses throughout the community. An adaptation plan will need to address removal and/or height reduction of these species for safety during tropical storms and other high wind events. .

Conclusions

The primary focus of this project is the vulnerability of Pelican Cove to climate change. This document includes an assessment of significant potential effects of climate change in the three areas of sea level rise, flooding, and damages from trees and other vegetation on the human and native ecosystems of Pelican Cove, including consequences for human and natural resources resulting from and related to sea level rise, aquatic and atmospheric temperature rise, changes in rainfall patterns, increased storm intensity, waterbody acidification, and general weather instability. This overview identifies potentially critical vulnerabilities that will need to be addressed by adaptation or accommodation at Pelican Cove.

At the current measured rates of sea level rise for Litter Sarasota Bay, Pelican Cove can expect 1 foot of eustatic sea level rise above the current mean tide by the year 2131; 2 feet of eustatic sea level rise above the current mean tide by the year 2245; and 3 feet of eustatic sea level rise above the current mean tide by the year 2341. Many climate change models with strong scientific bases anticipate a rapid acceleration of sea level rise above the current measured rate, caused but more rapid melting of land based ice in glaciers and the polar zones, increased releases of Green House Gases from human activities, agricultural practices, and natural sources released from melting . This set of models predict faster sea level rise such that, Pelican Cove can expect 1 foot of eustatic sea level rise above the current mean tide by the year 2051; 2 feet of eustatic sea level rise above the current mean tide by the year 2085; and 3 feet of eustatic sea level rise above the current mean tide by the year 2120.

Storm surge events from tropical storms will increase due to the higher sea level stand combined with a higher severity of storms and impact Pelican Cove sooner than the eustatic sea level rise effects. All of Pelican Cove is within the Category 3 storm surge zone, approximately half of the community is in the Category 2 storm surge zone and all of the estuarine shoreline Bayhouse and Harborhouse is in the Category 1 storm surge zone. for all directions of storm approaches with the exception of a storm crossing the state from east to west. Areas along Clower Creek within Pelican Cove are also in the Category 1 and 2 Strom Surge zones. The extent of these surges will reach further upslope and inland with the increased standing sea level. In addition rapid run-off from the urbanized impervious surfaces or the headwaters of Clower Creek will during rainy storms flood the riparian areas of Pelican Cove much more quickly even if the tide is low and wind fetch is blowing westward during a storm.

The existing drainage infrastructure of Pelican Cove depends upon rapid discharge to receiving waters.

Construction at Pelican Cove began in 1975 as six separate condominium associations which eventually merged into a single condominium association with six neighborhood.

The stormwater drainage and treatment system of Pelican Cove reflects this old design that had limited detention/retention and quick discharge to tidal waters. The road system within Pelican Cove reflects a strong dependence upon the road surface shape to direct surface water run-off directed to central gutter groves, edge swales and small basin stormwater ponds. Much of the non-point stormwater discharge goes directly into Sarasota Bay, Clower Creek or the Harbor basin without much treatment other than grassed surfaces. In some areas there is no treatment before road and building runoff enters the estuary directly. This is particularly true at the terminus of roadways and through directed pipes entering the Yacht Basin.

Some portions of the roads hold water in shallow pools without drainage until the water reaches sufficient height to exceed the depression's depth or evaporation does its work. These were typically along road edges at junctures with parking slots. The grassed swale system behind Bayhouse Building #5B is a good functional feature. Unfortunately this type of stormwater treatment is not replicated and may not be possible in the Harborhouse area or in locations like Bayhouse Building #8 where there is insufficient distance between buildings and the Bay and a sharp drop-off to a rip-rap and Australian pine shoreline.

The area facing north in front of *Bayhouse Buildings #8 and #9*; and the west facing shoreline of Harborhouse #21 have the most exposure to wind fetch generated waves with subsequent erosion,. The south facing Bayhouse Buildings #7, #6, #5B and Bayhouse Buildings #2 and #1 are wee protected by the mangrove islands that stop wave action and calm wind effects coming from the south and west. The wider mangrove shoreline hedges are more robust on the south facing shoreline. Both the Yacht Basin and Clower Creek above the juncture with the Yacht Basin Channel are depositional environments accumulating significant silt deposits above the original channel bottoms.

Erosion occurs on-site from three basic causes wave action form the Bay, flow down Clower Creek, and run-off from land surfaces. The current areas of Bay-side erosion is the area not protected by flanking mangrove islands at *Bayhouse Buildings #8 and #9*; and the west facing shoreline of Harborhouse #21. These areas already have been hardened with rip-rap behind vegetation fringes. There is erosion between buildings #8 and #9 where4 there is a discontinuation of rip-rap and water running off the Pelican Point Drive coupled with excess water coming from misdirected irrigation sprinkler heads run down slope into the area near the mouth of Clower Creek. Erosion is also occurring from areas behind Bayhouse #9 at a very low wooden board barrier that is being over-watered above it and is not retaining soil as it appears it was intended to do.

From site inspection the area of Bayhouse Buildings #7, #6, #5B and Bayhouse Buildings #2 and #1 have approximately 8 feet of elevation above the high tide mark. The Bayhouse Buildings #8, #9, and #10 appear to have 5 feet of elevation above current high tide.

East of the road bridge Clower Creek is blocked by vegetation that has grown across the creek bed and a significant amount of fallen vegetation has fallen into the creek and/or tangled into the living vegetation. This includes both native mangroves and exotics like Brazilian pepper.

The vegetation of Pelican Cove reflects a canopy that is composed of an original coastal oak hammock uplands flanked by a mangrove shoreline that has been invaded by the typical invasive exotics that move into disturbed areas and then landscaped intentionally as a form of botanical garden with a wide diversity of non-native species disperse among the residential and common areas. There are 82 species of trees at Pelican Cove at this time. There are 29 (35.37 %) native tree species on-site with oaks and cabbage palm the most common. There are 52 (63.41%) species of non-native tree species.

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The vegetation understory is principally exotic species ranging from sod grasses to typical nursery landscaping species like hibiscus and periwinkles and several invasive exotic species including Brazilian pepper, wedelia, and exotic ferns as well as some toxic species like cats-eye and Devil's trumpet.

There are pockets of coastal hammock shrubs with sea grape, inkberry, sea ox-eye daisey, silver buttonwood, and palmettos found shoreward of the mangrove fringes in the Bayhouse and lower Clower Creek areas.

This report is the first step in developing an adaptation plan for Pelican Cove. The following summation is informed to a large extent by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research 2008 report entitled "Adaptation Options for Climate-Sensitive Ecosystems and Resources Final Report". Maintaining the status quo in management of estuarine ecosystems would result in substantial losses of ecosystem services as climate change progresses. In the absence of effective avoidance, mitigation, minimization and adaptation, climate-related failures will appear in hydrology, water quality, fish and wildlife habitat, and community safety.

Changes in the climate will occur in the future even if mitigations, such as reductions in greenhouse gas emission, were to be implemented today. The stressors of air temperature and water temperature increases with subsequent changes in air quality and water quality can be expected to continue and the impacts of climate change variability and sea level rise, in particular, are inevitable. Climate change impacts from sea level are already evident in the growing demand for and costs of beach nourishment, increased coastal flooding, and more pronounced storm surges during tropical storm events.

Many of the anticipated consequences of climate change occur via mechanisms involving interactions among the stressors and variables. The magnitude of such interactive effects typically declines as each stressor or variable is better controlled, so enhanced adaptive management of traditional estuarine stressors has value as a management adaptation to climate change as well. The Pelican Cove Adaptation plan will provide suggested guidance in the three major areas of concern.

Among the consequences of climate change that threaten estuarine ecosystem services, the most serious involve interactions between climate-dependent processes and human responses to those climate changes In particular, conflicts will arise between sustaining natural coastal habitats and coastal private property, since current activities of protecting private shoreline property from erosion with hardening and placement of fill will become increasingly injurious to sub-tidal, littoral, and wetland habitats if continued as climate changes and sea level rises.

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Appendix A:

SARASOTA COUNTY CRITICAL FACILITIES SUBJECT TO SEA LEVEL RISE

SARASOTA COUNTY CRITICAL FACILITIES SUBJECT TO SEA LEVEL RISE

FACILITY TYPE	FACILITY NAME	ADDRESS	ELEVATION/ PROTECTION
302 FACILITY	ENGLEWOOD WATER OSMOSIS PLANT	SELMA AVENUE	5'-10' Protection Definite
302 FACILITY	FLORENTINE MARBLE MAUFACTURING	UNIVERSITY PARKWAY	5'-10' Protection Definite
302 FACILITY	MIDCO PETROLEUM-SARASOTA	6 TH STREET	5'-10' Protection Definite
302 FACILITY	GTE OF FLORIDA-NORTH PORT EAX CO	TAMIAMI TRAIL	5'-10' Protection Definite
302 FACILITY	GTE OF FLORIDA-SIESTA KEY EAX CO	MIDNIGHT PASS RD.	0' to 5' Protection Not Recommended
302 FACILITY	MIDCO PETROLEUM-VENICE	WARFIELD AVE.	5'-10' Protection Definite
302 FACILITY	CITY OF VENICE-ISLAND BEACH WWTP	SOUTH HARBOR DR.	5'-10' Protection Definite
302 FACILITY	NORTH PORT WATER TREATMENT PLANT	NORTH PORT BLVD.	5'-10' Protection Definite
CITY BUILDING	NORTH PORT- CITY HALL		5'-10' Protection Definite
CITY BUILDING	NORTH PORT-PLANNING DEPARTMENT		5'-10' Protection Definite
CITY BUILDING	NORTH PORT- POLICE DEPARTMENT	NORTH PORT BLVD.	5'-10' Protection Definite
COMMUNICATIONS	NORTH PORT- POLICE DEPARTMENT	NORTH PORT BLVD.	5'-10' Protection Definite
CORRECTIONAL FACILITY	NORTH PORT POLICE DEPARTMENT HOLDING CELL	NORTH PORT BLVD.	5'-10' Protection Definite
EMERGENCY MEDICAL SERVICES	NORTH PORT- FIRE RESCUE STATION 82	NORTH PORT BLVD.	5'-10' Protection Definite
FIRE STATION	CITY OF VENICE STATION #2-(#52)	GROVE STREET	5'-10' Protection Definite
FIRE STATION	SCFD-STATION 4	OLD BRADENTON RD.	5'-10' Protection Definite
FIRE STATION	LONGBOAT KEY FIRE DEPARTMENT	GULF OF MEXICO DR.	0' to 5' Protection Not Recommended
FIRE STATION	NORTH PORT- FIRE	NORTH PORT	5'-10' Protection

	RESCUE STATION 82	BLVD.	Definite
FIRE STATION	SCFD-STATION 3	N ADAMS DR.	5'-10' Protection Definite
FIRE STATION	SCFD-STATION 37- VFD #2-(#52)	GROVE STREET	5'-10' Protection Definite
FIRE STATION	ENGLEWOOD FIRE STATION #3-(#73)	OLD ENGLEWOOD RD.	5'-10' Protection Definite
FIRE STATION	LONGBOAT KEY FIRE DEPARTMENT		0' to 5' Protection Not Recommended
FIRE STATION	SCFD-STATION 36	TAMIAMI TRAIL	5'-10' Protection Definite
FIRE STATION	SCFD-STATION 2	WALDEMERE ST.	5'-10' Protection Definite
FIRE STATION	ENGLEWOOD STATION #2	PLACIDA RD.	5'-10' Protection Definite
FIRE STATION	NORTH PORT- FIRE RESCUE STATION 82	NORTH PORT BLVD.	5'-10' Protection Definite
FIRE STATION	NORTH PORT- FIRE RESCUE STATION 82	NORTH PORT BLVD.	5'-10' Protection Definite
FIRE STATION	SCFD-STATION 36	TAMIAMI TRAIL	5'-10' Protection Definite
GOVERNMENT BUILDING	CRIMINAL JUSTICE CENTER	Ringling BLVD.	0' to 5' Protection Not Recommended
GOVERNMENT BUILDING	CRIMINAL JUSTICE CENTER SERVICESBUREAU	Ringling BLVD.	0' to 5' Protection Not Recommended
GOVERNMENT BUILDING	HISTORICAL RESOURCES/CHIDSEY BUILDING	Plaza De Santo Domingo	0' to 5' Protection Not Recommended
GOVERNMENT BUILDING	CATTLEMEN ROAD COMPLEX, Bldg. C	Cattlemen RD.	0' to 5' Protection Not Recommended
GOVERNMENT BUILDING	CATTLEMEN ROAD COMPLEX, Bldg. E	Cattlemen RD.	5'-10' Protection Definite
GOVERNMENT BUILDING	CENTRAL STORES	Ashton RD.	5'-10' Protection Definite
GOVERNMENT BUILDING	Knights Trail Criminal Justice Bldg	Rustic RD.	0' to 5' Protection Not Recommended
GOVERNMENT BUILDING	MEDICAL EXAMINER	Hawthorne BLVD.	5'-10' Protection Definite
GOVERNMENT BUILDING	POLICE DEPT./ TOWN COMMISSION CHAMBERS	BAY ISLES RD.	0' to 5' Protection Not Recommended
HAZARDOUS MATERIAL SITE	NORTH PORT WATER TREATMENT PLANT	NORTH PORT BLVD.	5'-10' Protection Definite
HELIPORT	NORTH PORT-	NORTH PORT	5'-10' Protection

	HELIPORT	BLVD.	Definite
HOSPITAL	ENGLEWOOD COMMUNITY HOSPITAL	MEDICAL BLVD.	5'-10' Protection Definite
LANDING ZONES	HELIPAD (STATION 82)	NORTH PORT BLVD.	5'-10' Protection Definite
LAW ENFORCEMENT	LONGBOAT KEY POLICE DEPARTMENT	BAY ISLES	0' to 5' Protection Not Recommended
LAW ENFORCEMENT	Community Policing 2- SIESTA KEY	Ocean BLVD.	5'-10' Protection Definite
LAW ENFORCEMENT	Community Policing 4	N Tamiami TRAIL	5'-10' Protection Definite
LAW ENFORCEMENT	NORTH PORT- POLICE DEPARTMENT	NORTH PORT BLVD.	5'-10' Protection Definite
MAINTENANCE BUILDING	Facilities Maintenance- Bldg. 'A'	17Th ST.	5'-10' Protection Definite
NEXTEL TOWER SITES	F0439	MIDNIGHT PASS RD.	5'-10' Protection Definite
POTABLE WATER	NORTH PORT WATER TREATMENT PLANT	NORTH PORT BLVD.	5'-10' Protection Definite
POTABLE WATER	NORTH PORT WATER TREATMENT PLANT	NORTH PORT BLVD.	5'-10' Protection Definite
PUBLIC BUILDINGS & INFRASTRUCTURE	DEEP INJECTION WELL (AT LUDLOW AVENUE)	CAMPBELL DR.	0' to 5' Protection Not Recommended
PUBLIC BUILDINGS & INFRASTRUCTURE	FLOOD PRONE AREA (AT EAGER STREET)	US 41	5'-10' Protection Definite
PUBLIC BUILDINGS & INFRASTRUCTURE	FLOOD PRONE AREA (AT GROBE STREET)	US 41	5'-10' Protection Definite
PUBLIC BUILDINGS & INFRASTRUCTURE	NORTH PORT CITY HALL	NORTH PORT BLVD.	5'-10' Protection Definite
PUBLIC UTILITIES	Island Beach WWTP	1800 Harbor Dr S	5'-10' Protection Definite
REP LOSS	HISTORICALLY DAMAGED SECTION OF S. R. 789	GULF OF MEXICO DR.	0' to 5' Protection Not Recommended
SCHOOL	MANATEE COMMUNITY COLLEGE	S. TAMIAMI TRAIL	5'-10' Protection Definite
SCHOOL	MANATEE COMMUNITY	TAMIAMI TRAIL	5'-10' Protection Definite

SCHOOL	COLLEGE RINGLING SCHOOL OF ART AND DESIGN	TAMIAMI TRAIL	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	CARRIAGE HOUSE RESTAURANT	N INDIANA AVE.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	DEER CREEK MHP- AND MICHIGAN AVE	HORTON AVE.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	FAIR WINDS CONDOMINIUM	ALBEE RD.	0' to 5' Protection Not Recommended
SEWAGE TREATMENT PLANT	FIELD CLUB	FIELD RD.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	FLIGHT DECK RESTAURANT- AT U.S. 41	VAMO WAY	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	LAKE VILLAGE MHP	LAKE N. DR.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	LAKE VILLAGE MOBILE HOME COMMUNITY	LAKE DR.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	LYONS COVE CONDO	LOUELLA LANE	0' to 5' Protection Not Recommended
SEWAGE TREATMENT PLANT	OAK HAMMOCK PROF.CTR.(BENEVA CREEK)	BEE RIDGE RD.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	OUR LADY OF PERPETUAL HELP WWTP	SOUTH MOON DR.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	PALM & PINES MHP WWTP	N. TAIMIAMI TRAIL	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	RAMBLERS REST RESORT WWTP	NORTH RIVER RD.	0' to 5' Protection Not Recommended
SEWAGE TREATMENT PLANT	SARASOTA BAY MHP - R/O PLANT	WEST OAK	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	SARA MEM. HOSP. 1 1/2 MI. WEST OF RIVER RD	U.S.HWY 41	5'-10' Protection Definite

SEWAGE TREATMENT PLANT	SIESTA KEY UTILITIES AUTHORITY	OAKMONT PLACE	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	SORRENTO UTILITIES - R/O & EDR	MONTANA DR.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	SOUTH GATE AWWTP	PINE VALLEY DR.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	SOUTHBAY UTILITIES	YACHT HARBOR DR.	0' to 5' Protection Not Recommended
SEWAGE TREATMENT PLANT	VENICE CAMPGROUND WWTP	EAST VENICE AVE.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	FL0020508	Harbor DR.	5'-10' Protection Definite
SEWAGE TREATMENT PLANT	FL0025755	OAKMONT PLACE	5'-10' Protection Definite
SHELTER	SARASOTA JEWISH FEDERATION	SOUTH MCINTOSH RD.	5'-10' Protection Definite
TELEPHONE AND CELLULAR FACILITY	GTE BUILDING	BISCAYNE @ 41	5'-10' Protection Definite
WATER STORAGE FACILITY	SOUTH KEY WATER STORAGE FACILITY	GULF OF MEXICO DR.	5'-10' Protection Definite
WATER TREATMENT	CASPERSONS BEACH	Harbor DR.	5'-10' Protection Definite
WATER TREATMENT	DISABLED AMERICAN VE		5'-10' Protection Definite
WATER TREATMENT	ENGLEWOOD WATER DISTRICT		5'-10' Protection Definite
WATER TREATMENT	KINGS GATE RV PARK		5'-10' Protection Definite
WATER TREATMENT	NORTH PORT UTILITIES		0' to 5' Protection Not Recommended
WATER TREATMENT	RAMBLERS REST RESORT		5'-10' Protection Definite
WATER TREATMENT	SPANISH LAKES MHP		5'-10' Protection Definite
WATER TREATMENT	CASPERSEN BEACH		5'-10' Protection Definite
WATER	ENGLEWOOD WATER		5'-10' Protection

TREATMENT	DISTRICT		Definite
WATER	KINGS GATE RV		5'-10' Protection
TREATMENT	PARK		Definite
WATER	NORTH PORT		0' to 5' Protection
TREATMENT	UTILITIES		Not Recommended
WATER	SARASOTA CO		5'-10' Protection
TREATMENT	SPECIAL		Definite
WATER	SARASOTA CO		5'-10' Protection
TREATMENT	SPECIAL		Definite
WATER	NORTH PORT WATER	NORTH PORT	5'-10' Protection
TREATMENT	TREATMENT PLANT	BLVD.	Definite
WATER	NORTH PORT- CITY	NORTH PORT	5'-10' Protection
TREATMENT	WATER PLANT	BLVD.	Definite
WATER	SIESTA KEY	MIDNIGHT PASS	5'-10' Protection
TREATMENT	UTILITIES	RD.	Definite
WATER	VENICE GARDENS		5'-10' Protection
TREATMENT	UTILITIES		Definite
WATER			5'-10' Protection
TREATMENT	WOODBRIDGE DR 921		Definite
			5'-10' Protection
WELL	WELL NO 1	22ND ST.	Definite
			5'-10' Protection
WELL	WELL NO 1	22ND ST.	Definite
			5'-10' Protection
WELL	WELL NO 7	12TH ST.	Definite
			5'-10' Protection
WELL	WELL NO 7	12TH ST.	Definite