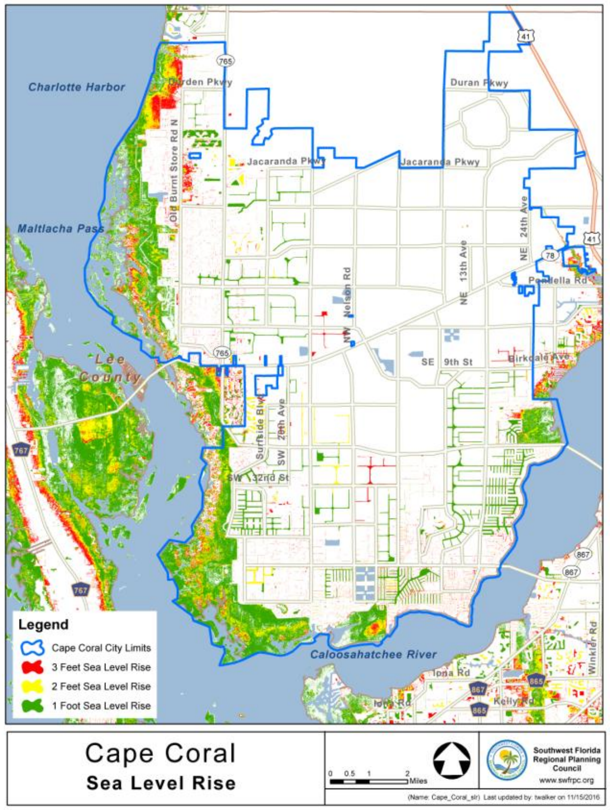
Cape Coral Climate Change Vulnerability Assessment



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Executive Summary

City of Cape Coral is currently experiencing climate change. The natural setting of City of Cape Coral coupled with extensive reinvestment in the areas closest to the coast have placed the region 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 (90%), lowest impact future climate change scenario predictions, the future for southwest Florida 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 City of Cape Coral in the face of such likely changes would result in substantial losses of ecosystem services and economic values as climate change progresses. In the absence of effective avoidance, mitigation, minimization and adaptation, climate-related failures will result in greater difficulty in addressing the priority problems identified in the City of Cape Coral Comprehensive Plan (CCCP): hydrologic alteration, water quality degradation, fish and wildlife habitat loss, and stewardship gaps.

This study examines the current climate and ongoing climate change in southwest Florida along with five future scenarios of climate change into the year 2100. These scenarios include:

1) a condition that involves a future in which mitigative actions are undertaken to reduce the human influence on climate change (Stanton and Ackerman 2007),

2) a 90% probable future predicted by the Intergovernmental Panel on Climate Change (IPCC 2007b),

3) a 50% probable future predicted by IPCC,

4) a 5% probable future predicted by the IPCC, and

5) a “very worst” future in which no actions are taken to address climate change (Stanton and Ackerman 2007). This fifth scenario also corresponds with some of the other worst case scenarios postulated by scientists who think the IPCC estimations are under-estimated (USEPA CRE 2008).

This report also assesses significant potential climate-related changes in air and water and the effects of those changes on climate stability, sea level, hydrology, geomorphology, natural habitats and species, land use changes, economy, human health, human infrastructure, and variable risk projections, in southwest Florida. 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.

Depending upon the method of prioritization utilized, some climate change effects will be experienced and can be compensated for in the relative near-term. Other effects with longer timelines will be more costly in habitat impact or human economic terms. There are a number of planning actions that, if undertaken now, could significantly reduce negative climate change effects and their costs in the future while providing positive environmental and financial benefits in the near term.

There are crucial areas where adaptation planning and implementation will be needed in order to avoid, minimize and mitigate the anticipated effects to the natural and man-altered areas of southwest Florida. Some effects, such as air temperature and water temperature increases, will be experienced throughout the region. Others, such as sea level rise and habitat shifts, will occur in specific geographic and clinal locations. In a regional vulnerability assessment 246 climate change management adaptations were identified (Beever et al. 2009) that could be utilized to address the various vulnerabilities identified for the region. Future adaptation plans will identify the management measures best suited for each geographic location.

Based upon a variety of effects analyses the prioritization ranking for the climate change vulnerabilities is in descending order Altered Hydrology; Climate Instability/ Storm Severity; Habitat and Species Changes; Geomorphic (Landform) Changes; Sea Level Rise and Water Temperature and Chemistry Changes ; Infrastructure Impacts and Land Use Changes; Air Temperature and Chemistry Changes and Human Health; Human Economy; and Variable Risk.

Monitoring of the effects and results of climate changes will be necessary to assess when and where adaptive management needs to be and should be applied. A critical goal of this monitoring is to establish and follow indicators that signal approach toward an ecosystem threshold that, once passed, puts the system into an alternative state from which conversion back is difficult to impossible. The likely effects of climate change, particularly tropical storms, drought and sea level rise, on southwest Florida ecosystems and infrastructure development are too great for policymakers, property owners, and the public-at-large to stand by and wait for greater evidence before considering strategies for adaptation. It is essential to plan and act now to avoid, mitigate, minimize, and adapt to the negative effects of climate change, and to examine the possibilities of providing benefits to human and natural systems by adapting to the changing planet.

Introduction

The City of Cape Coral is a coastal city located in Southwest Florida, a region 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 tributary canals, streams ,and creeks have placed the City 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 (90%), lowest impact future climate change scenario predictions, the future for southwest Florida 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.

Figure 1: City of Cape Coral with City Boundary Indicated

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 the Environmental Protection Agency's (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.

On November 19, 2007, the CHNEP Policy Committee added a climate change adaptation component to its Comprehensive Conservation and Management Plan (CCMP), later adopted on March 24, 2008. This set the stage for EPA Region 4 to fund CHNEP and, its host agency, the SWFRPC, to conduct an analysis of the effects that climate change stressors may have on ecosystems and human infrastructure within the region surrounding Charlotte Harbor and Lemon Bay. Stressors delineated in the EPA Climate Ready Estuaries (CRE) draft "Synthesis of Adaptations Options for Coastal Areas," were considered for use in the analysis. The goal of the analysis was to identify projected impacts and potential adaptation options for implementation within that portion of the CHNEP study area that is in the region served by the SWFRPC.

A database with climate effects and adaptation options forms the core of the regional assessment project; the progress and outputs of the project are being 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.

CHNEP and SWFRPC then partnered 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.

In 2009, the SWFRPC adopted "Climate Prosperity" as part of its Comprehensive Economic Development Strategy to promote energy efficiencies for "green" savings, to encourage and support "green" business opportunities, and to develop "green" talent in the workforce. The Council has formed an Energy & Climate Committee to develop plans for implementing the strategy throughout the region.

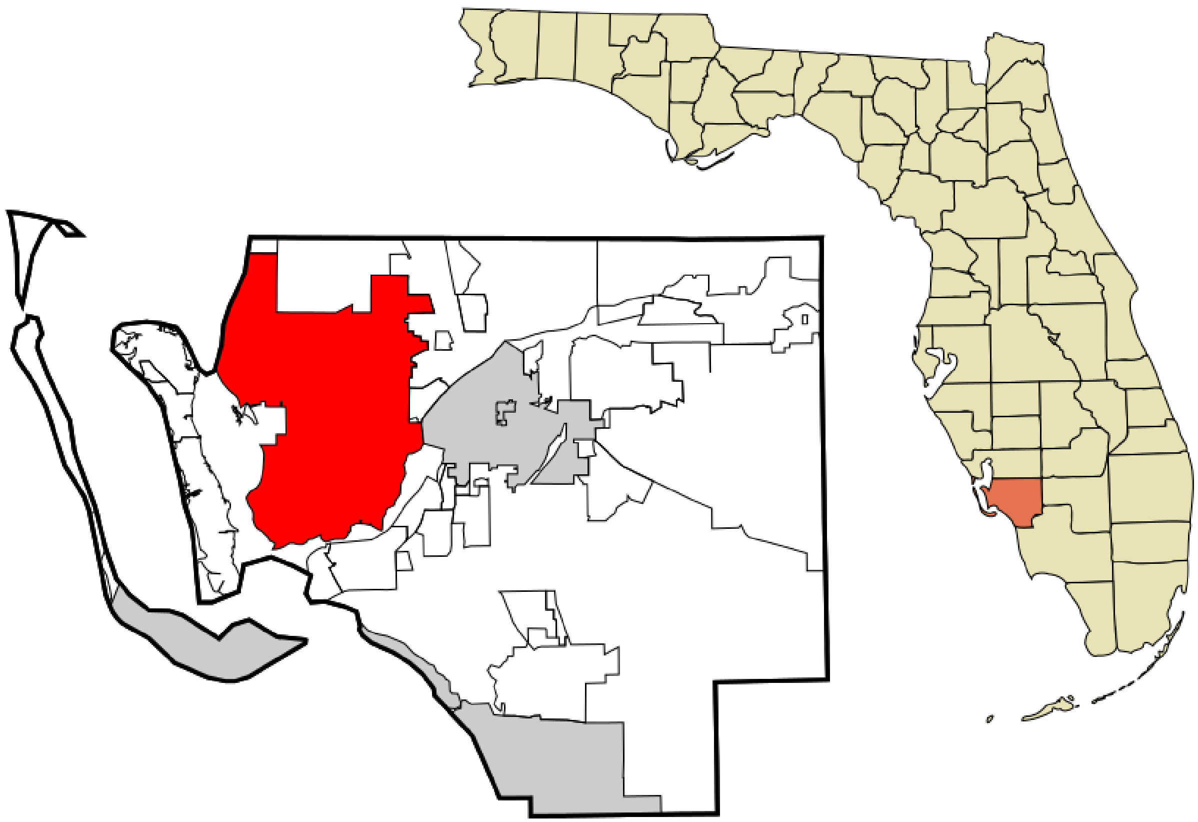


Figure 2: Total study area of unincorporated City of Cape Coral Climate Change Vulnerability Assessment

Climate change is currently occurring and more change is to be expected.

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).

The question for City of Cape Coral government and residents 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).

City of Cape Coral is particularly vulnerable to the effects of climate change. Topography is flat, 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 inland water bodies. The savanna climate is naturally extreme, even without new perturbations.

City of Cape Coral extends approximately15 miles north to south, from the Caloosahatchee River, directly north to the southern boundary line of the Yucca Pens Unit of the Cecil Webb-Fred C Babcock Wildlife Management Area (SWFRPC GIS). Bordered to the east by North Fort Myers and to the west by the Matlacha Pass Preserve State Park, the city is approximately 9.5 miles across at its widest point. The City of Cape Coral is comprised of 110.09 sq mi (285.1 km^2) square miles of land area and 91 sq mi (25.7 km^2) 9% of water including connected waters in a multitude of canals. There are approximately 440 miles of coastal shoreline including approximately 400 miles (640 km.) of canals, more than any other city in the world. Most of the canals are navigable and some have access to the Gulf of Mexico. Cape Coral's canal system is so extensive that local ecology and tides have been affected.

The average elevation of the City is 5 ft (2 m). Over 78% of the natural ecological communities, including hydrology, soils, and vegetation have been removed.

The marshes of the Matlacha Pass watershed includes in descending order: mixed high marsh (1,466.9 acres), shrub mangrove high marsh (449.5 acres), grassy high marsh (149.2 acres), succulent high marsh (123.3 acres), algal marsh (80.1 acres), saltern (48.5 acres), black needle rush marsh (14.0 acres), and leather fern marsh (0.3 acres). This is a total of 2,332.7 acres of salt marsh. Ninety-nine percent of the salt marshes of the Matlacha Pass watershed are high marsh. Review of historical (1954) aerial photographs indicate that the relative absence of low marsh is natural and the estuarine shorelines of this watershed were mangrove lined. Salt marshes are found in the Caloosahatchee river watershed in Glovers Bight/Piney Point, and Four-Mile Cove/Eco-Park.

Within the City, there are 9,752.4 acres of wetlands, including 1,297.24 acres of native freshwater wetlands and 8,454.76 acres of native saltwater wetlands. Native saltwater wetlands include 7,628.72 acres of mangroves and 826.04 acres of salt marsh. Currently, over 31 percent or 12.58 miles of coastal wetland shorelines have been lost or significantly altered in the City of Cape Coral watershed. The most significant coastal wetland losses have been on the estuarine Caloosahatchee River and tributary creeks that were converted to linear canals (CHNEP 2009). The average elevation of the City is 5 ft (2 m).

Cape Coral was founded in 1957. Real estate developers Leonard and Jack Rosen purchased a 103-square-mile (270 km^2) tract known as Redfish Point for $678,000 in that year and, in 1958, began development of the city as a master-planned, pre-planned community.

The Gulf American Land Corporation (GALC), was formed to develop the area. Canals were dug, streets paved, houses and businesses built.[Cape Coral was promoted like no other Florida development at that time. Celebrities were brought in to tout the benefits of "the Cape", as it is known locally. The first building was the Rosens' company headquarters, at the corner of Coronado and Cape Coral Parkway. Cape Coral's first permanent resident was Kenny Schwartz, the Rosens' general manager. Cape Coral's first four homes were completed in May 1958, on Riverside and Flamingo Drives.

Development continued through the early 1960s, mostly on Redfish Point, south of Cape Coral Parkway. By 1963, the population was 2,850; 1,300 buildings had been finished or were under construction; 80 mi (130 km) of road had been built, and 160 mi (260 km) of canals had been dug. The public yacht club, a golf course, medical clinic and shopping center were up and running. A major addition for Cape Coral was the construction of the 3,400 feet (1,000 m) long Cape Coral Bridge across the Caloosahatchee River, which opened in early 1964. Before the bridge, a trip to Fort Myers was more than 20 mi (32 km) via Del Prado Boulevard and over the Edison Bridge to cross the river.

There was significant promotion and advertising. Celebrities like Bob Hope, Anita Bryant, Jayne Mansfield, and Hugh Downs were brought in. A movie with Phyllis Diller, *The Fat Spy* (1966), was filmed in Cape Coral and so were episodes of the TV show *Route 66*.

The city incorporated in August 1970, and its population continued to grow rapidly until the real estate recession that gripped the region beginning in 2008.[

In 2016 Forbes Magazine named the City of Cape Coral as # 9 of the "Top 25 Cities To Retire in the United States"

Demographics, Population and Urbanized Area Growth

The following information applies to the City of Cape Coral. Table references are from the University of Florida Bureau of Economic and Business Research (UFBEBR) Warrington College of Business Florida Statistical Abstract.

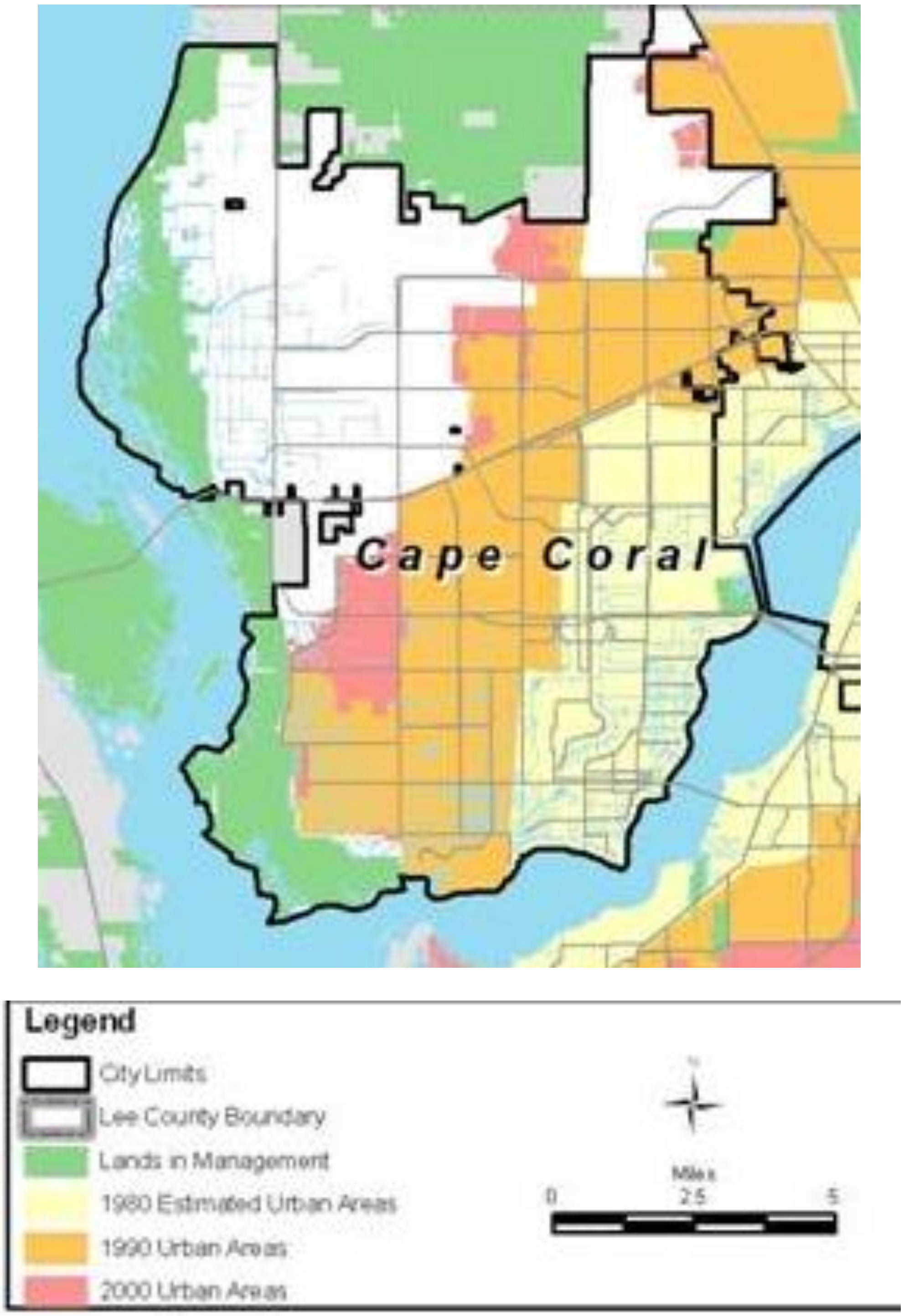


Figure 3: Urbanized Area Growth in the City of Cape Coral Study Area

The Census Bureau defines an urbanized area as a contiguous area of over 1,000 people per square mile. The first urbanized area in Lee County, Cape Coral/ Fort Myers, was designated as a result of the 1970 census. The geographic boundary of this area did not change much for the 1980 census. In 1980, the only urbanized area within Lee County was Cape Coral/ Fort Myer. The most geographically significant increase of urbanized area for 1990 was in Cape Coral. By the year 2000, the urbanized area had greatly expanded and new urban areas included coastal Estero, Bonita Springs, eastern Sanibel Island and Lehigh Acres, (Figure 4).

The latest decennial census of the population was performed in the year 2010. Geographic Information System (GIS) techniques were used to analyze the study area population. There is double-counting where census blocks cross basin boundaries. Study area population nearly quadrupled between 1980 and 2010 by which time there were 154,286 residents. The study area has been experiencing exponential growth and there is a substantial difference in population between coastal counties and interior counties..

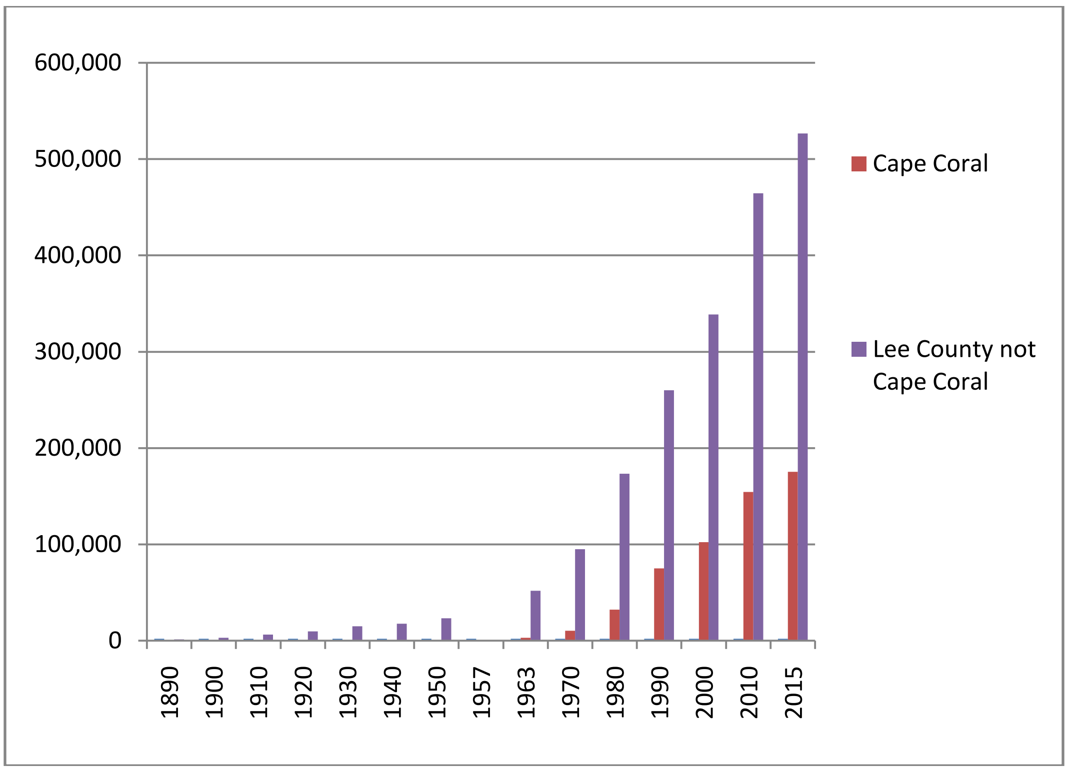


Figure 4: Comparison of Historic Population Growth in Lee County and the City of Cape Coral

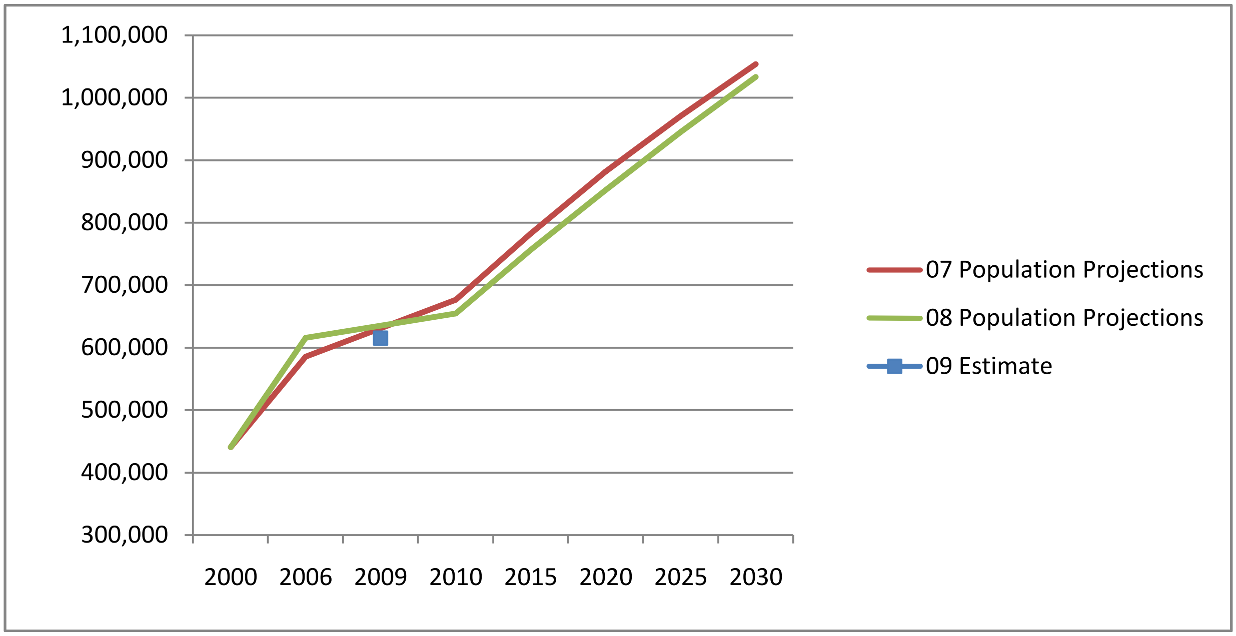


Figure 5: Comparison of Projected Growth and Recent Estimates in Cape Coral/ Fort Myers urbanized area

The population of City of Cape Coral was 181,211 in the year 2015. According to the University of Florida's Bureau of Economic and Business Research, in the year 2000, it was projected that, by 2030, using medium population projections the population of City of Cape Coral would be 314,201. The total estimated population of City of Cape Coral increase of about 138% from 1990 to 2015 which is an average annual population increase of approximately 5.5% (Figure 4). This represents a total of 69,618 households in City of Cape Coral. The median age is 43.4.

Under the current local government comprehensive plans with planning horizons of 2010 to 2025, urban uses are expected to increase. The City of Cape Coral's Comprehensive Plan assumes that a majority of the new residents will continue to choose traditional single-family housing or multifamily apartment/condominiums. Together with supporting commerce, office and industrial development, the plan projects that these urban uses will cover more than 70 % of the City of Cape Coral's land area by the year 2030. At the same time, areas devoted to natural preserves and water resources are not projected to grow.

All of the residents City of Cape Coral live within 10 miles of the Gulf of Mexico or another estuarine coast. These diverse, productive coastal and marine ecosystems provide food and other products, valuable and irreplaceable ecological functions, and aesthetic and recreational opportunities. The County's life-support system, economy, and quality of life depend on preserving and sustaining these resources over the long-term.

The Current Climate of City of Cape Coral and 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 Intergovernmental Panel on Climate Change (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).

Cape Coral features a climate on the border between a humid subtropical (*Cfa*) and a tropical monsoon climate (*Am*) under the classification system. The area averages 355 days of sunshine each year, but experiences precipitation on 145 days per year. While the summers are very warm, humid and rainy, the winters in Cape Coral are dry with moderate temperatures. Cape Coral receives about 54 inches of rain each year, the majority of which falls from June to September. During the summer months, afternoon rains are heavy yet brief. The city is affected by the annual hurricane season, which begins officially on June 1 and continues through November. This climate of southwest Florida is also considered 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).

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 that are 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 trade winds, 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 (°F), the average January temperature is 64 to 65°F, and the average August temperature is 82°F. Southwest Florida is one of only two areas in the southeastern United States where air temperatures exceed 90°F more than 120 days of the year. Typically, there is a 1°F difference between north border and south border City of Cape Coral. Inland areas typically 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°F can occur between coastal and inland areas a few miles apart. A similar gradient of about six to 10°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.

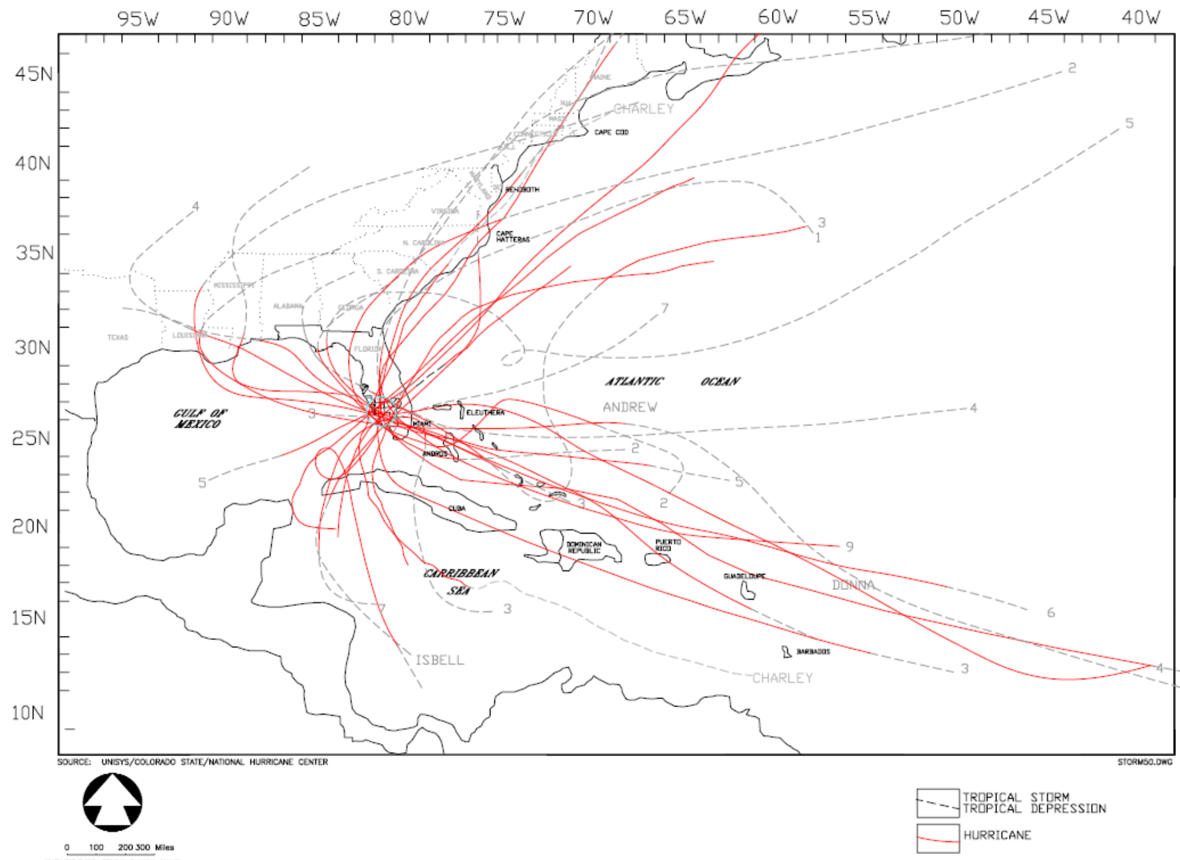
Hurricane season (June 1 to November 30) is especially brutal on southwest Florida. No one in the region lives more than 75 miles from the coast, and, while storms have effects wherever they strike, they have particularly heavy impacts in coastal areas. Storm surges, wave action, high winds, and heavy 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.

Hydrometerological 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 access to inadequate evacuation and shelter systems place southwest Florida squarely in the danger zone for major disasters.

Between 1873 and 1993, Southwest Florida experienced sixty 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).



ATLANTIC HURRICANES 1851 - 2004
HURRICANES PASSING WITHIN 50 MILES OF 26.6N, 81.9W

Between 1994 and 2016 alone, there were 17 hurricanes and tropical storms. These more recent storms resulted in 21 deaths, 833 injuries, $23.1 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).

Tornadoes are relatively common in Cape Coral (7 events in 5 years 2004-2009). A tornado is a violent windstorm characterized by a twisting, funnel-shaped cloud. A Waterspouts are weak tornadoes that form over warm water and are most common along the Gulf Coast and the southeastern states. Waterspouts occasionally move inland, becoming tornadoes and causing damage and injuries.

Florida has two tornado seasons. The summer tornado season runs from June until September and has the highest frequencies of storm generation, with usual intensities of EF0 or EF1 on the Fujita Scale. This includes those tornadoes associated with land-falling tropical cyclones.

The deadly spring season, from February through April, is characterized by more powerful tornadoes because of the presence of the jet stream. When the jet stream digs south into Florida and is accompanied by a strong cold front and a strong squall line of thunderstorms, the jet stream's high level winds of 100 to 200 mph often strengthen a thunderstorm into what meteorologists call a supercell or mesocyclone. These powerful storms can move at speeds of 30 to 50 mph, produce dangerous downburst winds, large hail, and are usually the most deadly tornadoes.

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 (90%) to occur in the future, while “possible” means that it may occur (50%), 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 IPCC 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 2007, the Panel issued its fourth report on global climate change (previous reports were issued in 1990, 1995, and 2001, with supplements and additional reports in intervening years) (IPPC 2007a). 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 2008, FOCC 2009). The work of the IPCC (2008) 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 the Southwest Florida Regional Planning Council/ Charlotte Harbor national Estuary Program Regional Vulnerability Assessment (Beever et al. 2009) and a review of 354 professional source documents from federal, state, local, academic and planning sources. These documents are listed in the Citations.

A total of 84 potential effects in 12 categories, were identified 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 (Ogden and Davis 1999). 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**. Consequences for human ecosystems will be expressed in **Human Economy, Human Health, Infrastructure, Land Use Changes,** and **Variable Risk**.

Potential Climate Futures

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 EPA 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 of the EPA report.

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 1: Sea level projection by year for City of Cape Coral and 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 green house 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 green house 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,* 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 2: Two other alternate future climate scenarios for City of Cape Coral and 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 2 above, 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 2. 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 (°C) 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 CO2-eq, as in scenario RCP2.6. For a radiative forcing that corresponds to above 700 ppm CO2-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.

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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 3 | 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

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. 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°F 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 1.1°F (0.6°C) since 1901 (IPPC 2007b). Since the 1980s, the atmospheric column average water vapor concentration has increased by 1.2 percent (IPPC 2007b). Even with all this being said, coastal air temperature observations around Florida since the 1830s do not show any statistically significant trends (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 4: 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 individuals 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 5: Mean annual temperature changes for City of Cape Coral and 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°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. Extirpation of cooler-water species, altered reproductive rates and maturation leading to declining fish and animal populations, increased evaporation of surface water, reduction in water quality due to increased growth of nuisance algae and lower oxygen levels, and increased demand for electricity for cooling indoors along with 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°F (0.6°C) over the past 100 years (IPCC 2007b). Water temperatures at the sea surface rose by an average of 0.54°F (0.3°C) 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).

Hypoxia currently occurs in the dead end unflushed canals of parts of Cape Coral during hot summer months when freshwater inflows can overlay denser salt waters. It more rarely occurs in the Caloosahatchee River during periods of very high freshwater flows from a combination of high precipitations and human water releases from the upper watershed and Lake Okeechobee.

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).

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 (90%) that water temperatures at the sea's surface will continue to increase at the average rate of 0.54°F (0.3°C) 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 3.6°F (2°C) 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. In those conditions, 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 contribute to 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 6: The pH Scale
Source: NMEA

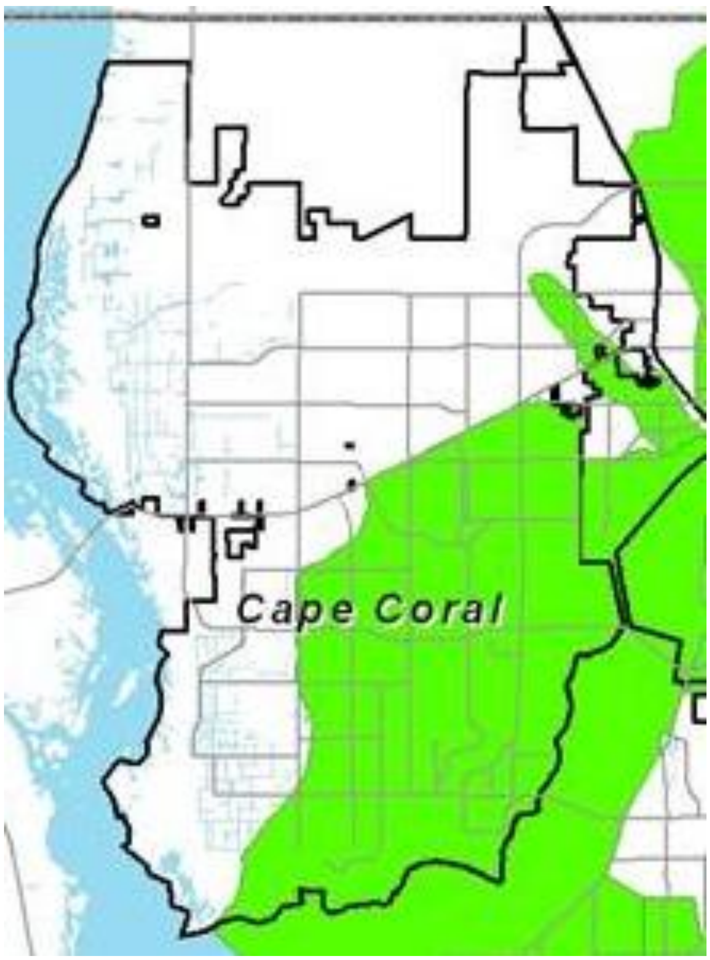


Figure 6: Nutrient impairments in the City of Cape Coral watershed
Source: CHNEP Water Atlas, at USF:, FDEP FINAL TMDL Report Nutrient TMDL for the Caloosahatchee Estuary (WBIDs 3240A, 3240B, and 3240C) t

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, further 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 (AMO) 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 the AMO, and others suggest climate change related to anthropogenic increases in irradiative 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. Wind shear plays a significant role and 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.

The pattern of storm surges are dependent upon the elevation of the land, the pattern of coastal bathymetry and the intensity of the storm wind speeds and directional speed.

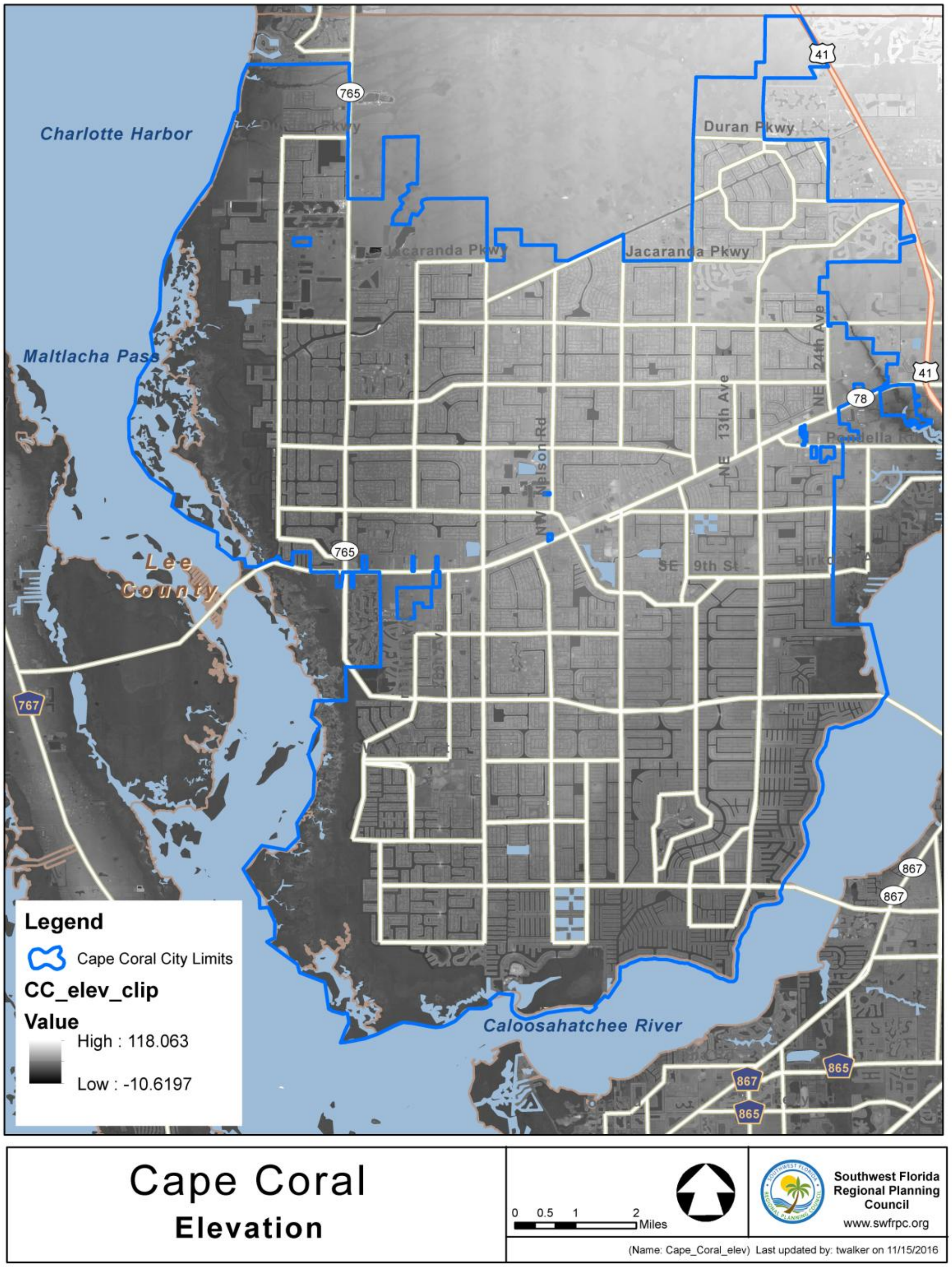


Figure 7: Land elevation in feet in the City of Cape Coral watershed

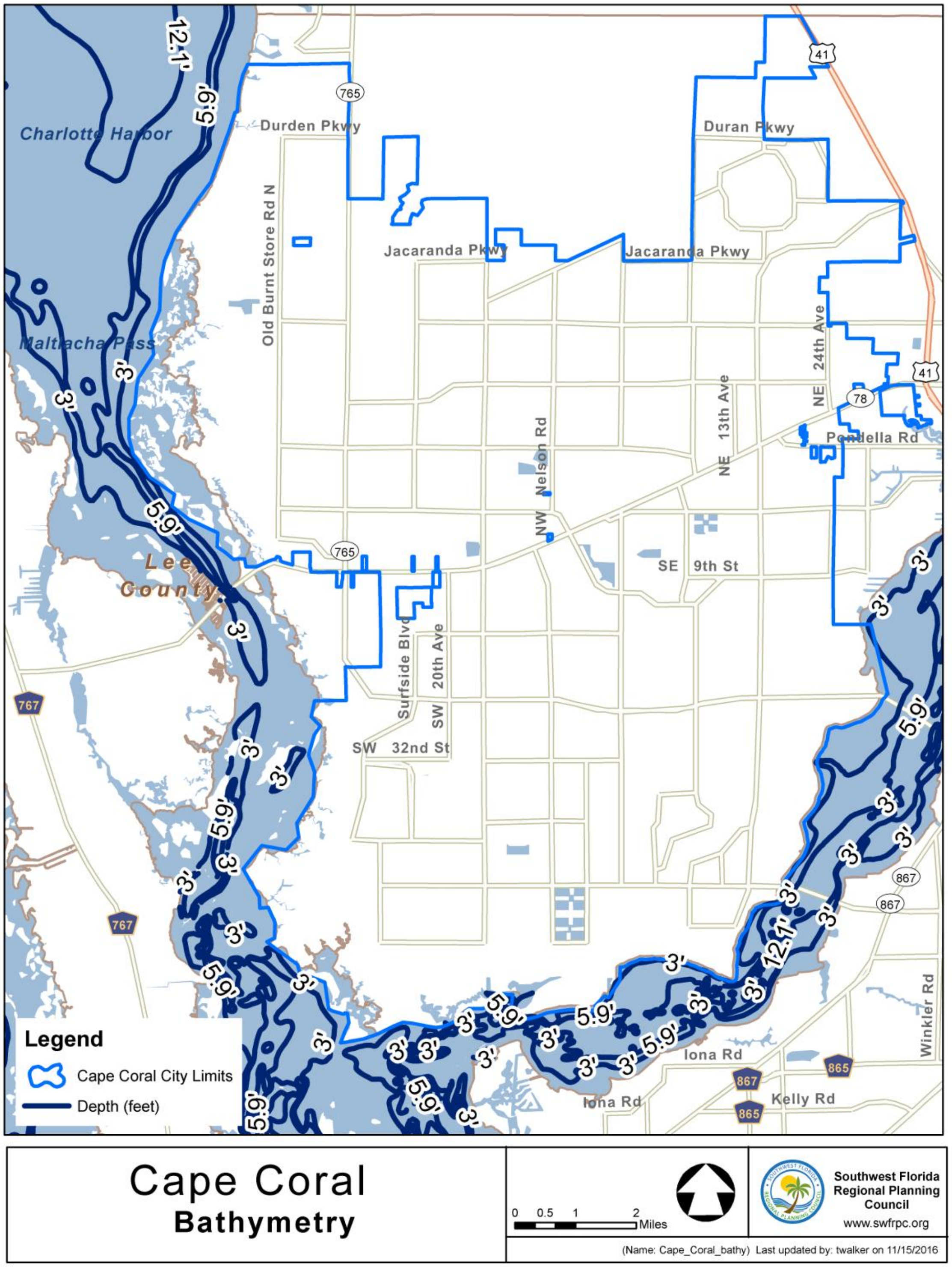


Figure 8: Bathymetry in feet in the City of Cape Coral watershed

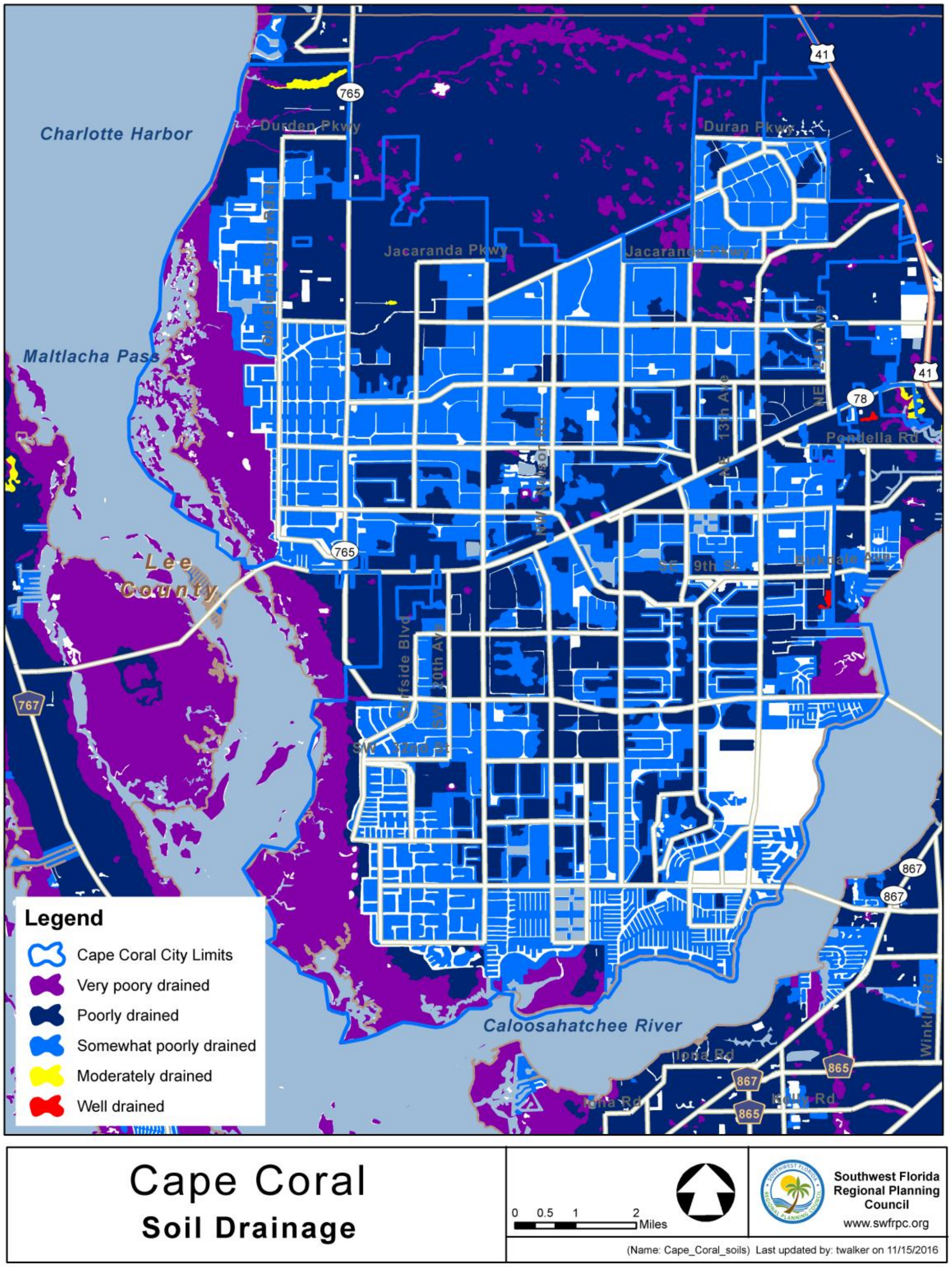


Figure 9: Soil drainage capacity in the City of Cape Coral

The following are the current directional storm surge maps for the City of Cape Coral.

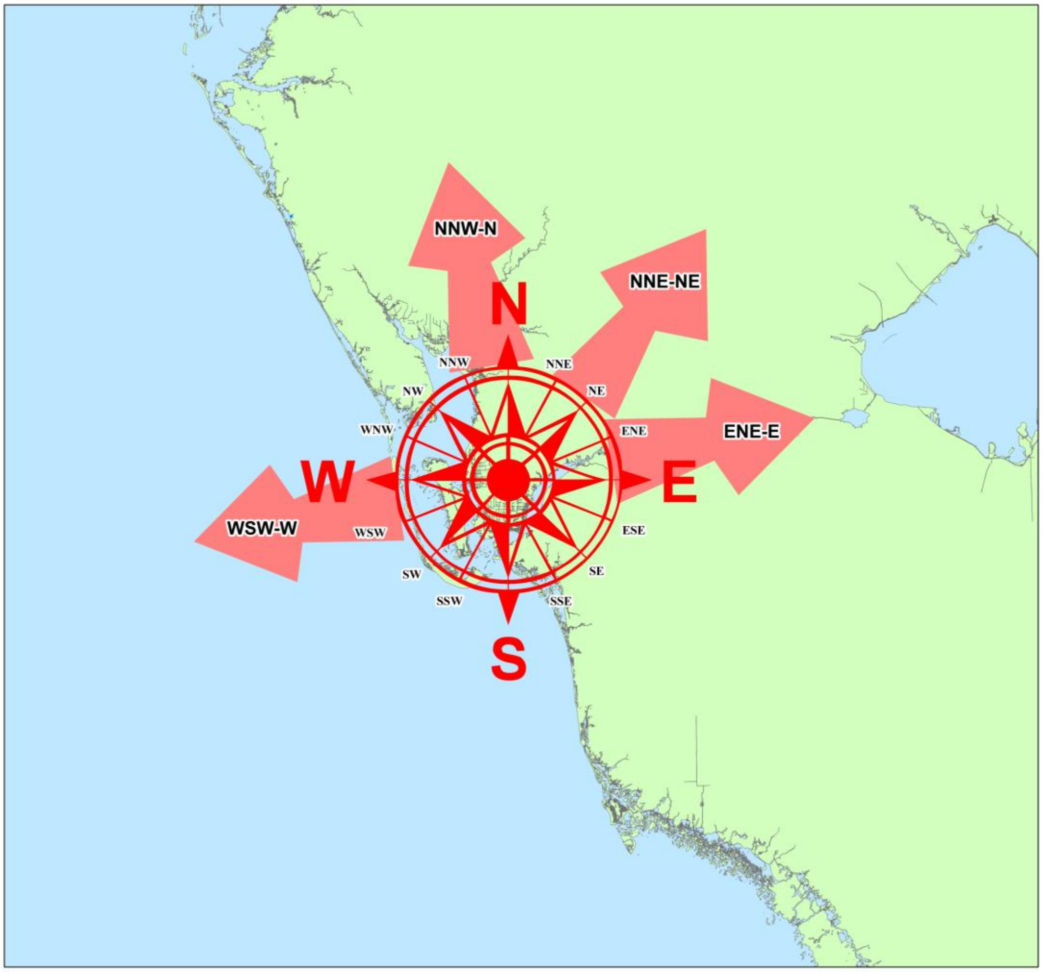


Figure 10: Storm Surge Directions for the City of Cape Coral reflecting the different patterns that tropical storms and hurricanes can approach the city.

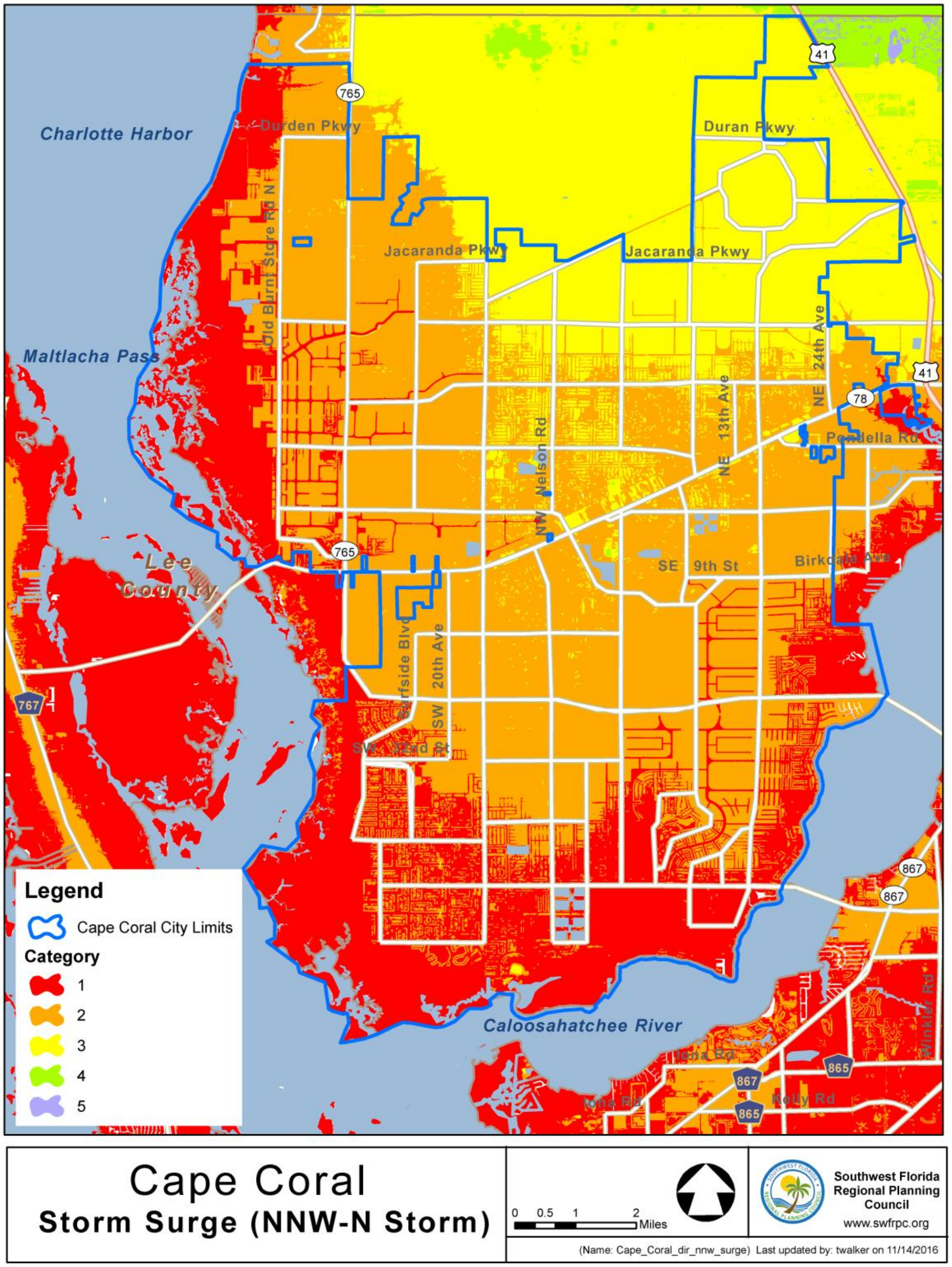


Figure 11: North/ Northwest Storm Surge Boundaries for City of Cape Coral

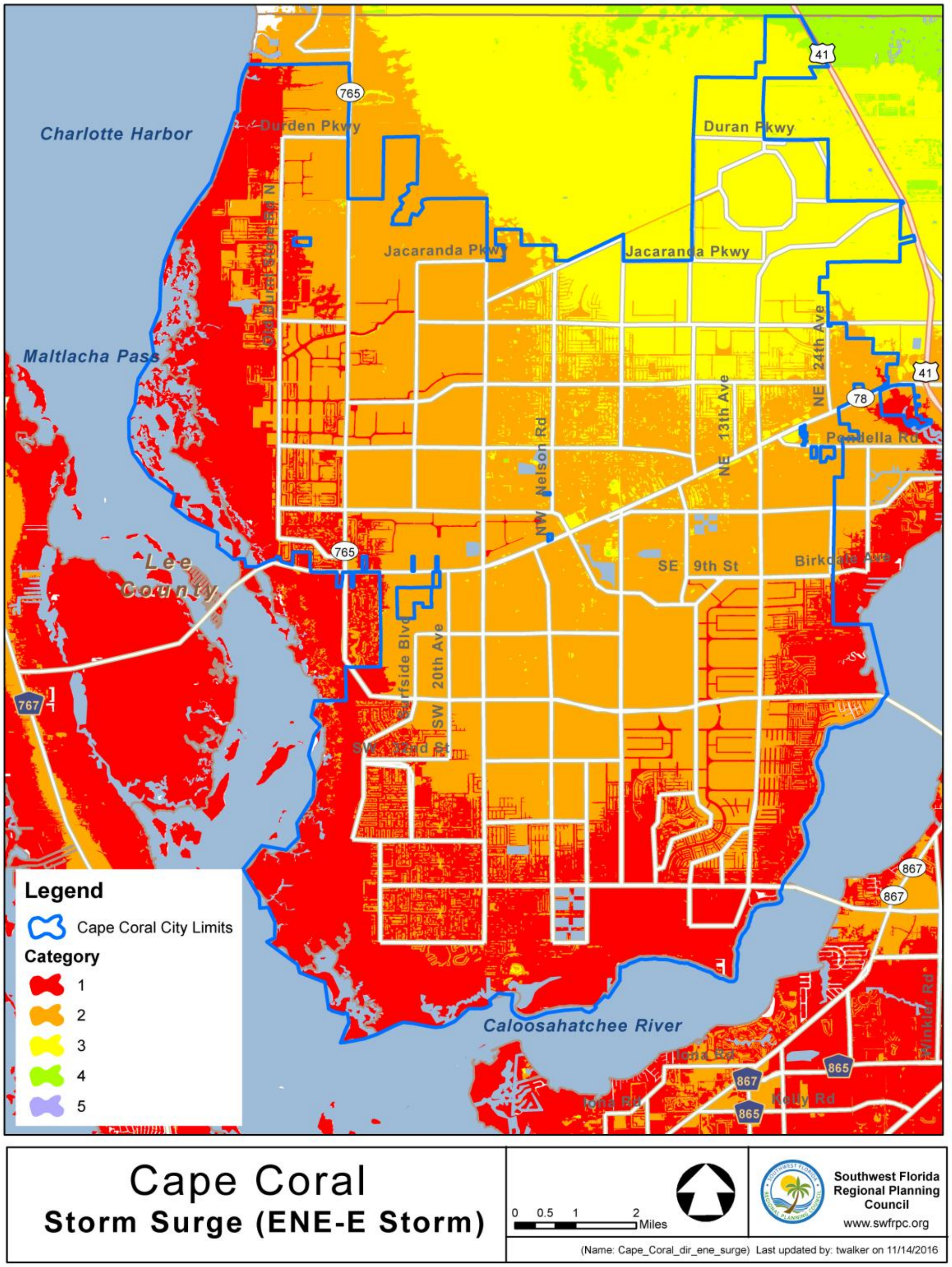


Figure 12: East- Northeast/ East Storm Surge Boundaries for City of Cape Coral

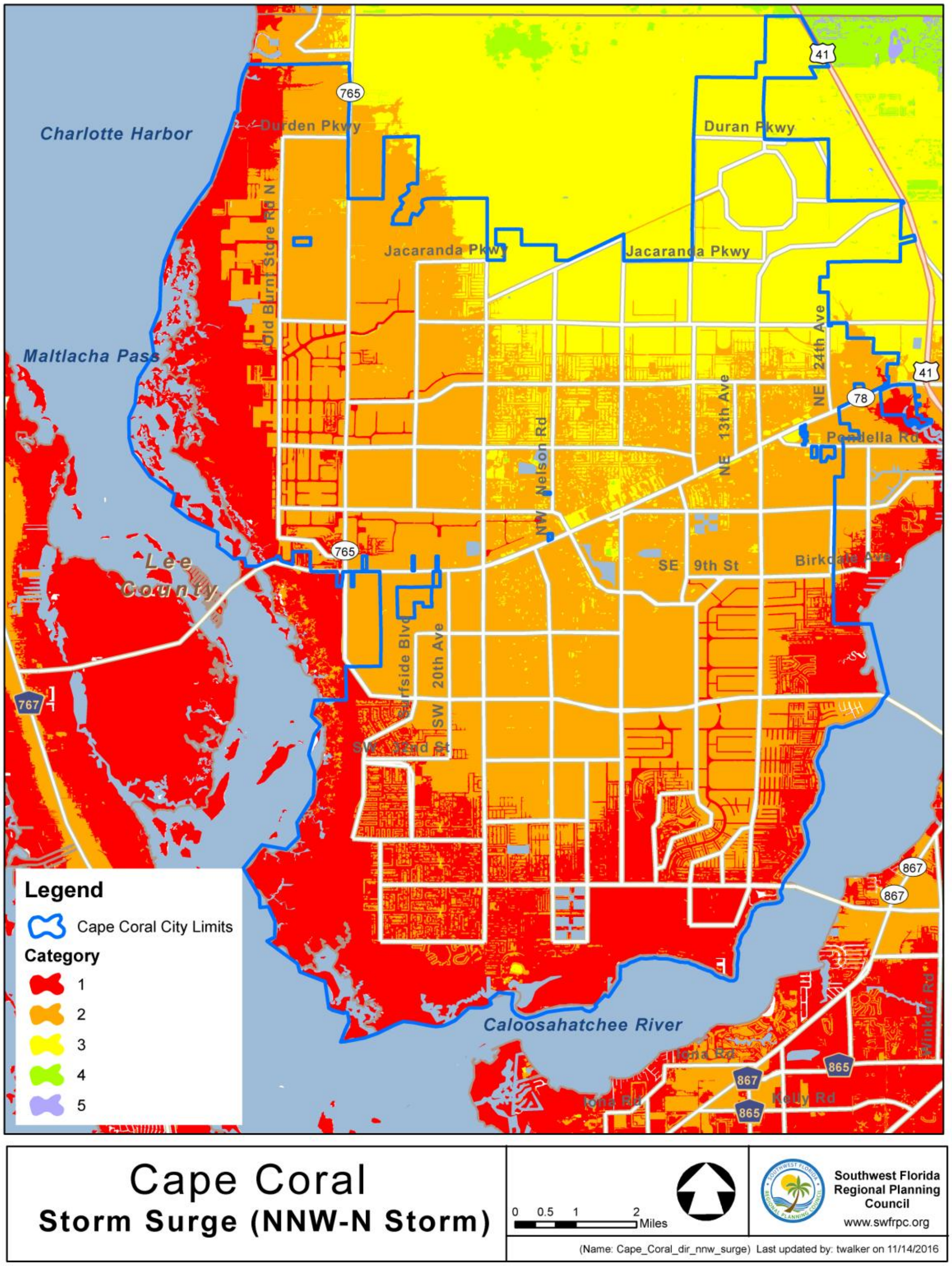


Figure 13: North- Northwest/ North Storm Surge Boundaries for City of Cape Coral

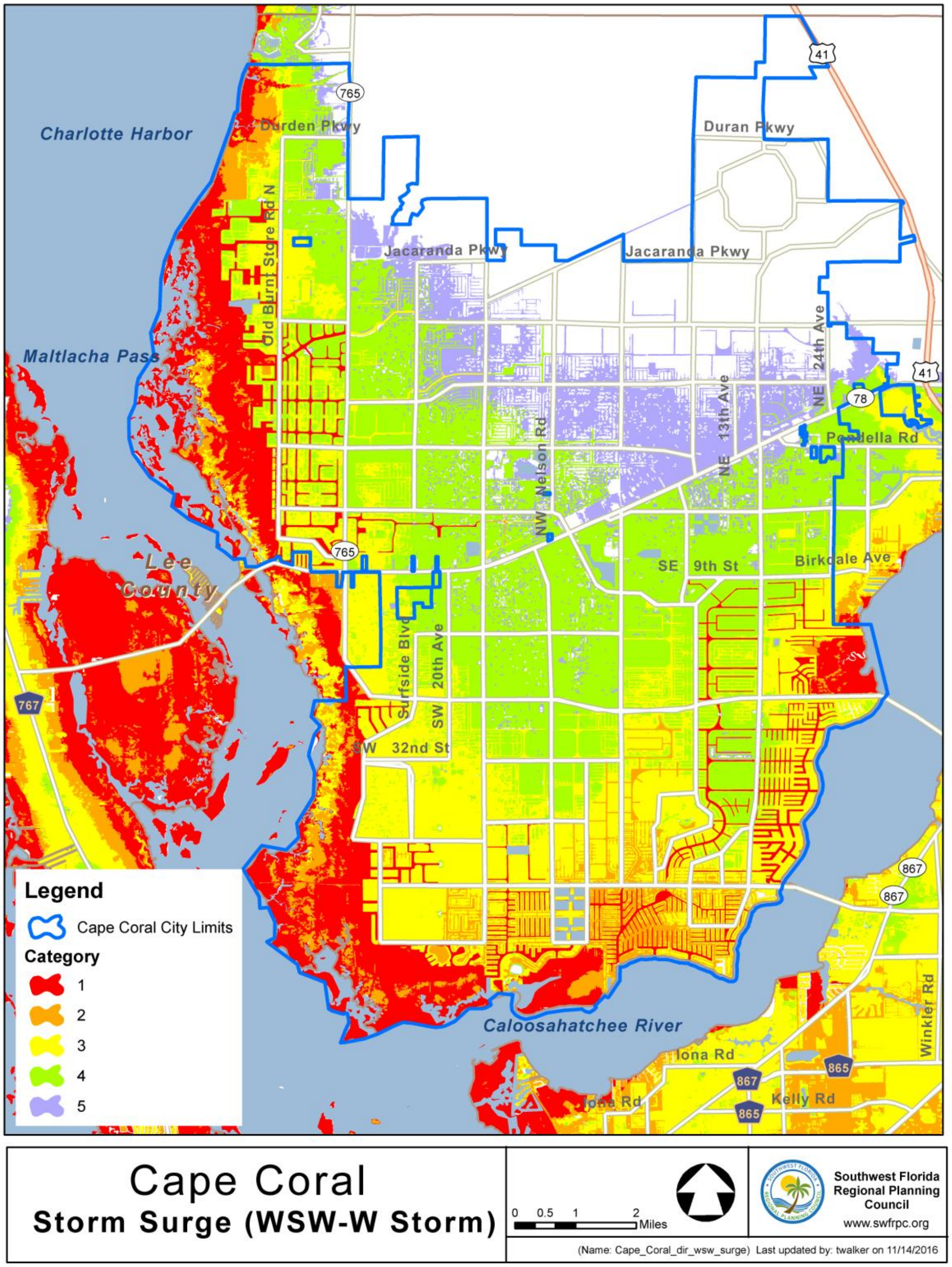


Figure 14 West-Southwest/ West Storm Surge Boundaries for City of Cape Coral

North/Northwest Storm Surge Acreage			
Category of Storm Surge	Acres in the City of Cape Coral	Cumulative Acres	% of the City of Cape Coral
1	23,347.48	23,347.48	30.63%
2	40,394.82	63,742.30	83.63%
3	12,420.77	76,163.07	99.93%
4	47.76	76,210.83	99.99%
5	2.78	76,213.61	99.996%
Not in Surge Zone	2.98		0.004%

East/Northeast Storm Surge Acreage			
Category of Storm Surge	Acres in the City of Cape Coral	Cumulative Acres	% of the City of Cape Coral
1	25,357.64	25,357.64	33.27%
2	40,667.82	66,025.45	86.64%
3	10,045.73	76,071.19	99.82%
4	137.60	76,208.78	100.00%
5	1.40	76,210.18	100.00%

North/Northeast Storm Surge Acreage			
Category of Storm Surge	Acres in the City of Cape Coral	Cumulative Acres	% of the City of Cape Coral
1	25,423.43	25,423.43	33.38%
2	41,046.30	66,469.73	87.28%
3	9,667.08	76,136.81	99.97%
4	19.77	76,156.57	100.00%
5	1.39	76,157.97	100.00%

West/Southwest Storm Surge Acreage			
Category of Storm Surge	Acres in the City of Cape Coral	Cumulative Acres	% of the City of Cape Coral
1	12,445.03	12,445.03	17.66%
2	4,274.48	16,719.51	23.73%
3	16,141.44	32,860.95	46.64%
4	21,771.83	54,632.79	77.54%
5	7,813.37	62,446.16	88.63%
Not in Surge Zone	13,770.43		19.54%

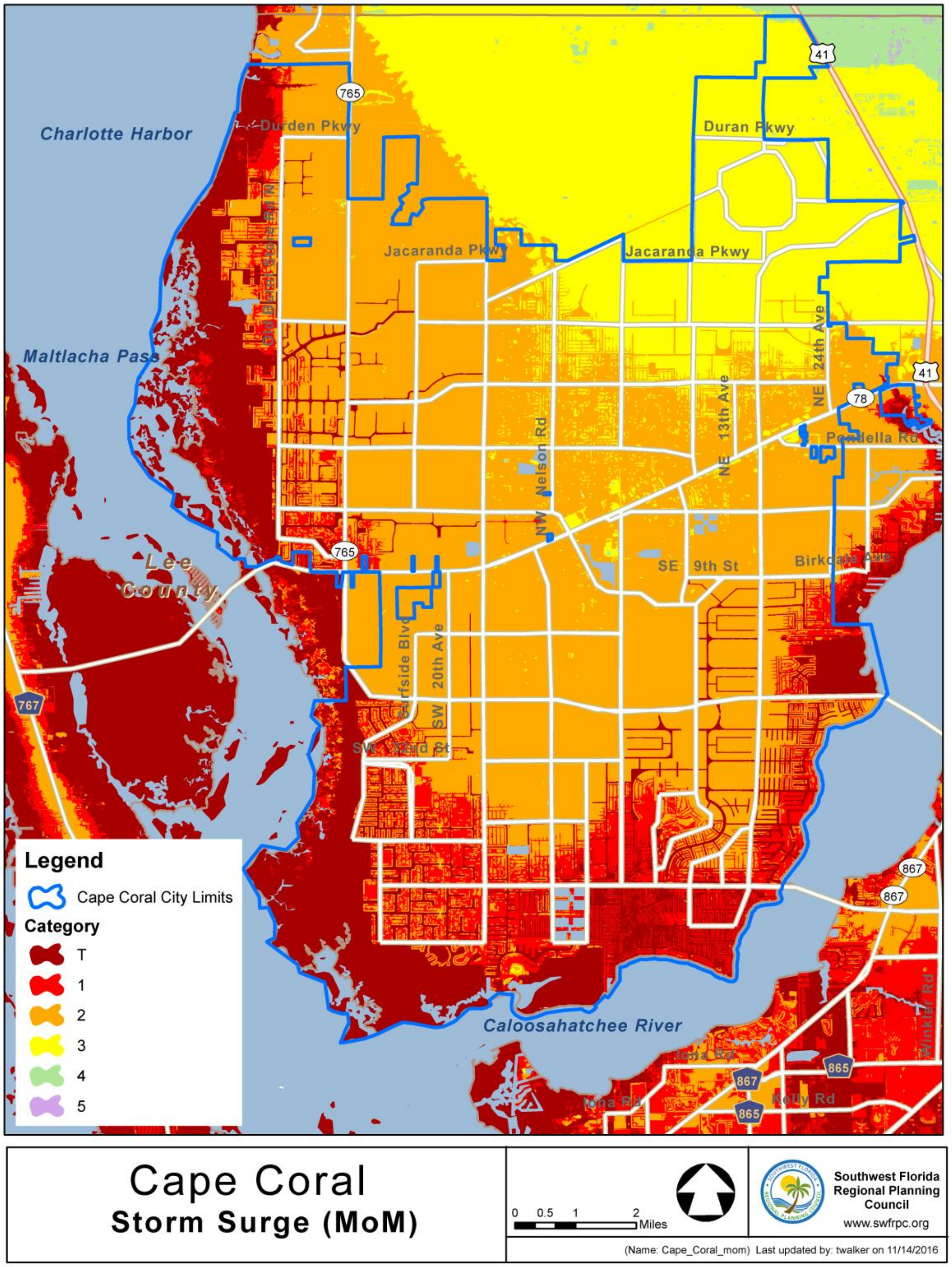


Figure 15 Maximum of the Maximum MoM Storm Surge Boundaries for City of Cape Coral

The Maximum of the Maximum Envelope of High Water (MoM) provides a worst case snapshot for a storm category under "perfect storm" conditions. Each MoM considers combinations of forward speed, trajectory, and initial tide level. These projects are compiled when a SLOSH basin is developed or updated. As with Maximum Envelope of High Water (MEOW), MoM is not storm specific and are available to view in the SLOSH display program for all basins. No single hurricane will produce the flooding depicted in the MoM. Instead, the product is intended to capture the worst case high water value at a particular location for hurricane evacuation planning . The MoM is also used to develop the hurricane evacuation zones.

Maximum of Maximum Storm Surge Acreage			
Category of Storm Surge	Acres in the City of Cape Coral	Cumulative Acres	% of the City of Cape Coral
Tropical Storm	16,901.05	16,901.05	22.17%
1	7,622.06	24,523.11	32.17%
2	41,733.26	66,256.37	86.91%
3	9,894.39	76,150.76	99.998%
4	80.57	76,231.33	99.998%
5	1.39	76,232.72	100.00%

Photograph 1: Red mangrove fringing forest killed by Hurricane Charley August 2004.
This is a site of CHNEP restoration effort studies.
Source: CHNEP 2008

Lee County has developed Local Mitigation Strategies (LMS) for anticipated natural disasters including flooding and the impacts of tropical storms and hurricanes. The LMS estimates the effects of different levels of tropical storm impacts on infrastructure and properties and estimates potential financial losses/damages from such events. The last updates are from 2011. The following figures indicate the magnitude of the vulnerability of the County 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. At this time we have not been able to acquire the information on structures by surge zone of the City of Cape Coral separated from the total information for Lee County.

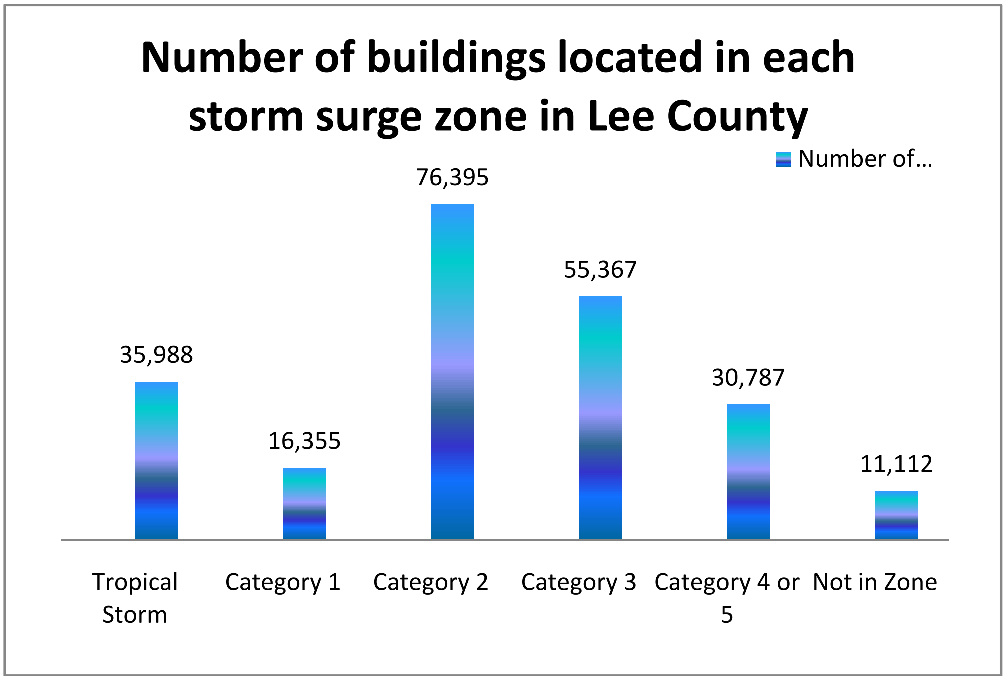


Figure 16: Number of buildings located in each tropical storm and hurricane storm surge zone in coastal City of Cape Coral study area

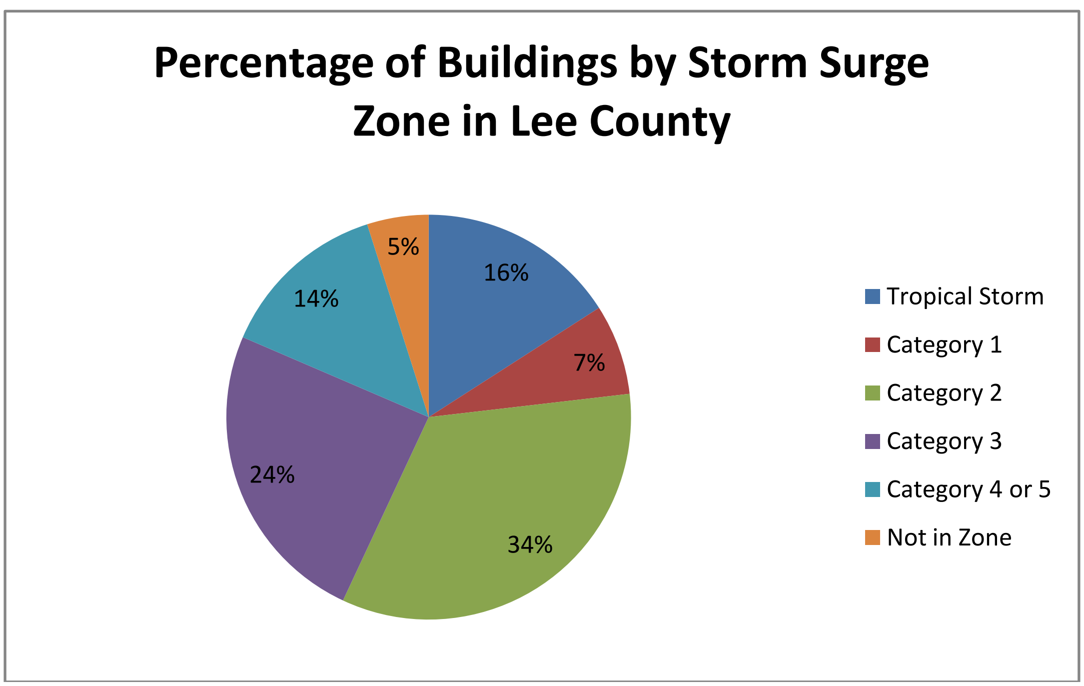


Figure 17: Proportion of buildings located in each tropical storm and hurricane storm surge zone in coastal City of Cape Coral study area

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).

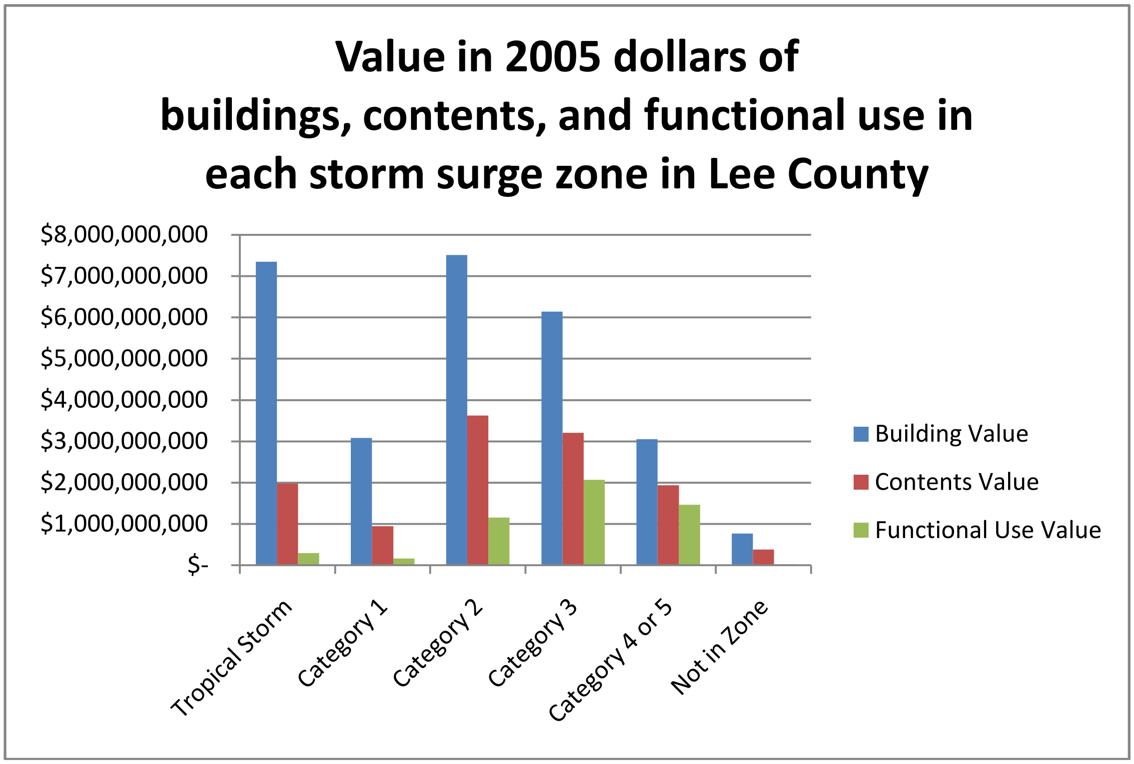


Figure 18: Monetary value in 2005 dollars of buildings, contents, and functional use in each storm surge zone in City of Cape Coral

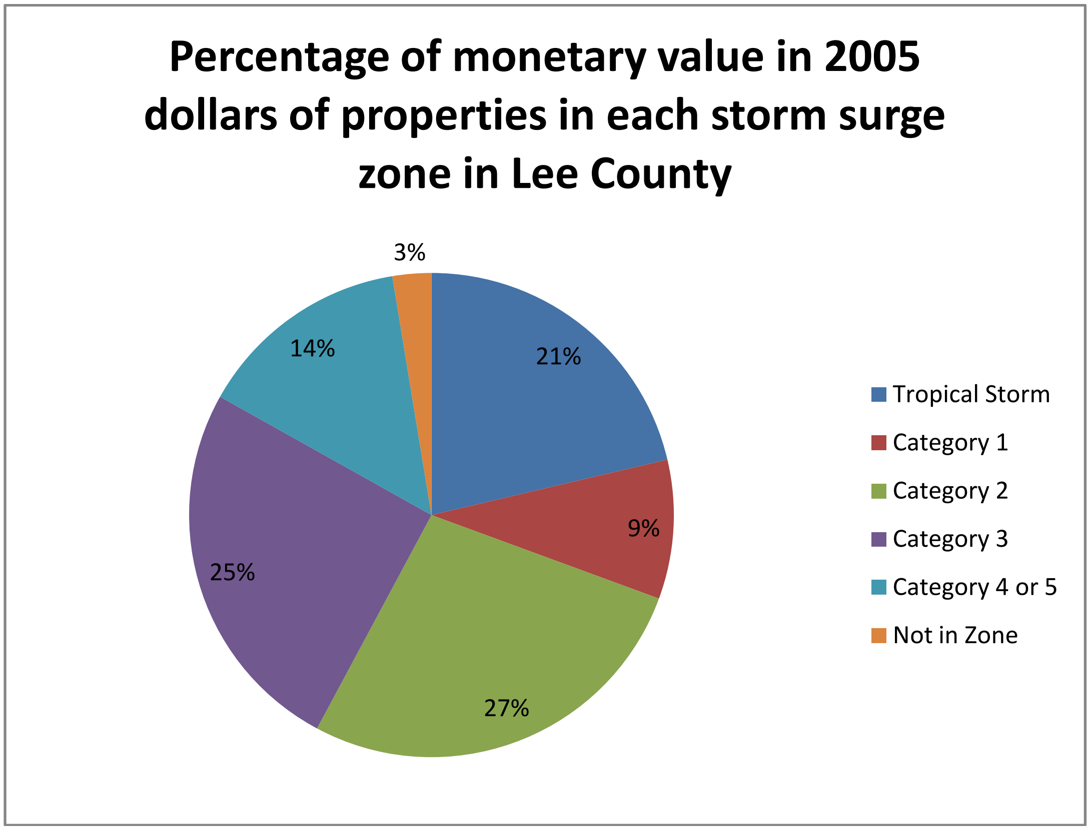


Figure 19: Percentage in monetary value in 2005 dollars of properties in each storm surge zone in coastal City of Cape Coral/SWFPC study area

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, 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).

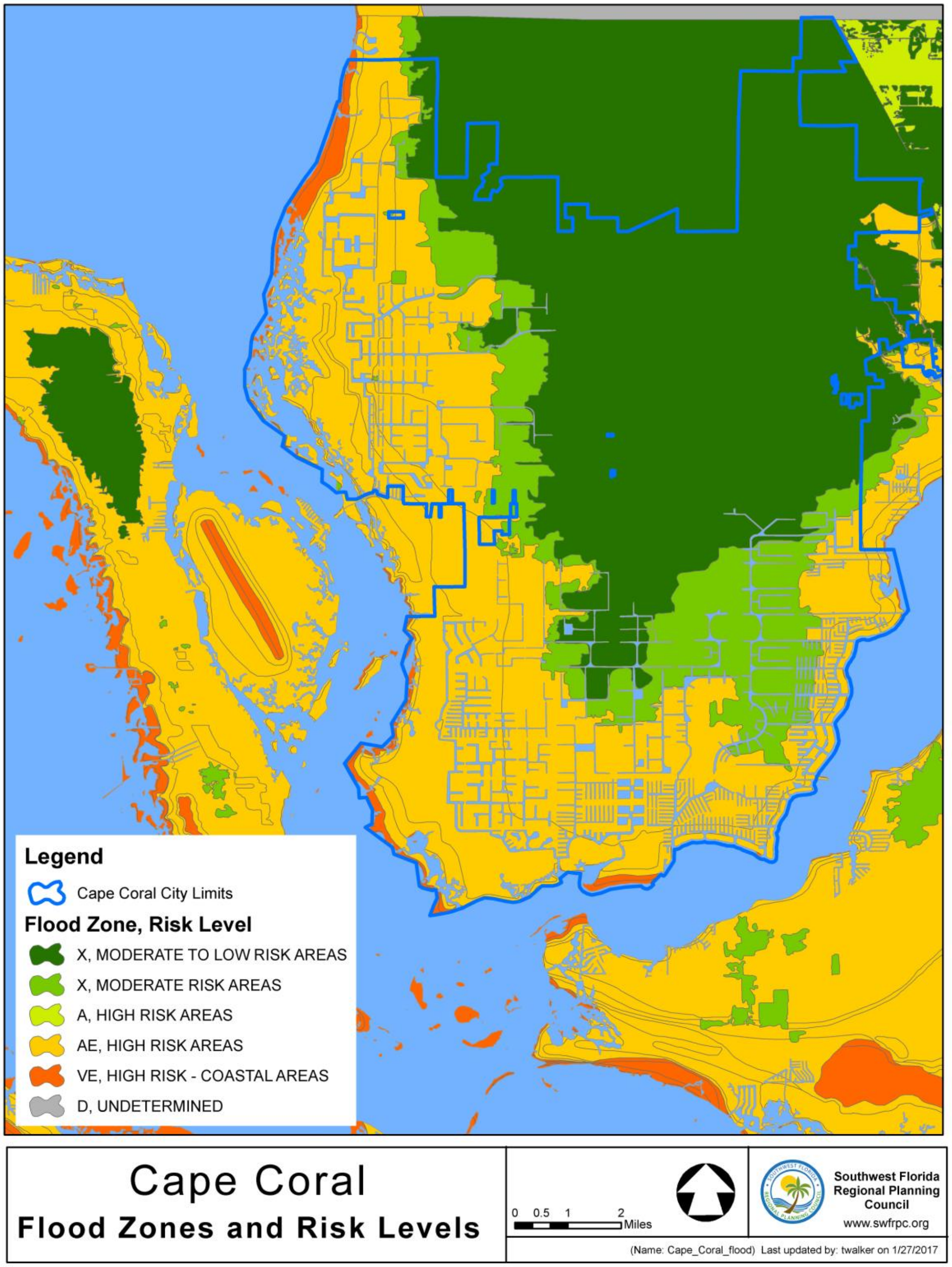


Figure 20: Unified Flood Risk Zones for the City of Cape Coral

Sea Level Rise

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 21) (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).

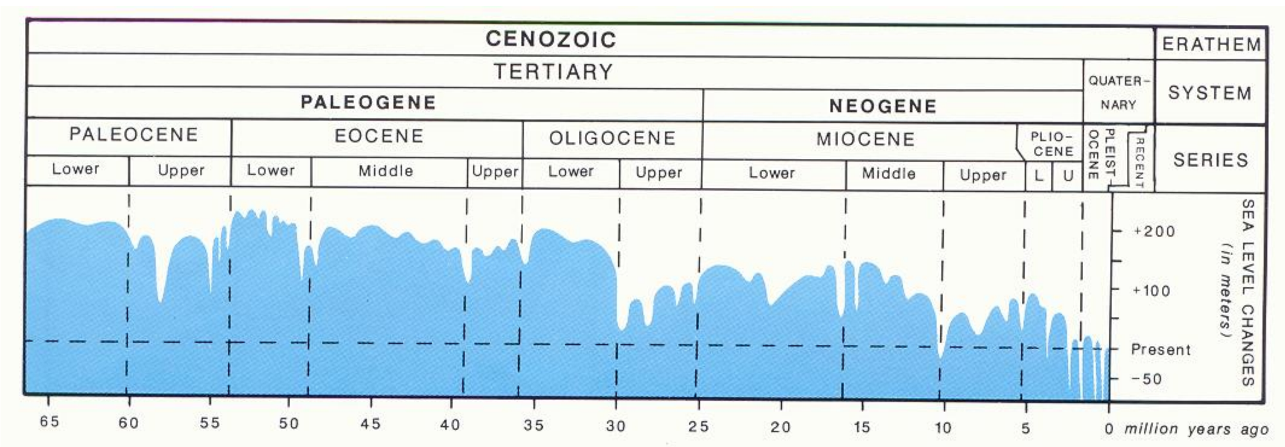


Figure 21: Sea level changes during the last 65 million years

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 22).

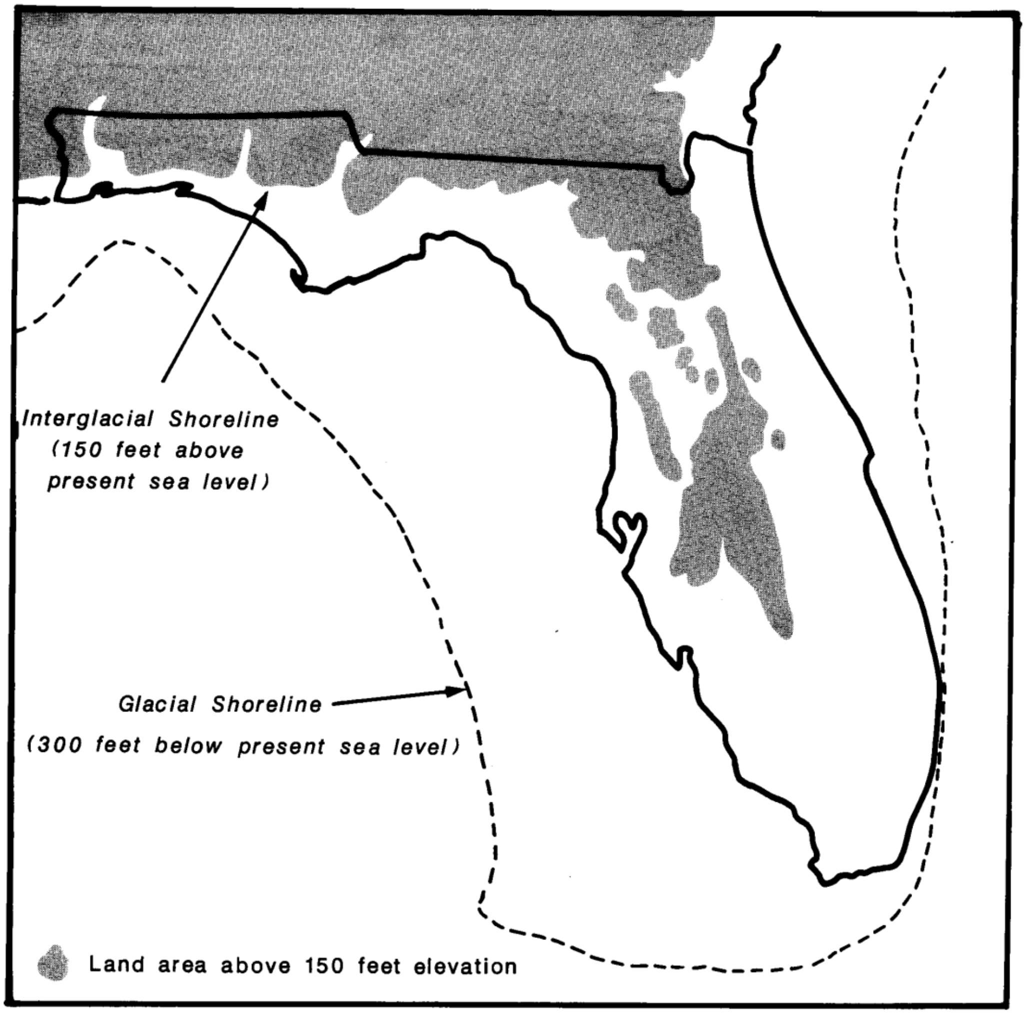


Figure 23: Shoreline of Florida between 1.8 million to 10,000 years ago

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 23) (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 24 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).

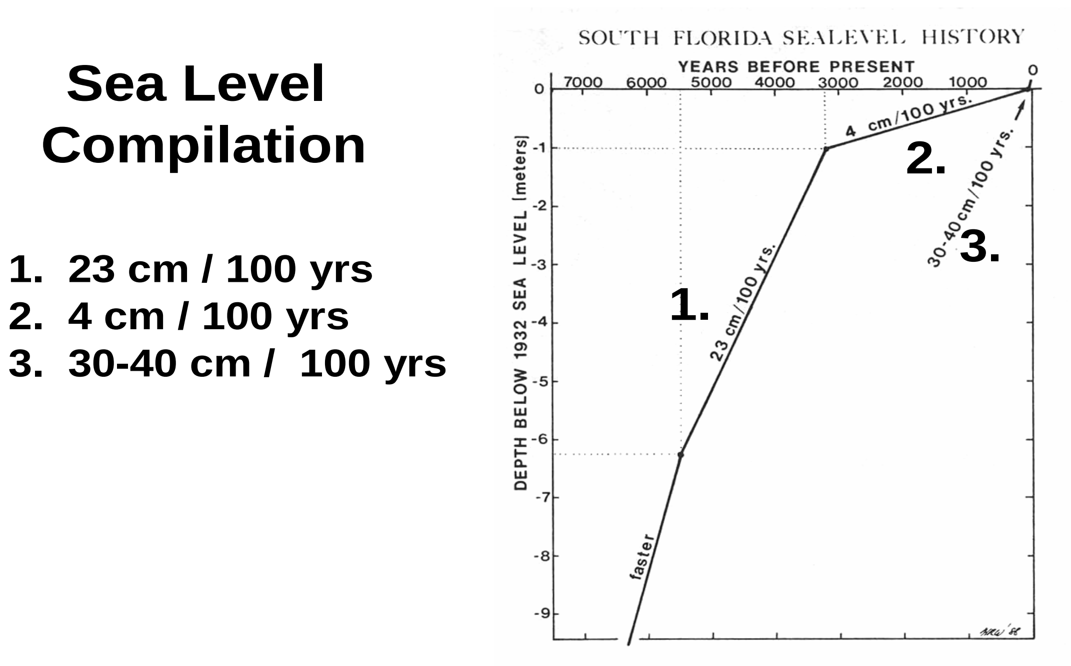


Figure 24: Sea level rise rates compiled by Wanless et al. (1994)

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.

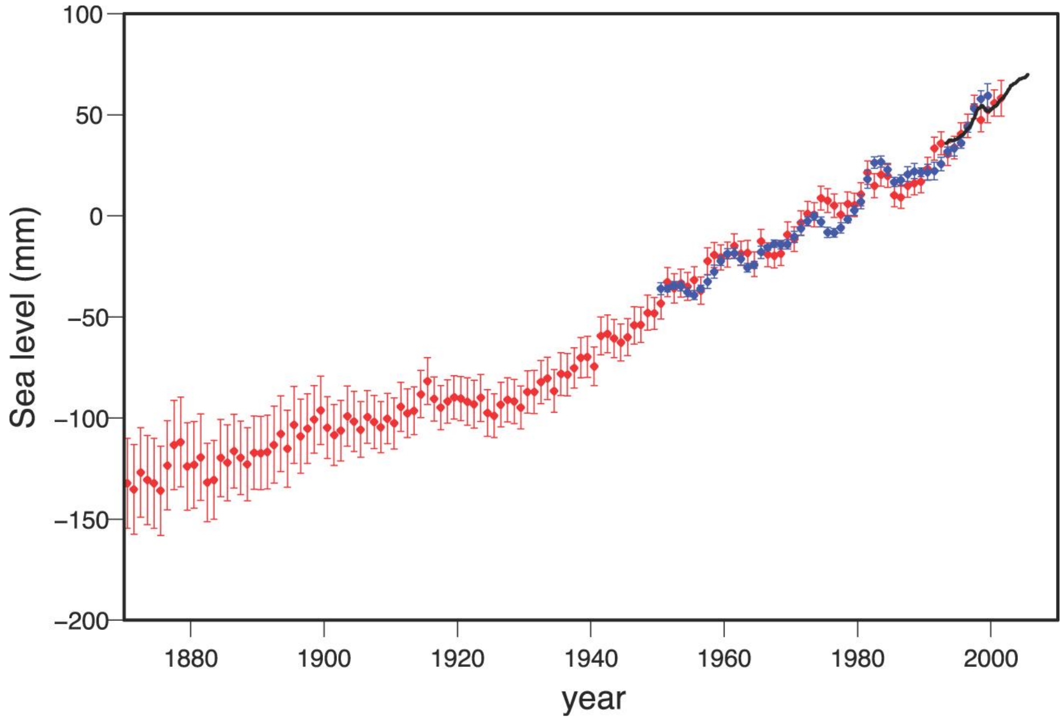


Figure 25: Annual averages of global mean sea level in millimeters
The red curve shows reconstructed sea level fields since 1870 (updated from Church and White, 2006); the blue curve shows coastal tide gauge measurements since 1950 (from Holgate and Woodworth, 2004) and the black curve is based on satellite 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

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 26 for sea level trends in selected cities.

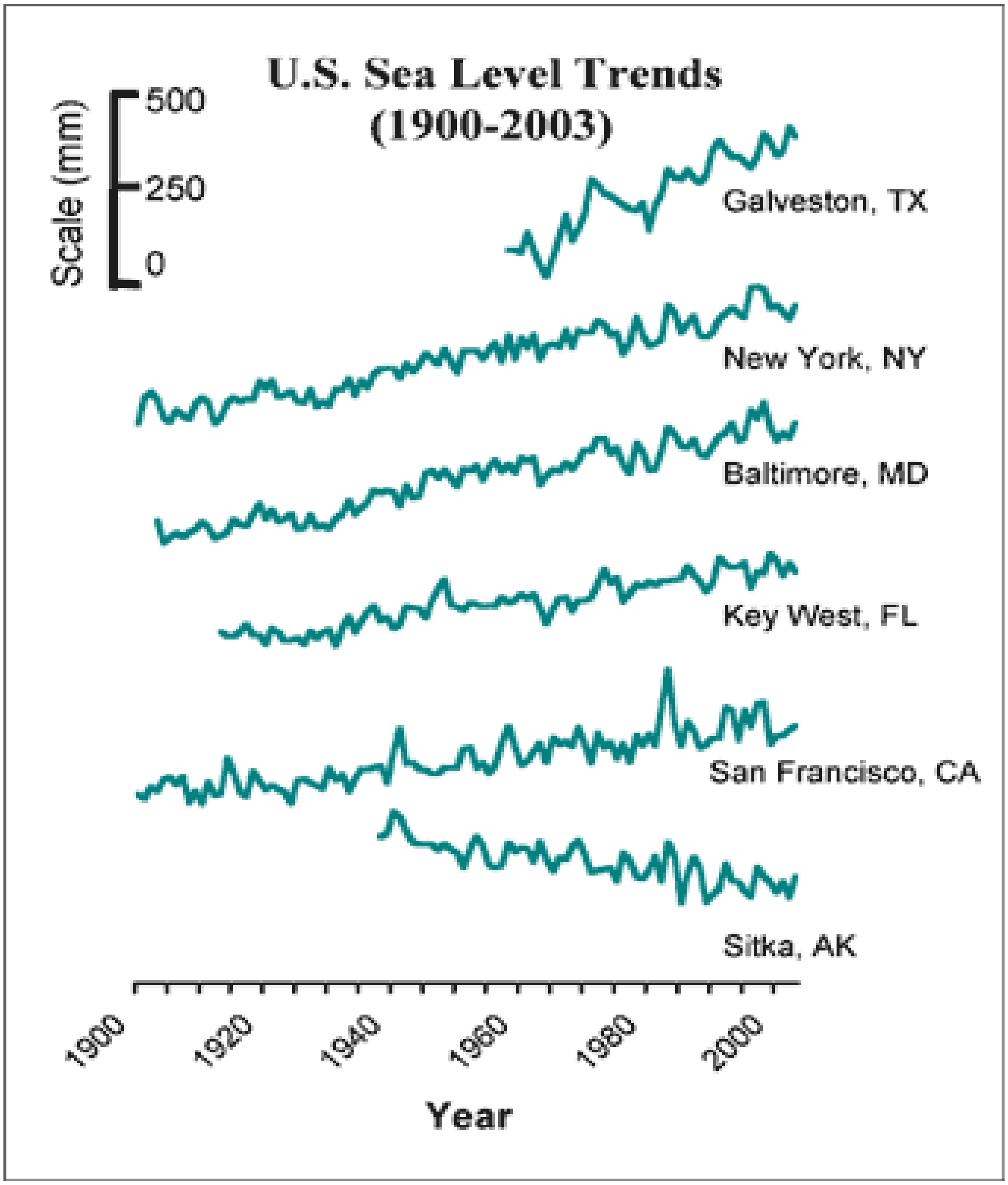


Figure 26: U.S. Sea Level Trends
Source: Monthly and Annual Mean Sea Level Station Files from the Permanent Service for Mean Sea Level (PSMSL) at the Proudman Oceanographic Laboratory

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 27 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).

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.

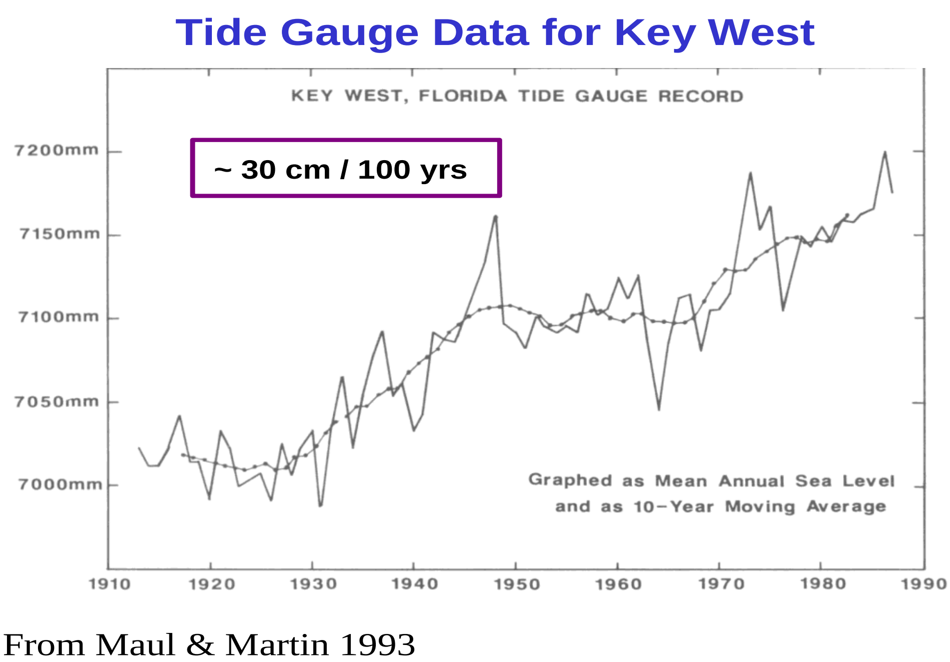


Figure27: Mean annual sea level at Key West, Florida 1910-1990

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

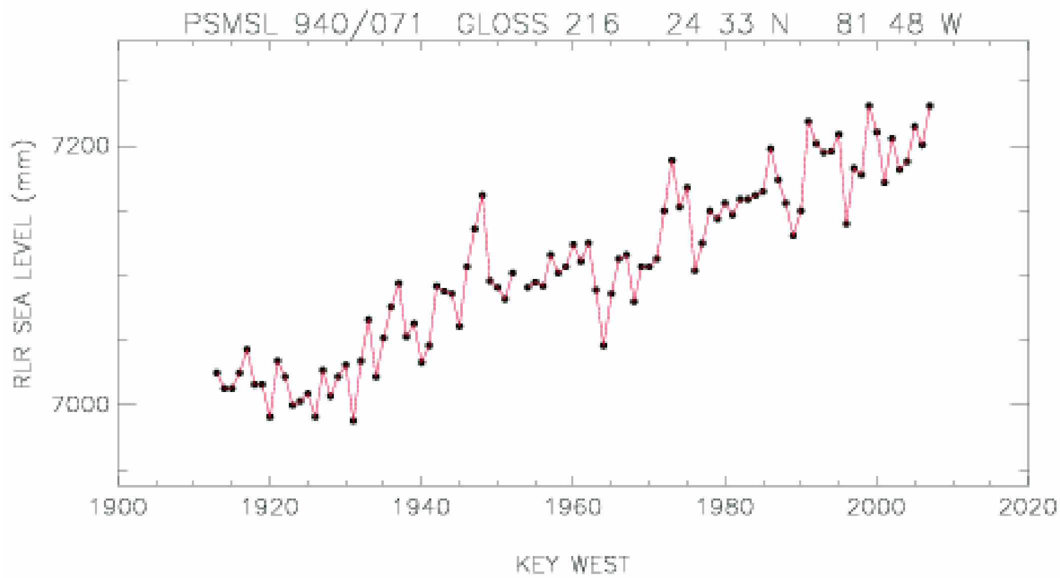


Figure28: Mean Annual Sea Level at Key West, Florida 1910-2009
Source: Permanent Service for Mean Sea Level (PSMSL), hosted at the Proudman Oceanographic Laboratory (POL)

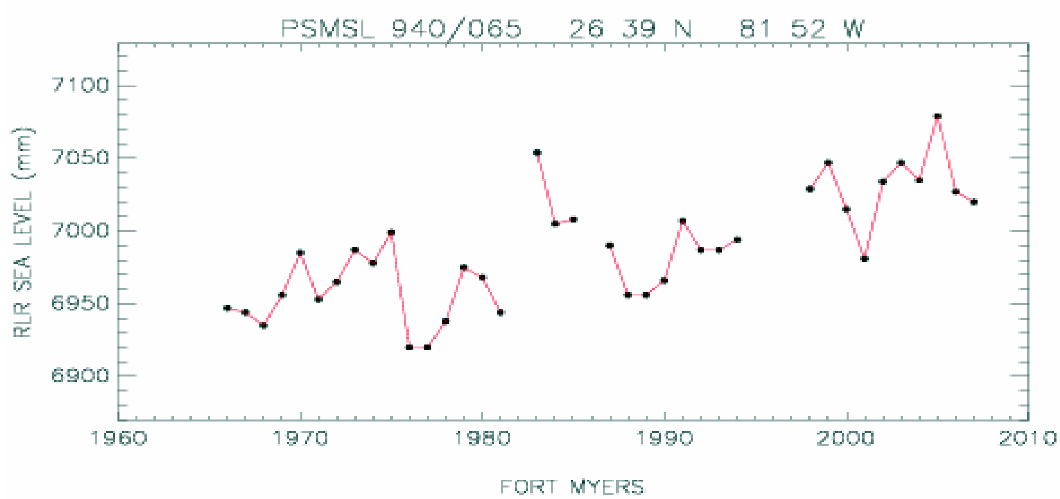


Figure 29: Mean Annual Sea Level at Fort Myers, Florida 1910-2009
Source: Permanent Service for Mean Sea Level (PSMSL), hosted at the Proudman Oceanographic Laboratory (POL)

Potential Future Climate Effects: Sea Level

The current 2016 measured rate of sea level rise for the City of Cape Coral is 2.85 mm per year. This is a 4.4% increase over the measured rate in the year 2014. At this current rate the sea level would be 1 foot higher in 107 years; two feet higher in 214 years; and 3 feet higher in 321 years. Put another way sea level will be 1 foot higher in 2123, 2 feet higher in 2230; and 3 feet higher in 2337.

The five sea level rise "severity" scenarios were discussed in the Potential Climate Futures section.

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 7: 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).

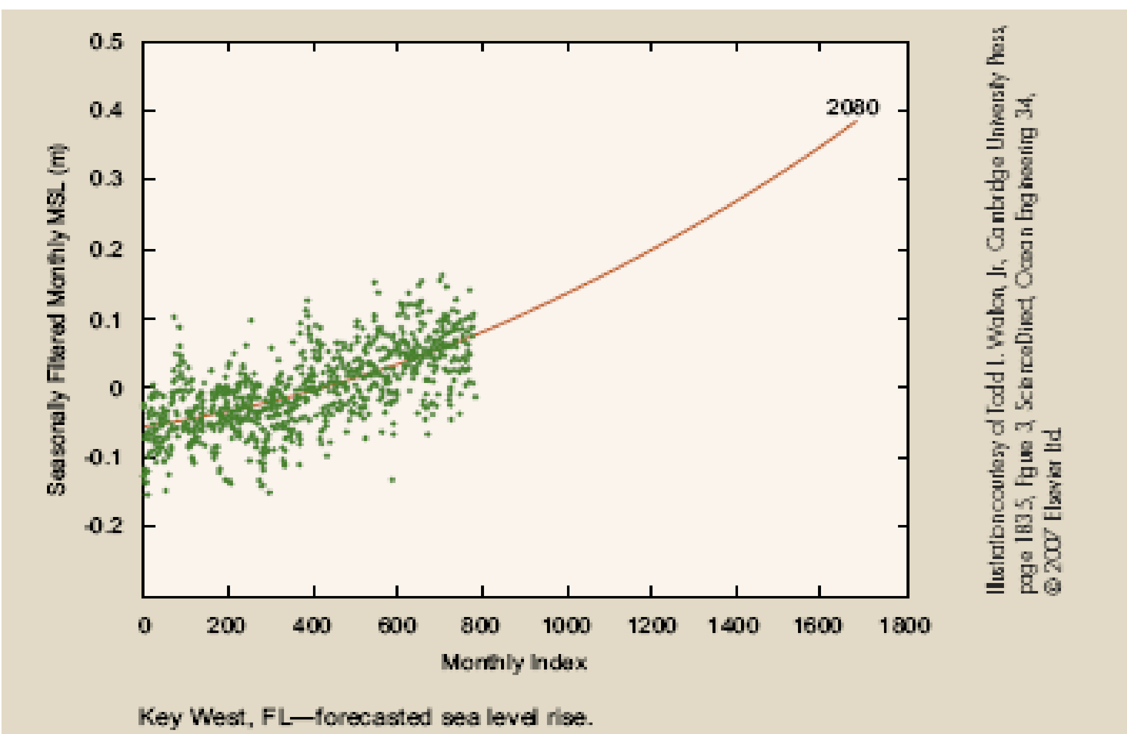


Figure 30: Forecasted Sea Level Rise at Key West, Florida

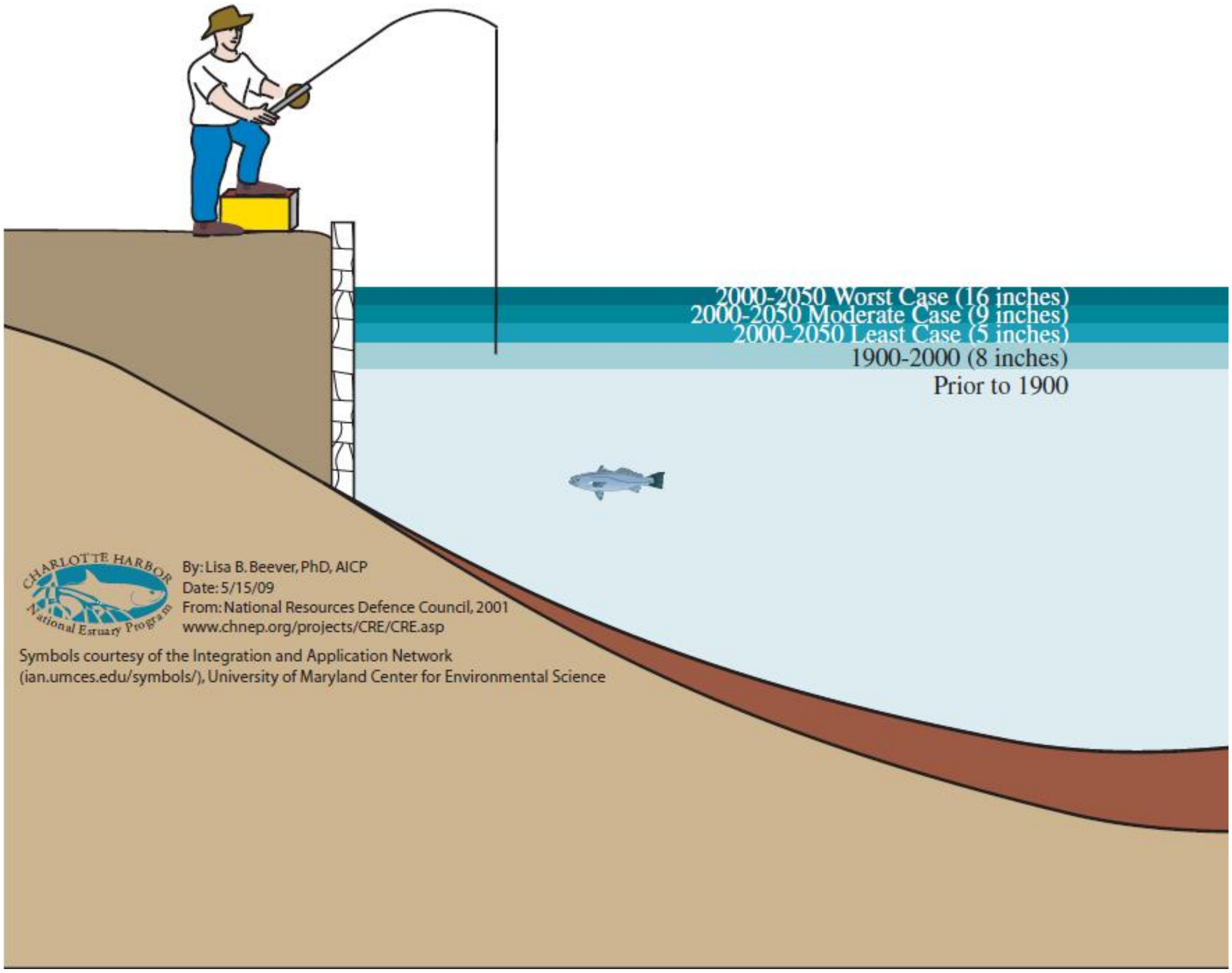


Figure 31: Sea level rise in three different probabilities in the year 2050 for City of Cape Coral at Cape Coral Bridge Bulkhead.
Least case (90% probable), moderate case (50% probable) and worst case (5% probable)
Source: IPCC 2007

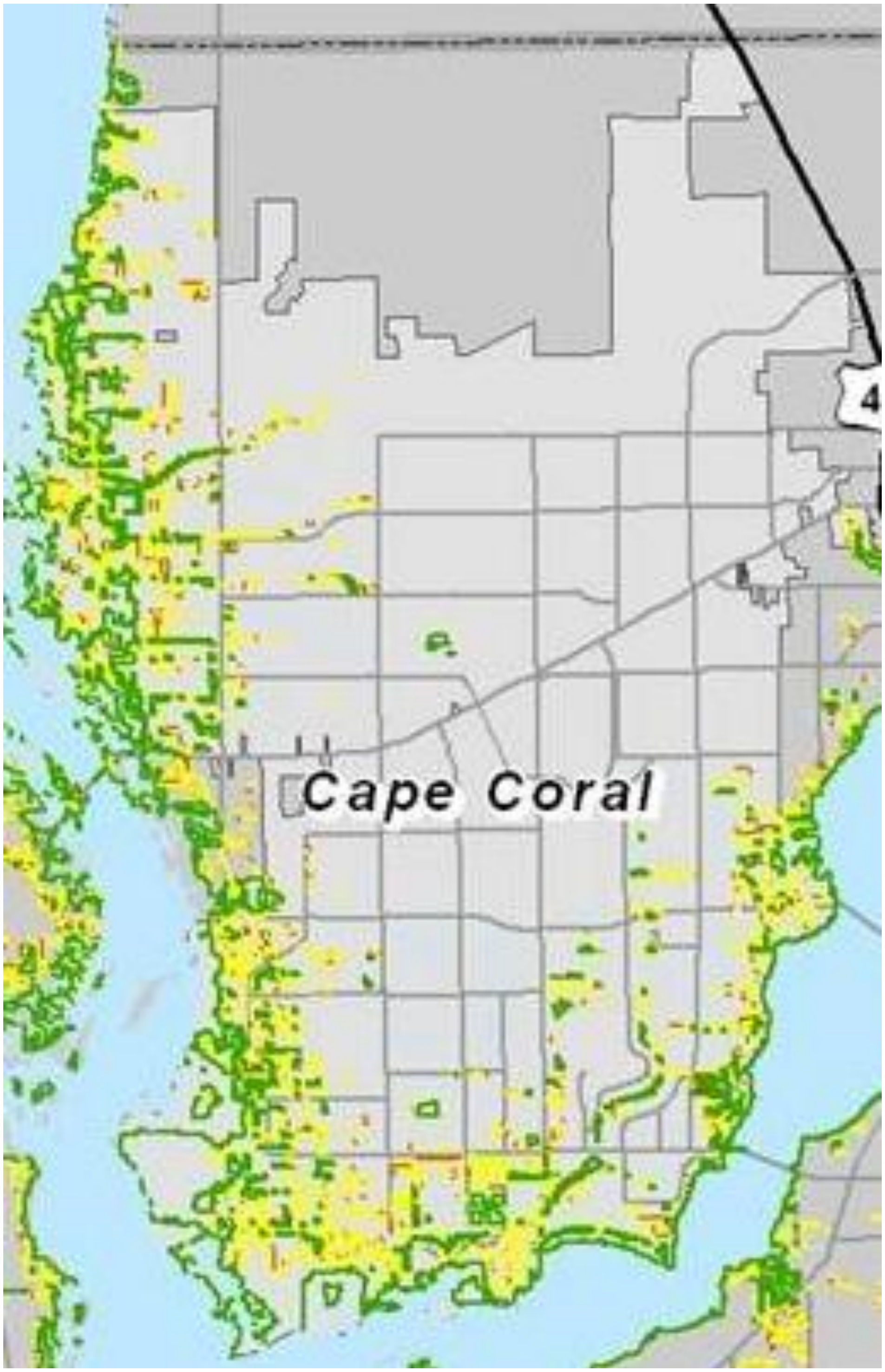


Figure 32: Estimated Sea Level Rise Year 2050 in Three Probability Scenarios

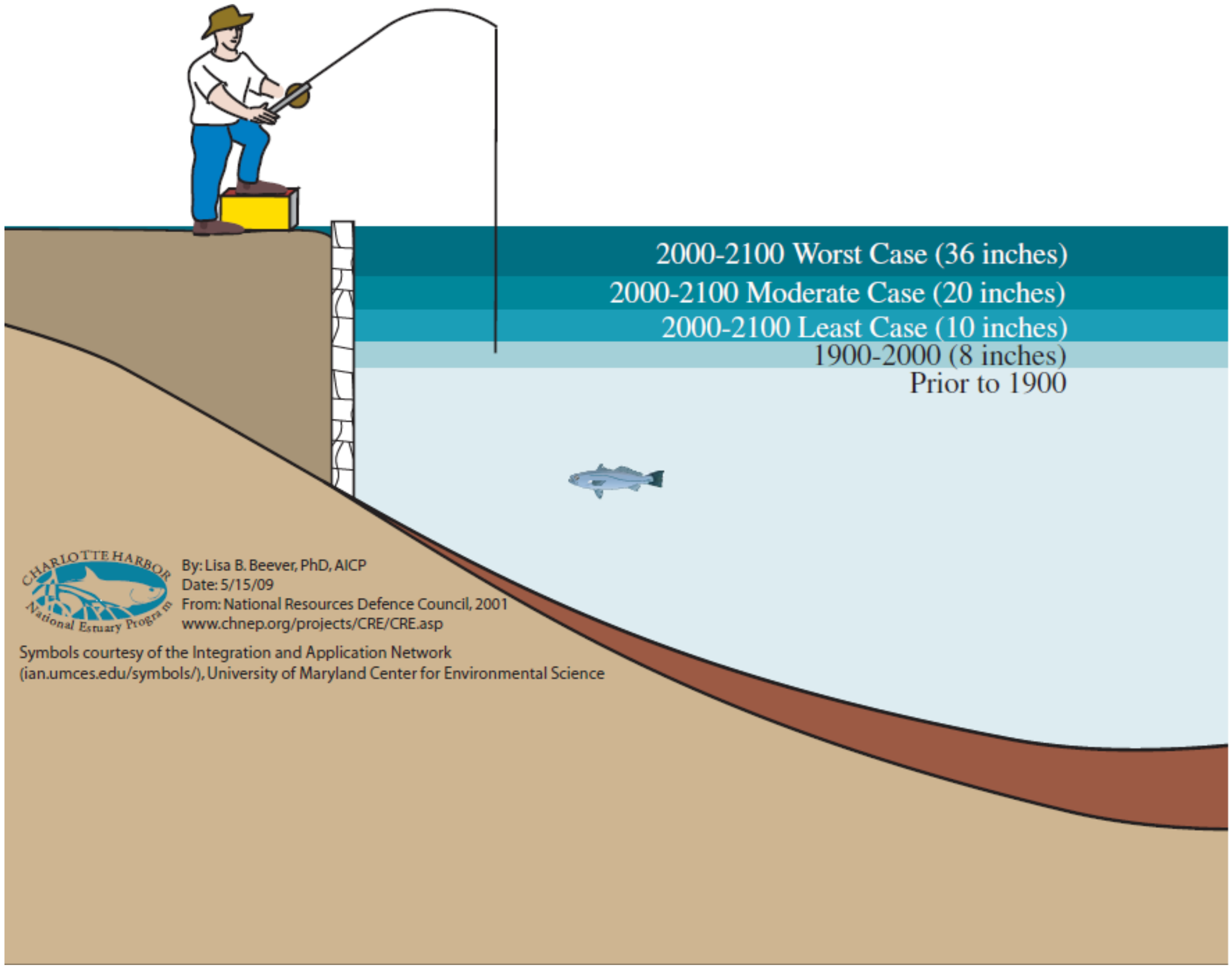


Figure 33: Sea level rise in three different probabilities in the year 2100 for City of Cape Coral at Cape Coral Bridge Causeway Bulkhead

Least case (90% probable), moderate case (50% probable) and worst case (5% probable)

Source: IPCC 2007

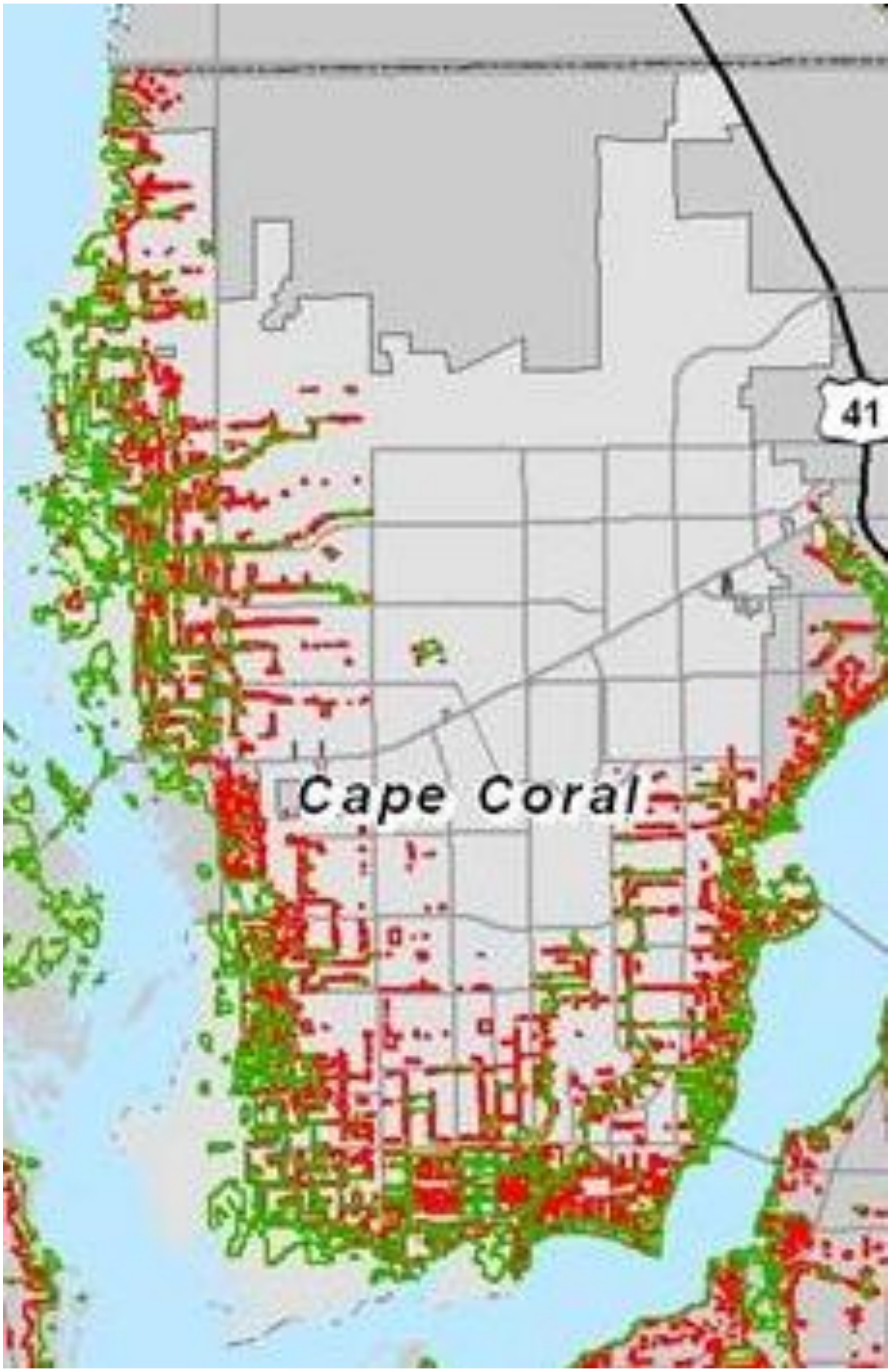


Figure 34 Estimated Sea Level Rise Year 2100 in Three Probability Scenarios

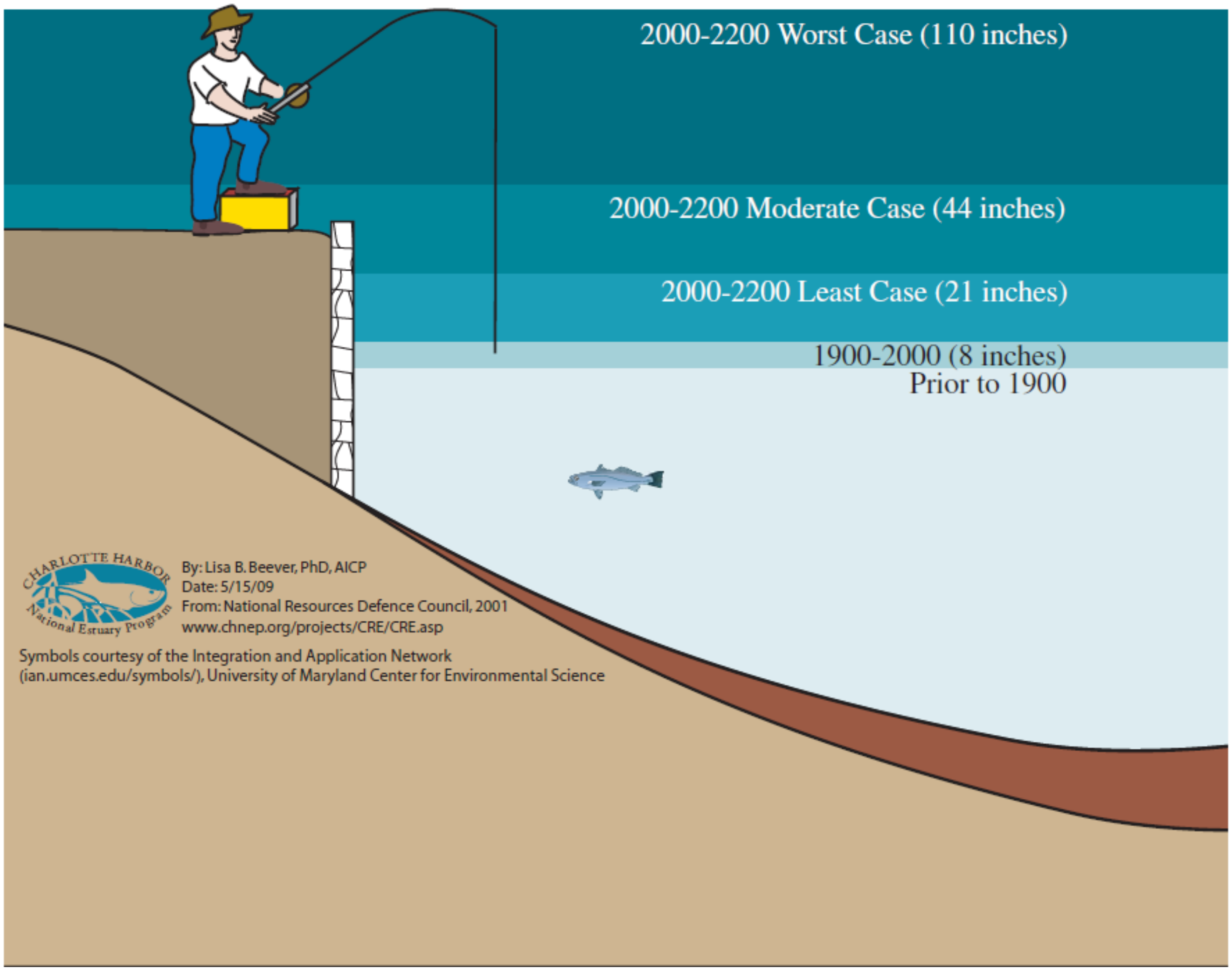


Figure 35: Sea level rise in three different probabilities in the year 2200 for City of Cape Coral at the Cape Coral Bridge Causeway Bulkhead.

Least case (90% probable), moderate case (50% probable) and worst case (5% probable)

Source: IPCC 2007

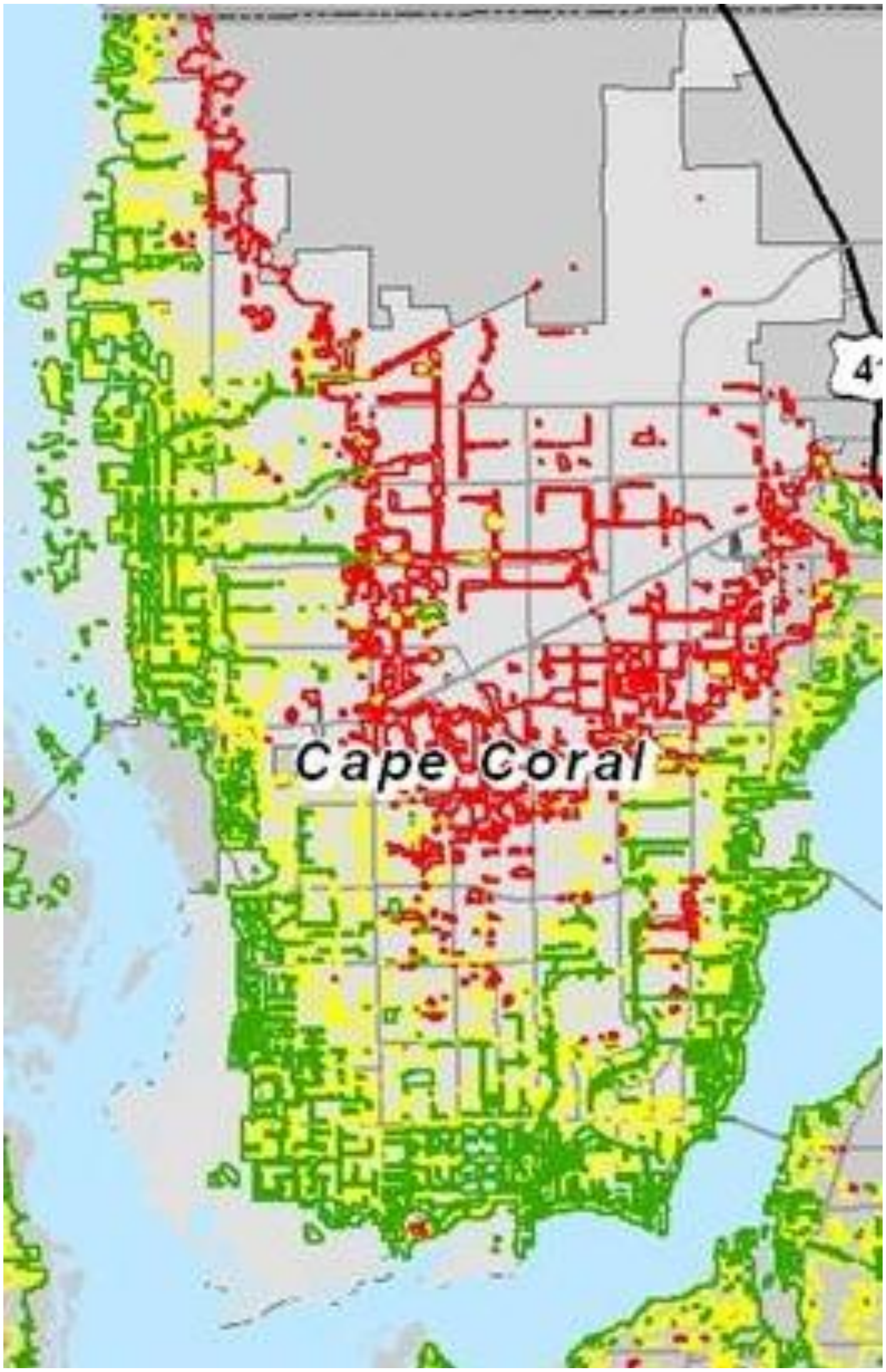


Figure 36: Estimated Sea Level Rise Year 2200 in Three Probability Scenarios

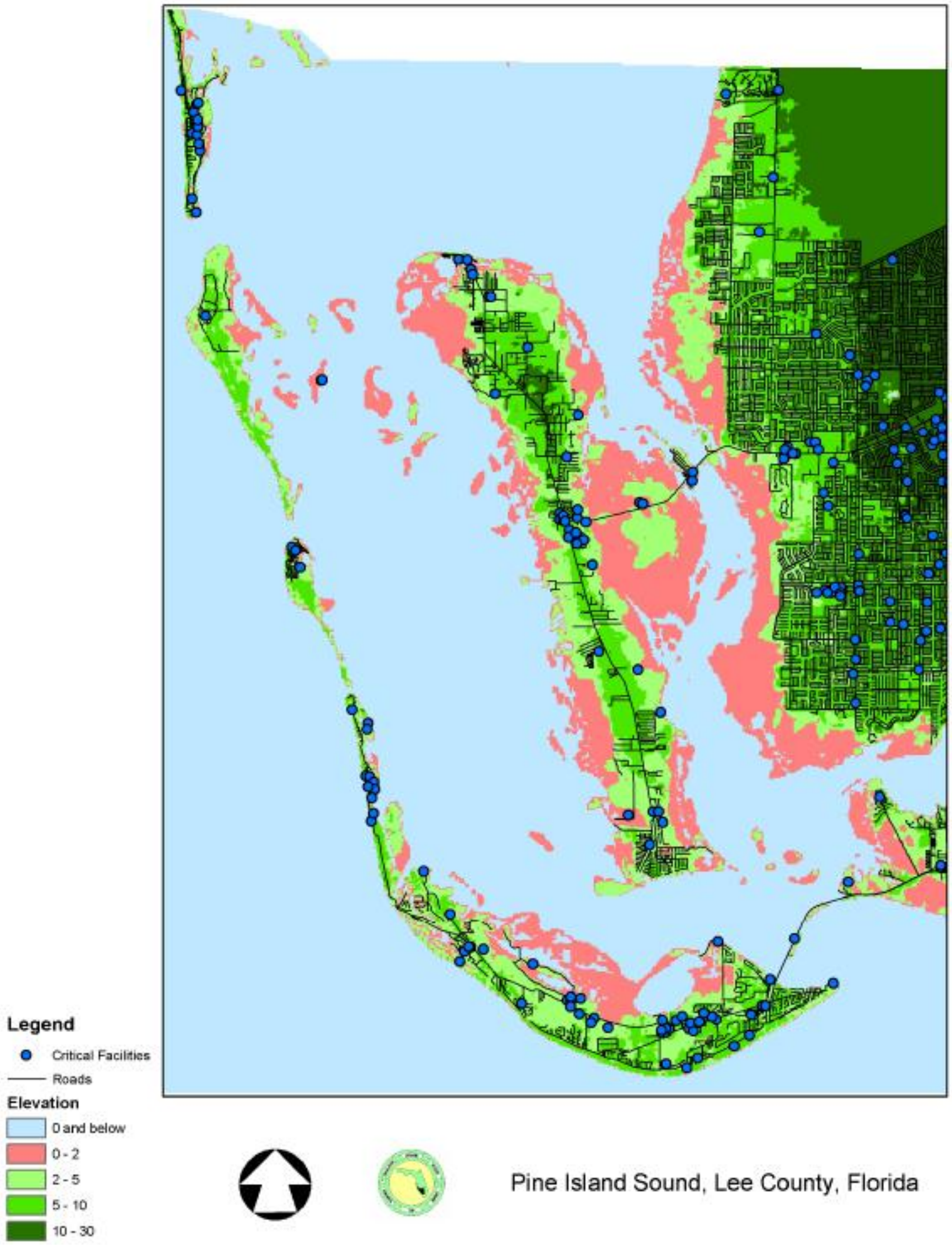


Figure 37: Two-foot contour sea level rise for the Pine Island Sound, Matlacha Pass, and San Carlos Bay Area. This is the prediction of Karl et al. (2007) for the year 2100; approximately equivalent to a 90% probability 2200 prediction (IPCC 2007); a 5% Probability 2075 prediction (IPCC 2007); or the 2050 Business as Usual Worst Case scenario (Stanton and Ackerman 2007).

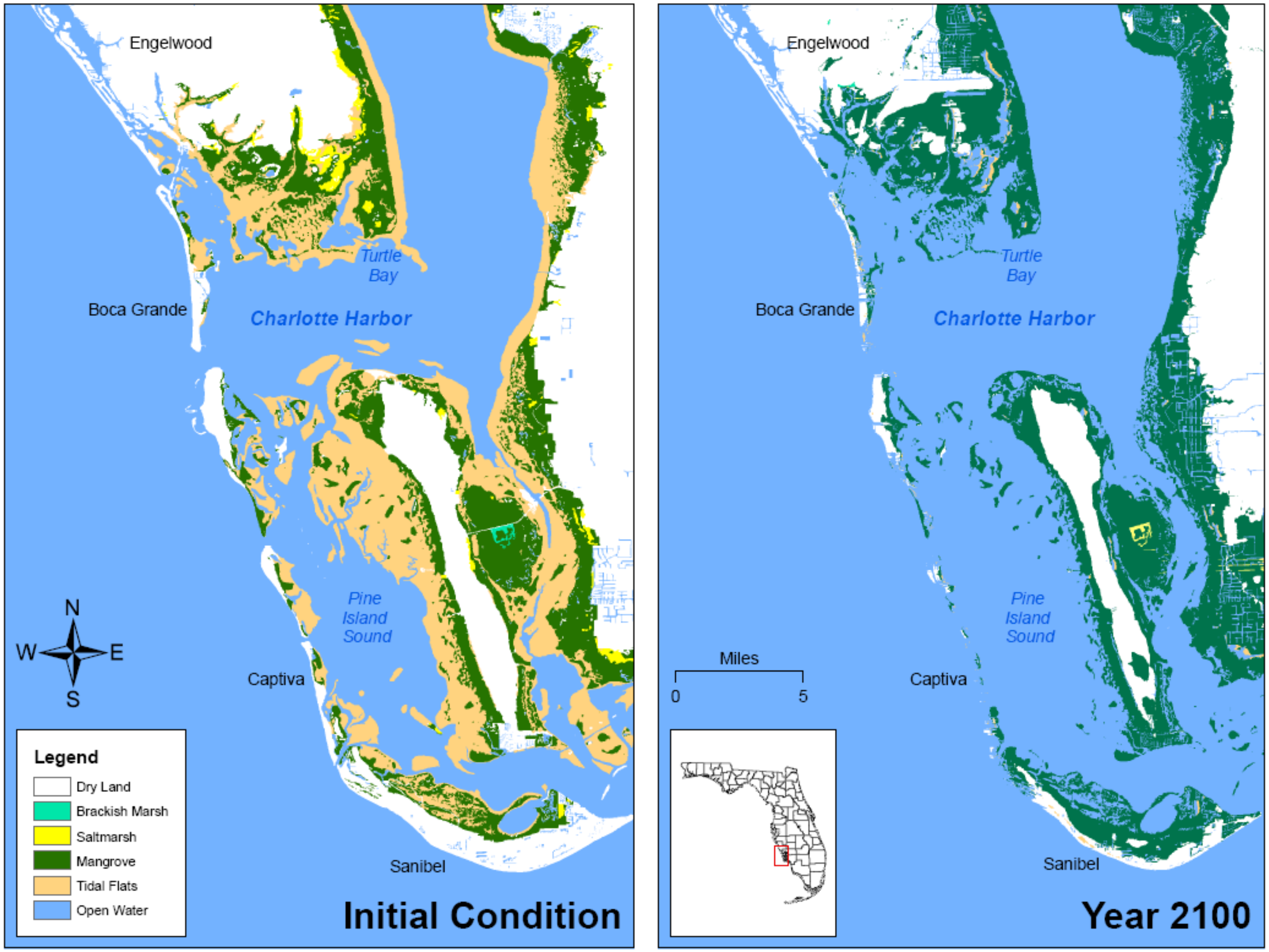


Figure 38: Three-foot contour sea level rise Sea Level Rise in Lower Charlotte Harbor Estuary Year 2100.
This is the 5% probability worst case IPCC (2007) scenario.

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. 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 City of Cape Coral, with complete Lidar data at this time. 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

Table8: Predicted year of different elevation levels (NGVD) of sea level rise for different future scenarios

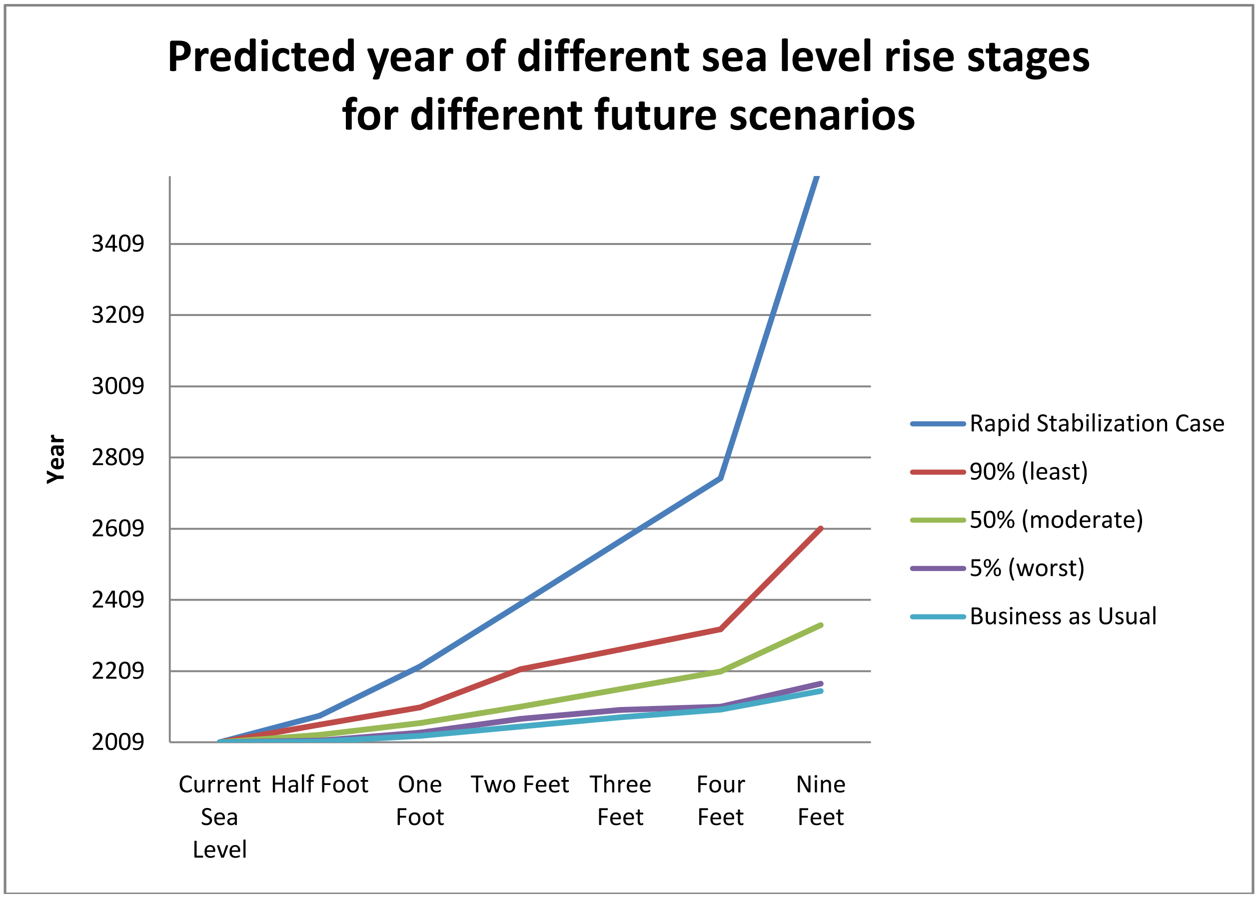


Figure 39: Approximate predicted year of different elevation levels (NGVD) of sea level rise for different future scenarios

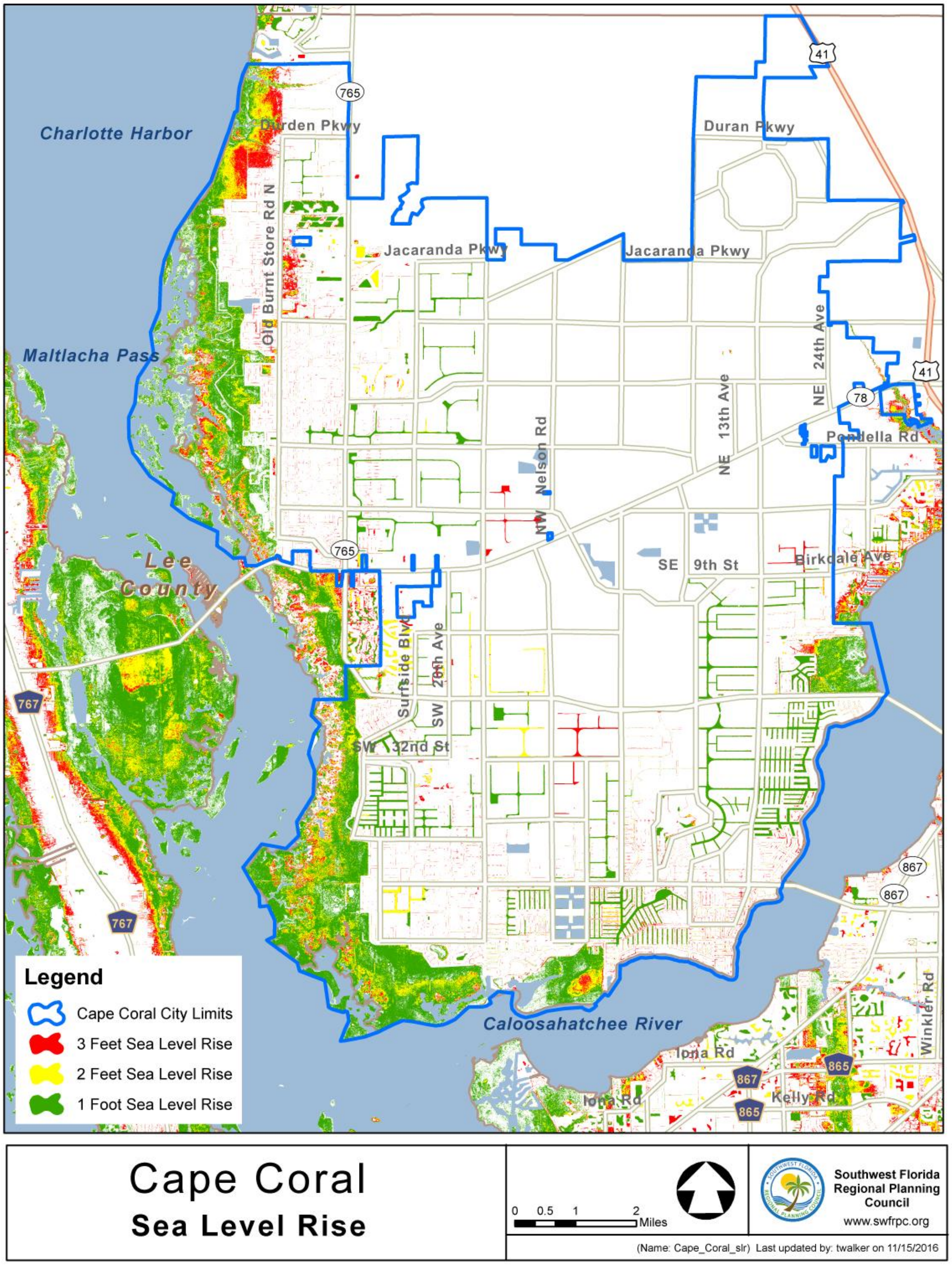


Figure 40: Sea Level Rise at 1, 2, and 3 Feet

Area Affected by Different Levels of Sea Level Rise			
Increase in Sea Level (in feet)	Acres of the City of Cape Coral Affected	Cumulative Acres Affected	Percentage of the City
1	7,053.70	7,053.70	10.01%
2	2,297.58	9,351.28	13.27%
3	1,578.96	10,930.25	15.51%

Table 9: Acres of land at and below different sea level rise elevations in the City of Cape Coral

Cape Coral/ Fort Myers urbanized area	Half Ft	1 Ft	1.5 Ft	2 Ft	3 Ft	4 Ft	9 Ft
	Acres	Acres	Acres	Acres	Acres	Acres	Acres
Coastal Strand	0.84	2.02	4.76	12.28	29.44	88.74	710.84
Sand/Beach	37.08	72.98	117.21	159.05	219.20	278.08	382.11
Dry Prairie	22.72	58.54	128.26	237.38	648.88	1,230.19	4,452.41
Mixed Pine-Hardwood Forest	12.25	40.49	105.17	193.05	368.66	612.90	1,245.02
Hardwood Hammocks and Forest	52.31	143.99	321.41	538.80	1,126.95	1,894.64	4,474.55
Pinelands	112.08	437.05	1,068.55	2,069.10	4,829.68	7,721.16	16,668.56
Tropical Hardwood Hammock	3.43	11.07	23.66	45.24	87.68	127.68	183.69
Freshwater Marsh and Wet Prairie	20.59	43.32	103.57	175.51	339.80	526.93	1,202.70
Shrub Swamp	18.39	65.29	149.60	248.54	444.25	581.05	970.77
Cypress Swamp	16.70	50.78	111.78	181.62	370.59	513.06	1,091.35
Cypress/Pine/Cabbage Palm	11.44	38.73	84.34	142.28	275.83	361.32	659.74
Mixed Wetland Forest	15.33	64.61	153.84	248.51	440.99	638.06	1,317.61
Hardwood Swamp	30.04	124.97	271.97	419.42	686.73	939.40	1,617.57
Salt Marsh	167.33	576.17	1,516.82	2,403.36	3,921.61	4,332.12	4,679.41
Mangrove Swamp	6,029.46	14,497.23	22,240.81	26,928.51	31,824.22	33,254.71	33,999.58
Open Water	1,788.49	3,605.52	5,421.89	6,741.97	8,557.92	9,972.52	13,660.87
Shrub and Brush land	2.37	6.78	11.71	20.45	51.57	102.02	475.10
Grassland	0.01	0.01	0.12	0.63	1.59	3.43	6.99

Bare Soil/Clear-cut	11.77	25.84	60.24	110.27	222.22	408.39	1,655.42
Improved Pasture	4.35	18.78	25.99	36.02	99.23	226.55	2,132.31
Unimproved Pasture	0.05	0.61	1.29	30.00	101.84	159.12	515.34
Citrus	0.00	2.90	8.73	21.82	77.64	228.40	1,521.45
Row/Field Crops	0.00	0.16	3.78	23.53	93.88	286.54	760.24
Other Agriculture	0.00	0.00	0.39	4.85	18.93	80.62	413.62
Exotic Plants	0.00	0.00	0.00	0.19	1.23	2.35	35.75
High Impact Urban	237.27	681.44	1,437.77	2,543.28	5,938.12	11,800.74	53,005.86
Low Impact Urban	22.07	80.90	183.50	326.60	828.72	1,758.87	7,840.63
Extractive	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	8,616.39	20,650.18	33,557.17	43,862.26	61,607.40	78,129.59	155,679.49

Table 10: Acres of habitat or land use at and below different elevations in Cape Coral/ Fort Myers urbanized area
Note: number includes the prior acreage

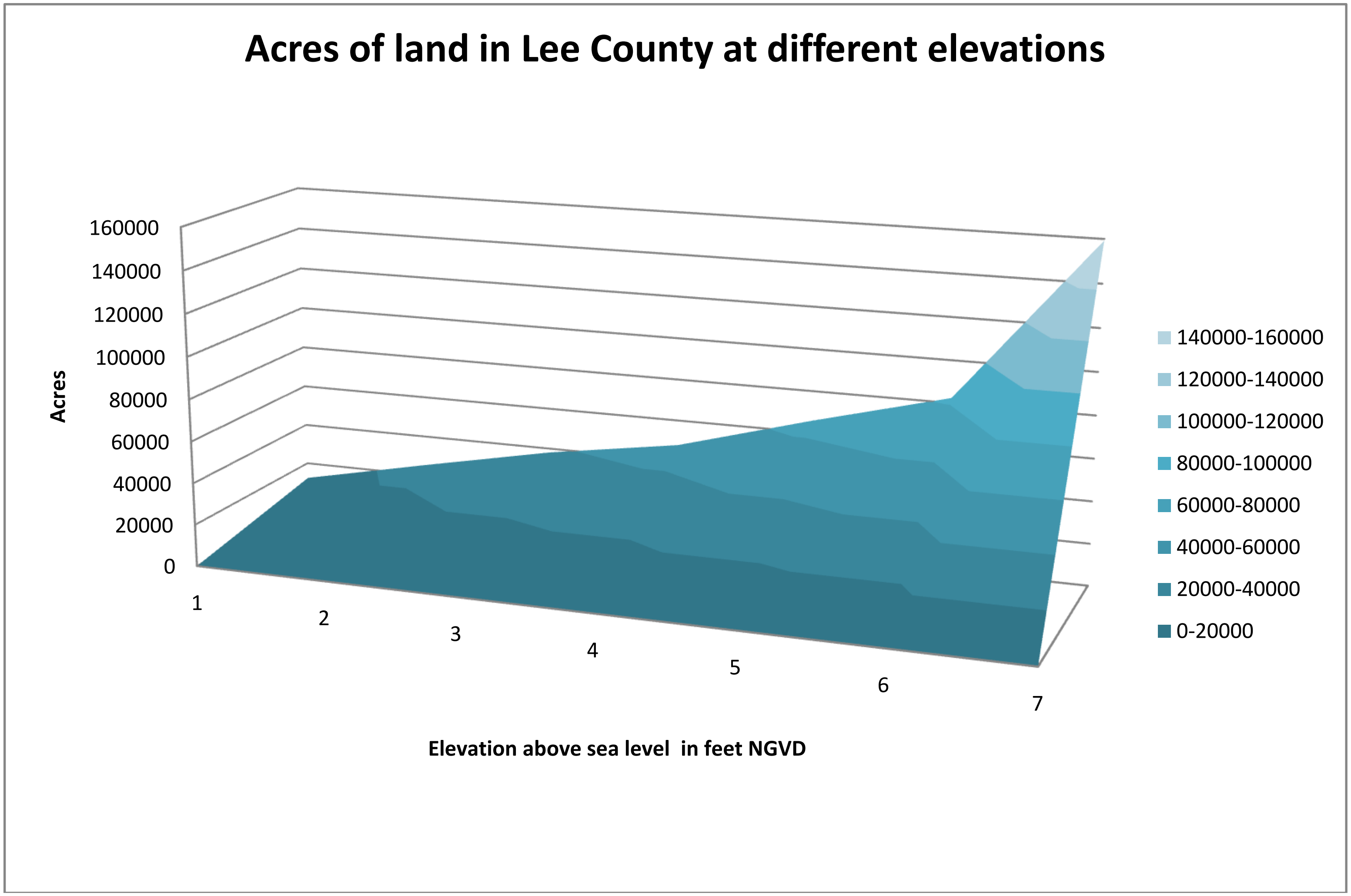
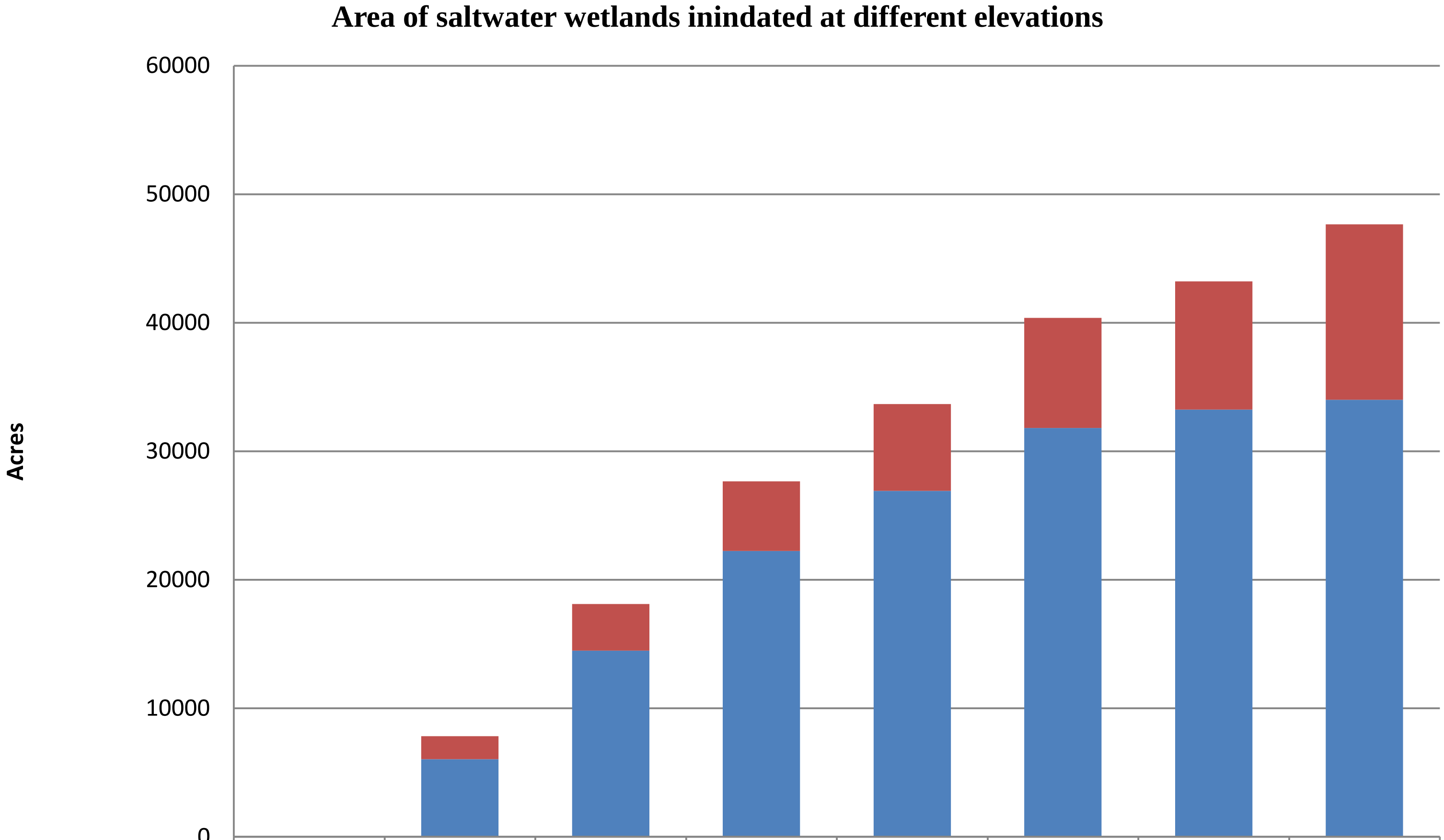
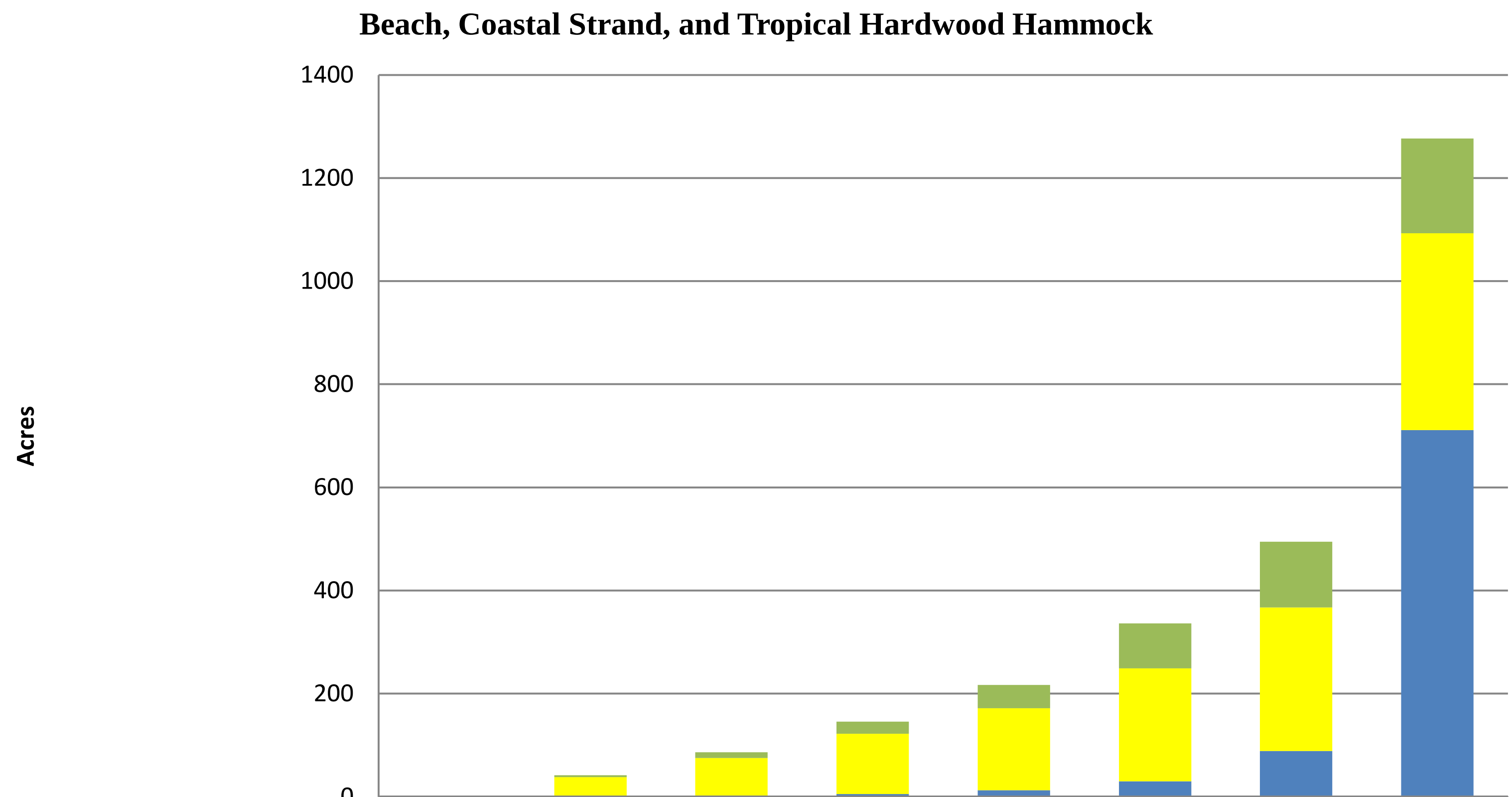


Figure 41: Acres of habitat or land at and below different elevations in Cape Coral/ Fort Myers urbanized area



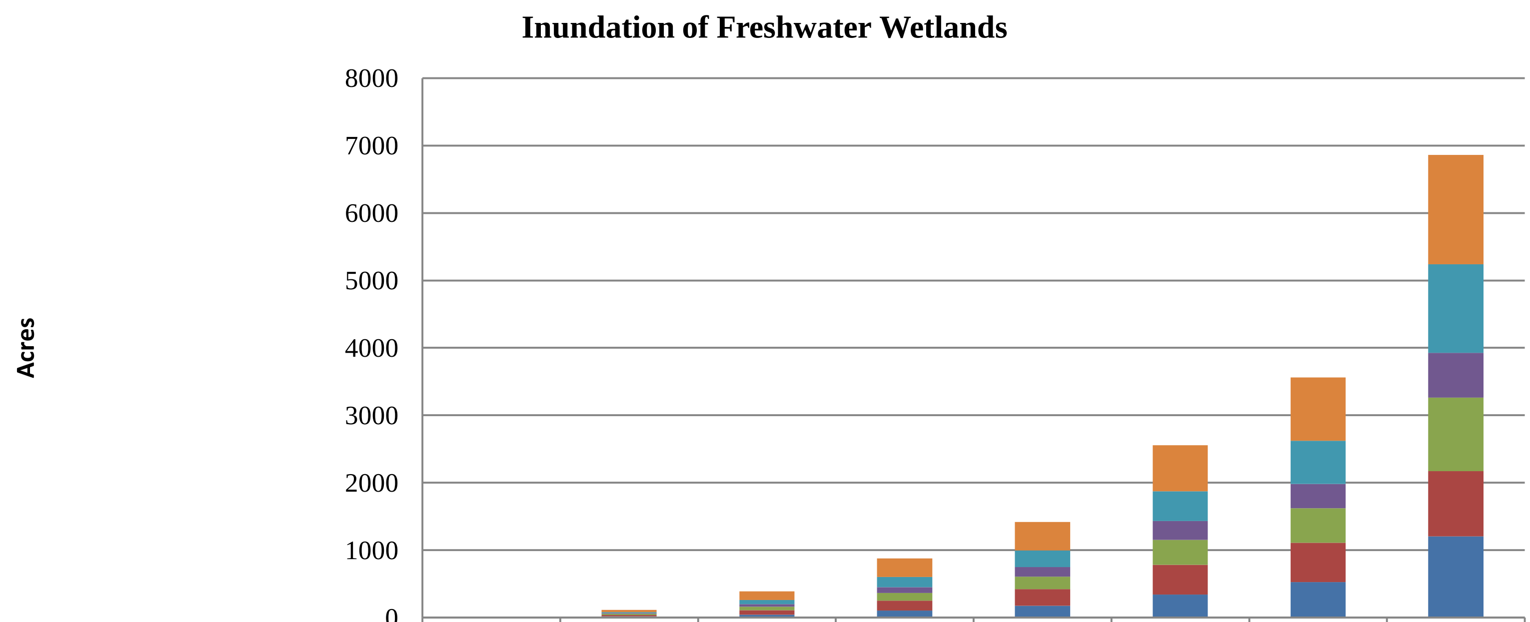
	0 Ft	Half Ft	1 Ft	1.5 Ft	2 Ft	3 Ft	4 Ft	9 Ft
Salt Marsh	0	1,788.49	3,605.52	5,421.89	6,741.97	8,557.92	9,972.52	13,660.87
Mangrove Swamp	0	6,029.46	14,497.23	22,240.81	26,928.51	31,824.22	33,254.71	33,999.58

Figure 42: Acres of mangrove and salt marsh habitat at and below different elevations in Cape Coral/ Fort Myers urbanized area



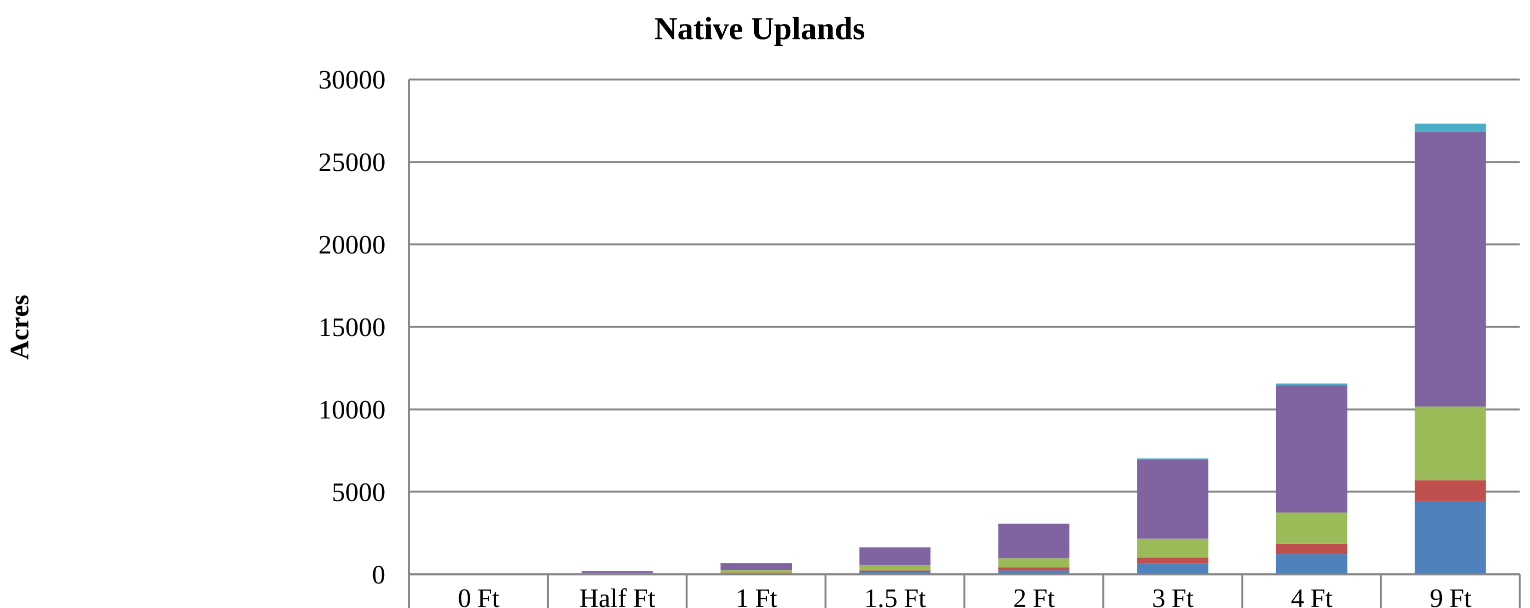
	0 Ft	Half Ft	1 Ft	1.5 Ft	2 Ft	3 Ft	4 Ft	9 Ft
Tropical Hardwood Hammock	0	3.43	11.07	23.66	45.24	87.68	127.68	183.69
Sand/Beach	0	37.08	72.98	117.21	159.05	219.20	278.08	382.11
Coastal Strand	0	0.84	2.02	4.76	12.28	29.44	88.74	710.84

Figure 43: Acres of beaches and coastal strand habitat in Cape Coral/ Fort Myers urbanized area at and below different elevations



	0 Ft	Half Ft	1 Ft	1.5 Ft	2 Ft	3 Ft	4 Ft	9 Ft
Hardwood Swamp	0	30.04	124.97	271.97	419.42	686.73	939.40	1,617.57
Mixed Wetland Forest	0	15.33	64.61	153.84	248.51	440.99	638.06	1,317.61
Cypress/Pine/Cabbage Palm	0	11.44	38.73	84.34	142.28	275.83	361.32	659.74
Cypress Swamp	0	16.70	50.78	111.78	181.62	370.59	513.06	1,091.35
Shrub Swamp	0	18.39	65.29	149.60	248.54	444.25	581.05	970.77
Freshwater Marsh and Wet Prairie	0	20.59	43.32	103.57	175.51	339.80	526.93	1,202.70

Figure 44: Acres of freshwater wetlands habitat in Cape Coral/ Fort Myers urbanized area at and below different elevations



	0 Ft	Half Ft	1 Ft	1.5 Ft	2 Ft	3 Ft	4 Ft	9 Ft
Shrub and Brushland	0	2.37	6.78	11.71	20.45	51.57	102.02	475.10
Pinelands	0	112.08	437.05	1,068.55	2,069.10	4,829.68	7,721.16	16,668.56
Hardwood Hammocks and Forest	0	52.31	143.99	321.41	538.80	1,126.95	1,894.64	4,474.55
Mixed Pine-Hardwood Forest	0	12.25	40.49	105.17	193.05	368.66	612.90	1,245.02
Dry Prairie	0	22.72	58.54	128.26	237.38	648.88	1,230.19	4,452.41

Figure 45: Acres of uplands habitat in Cape Coral/ Fort Myers urbanized area at and below different elevations

Future Land Use	Acres	Sq. Miles	% of County
Agriculture	467	0.73	0
Commercial	9,247	14.45	1.7
Estate	16,110	25.17	.1
Industrial	2,597	4.06	0.5
Multi-Family	1,937	3.03	0.3
Preserve	247,286	386.38	47.5
Single Family	89,621	140.03	17.2
Total Acreage	**367,266**	**573.85**	**70.6**

Table 11 Cape Coral/ Fort Myers urbanized area 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	Acres	Sq. Miles	% of County
0' to 10' NGVD Uplands, Not Protected	11,797	18.43	2.3
0' to 10' NGVD Uplands, Protection Likely But Wetland Migration Possible	85,430	133.48	16.4
0' to 5' NGVD Uplands, Protection Not Likely	346	0.54	0
Wetlands	57,168	89.33	11
Total Acreage	**154,741**	**241.78**	**29.7**

Table 12: Cape Coral/ Fort Myers urbanized area "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	Acres	Sq. Miles	% of Wetland Type in Cape Coral/ Fort Myers urbanized area
Cypress	2,876.0	4.5	13.2%
Cypress/Pine/Cabbage Palm	17,42.4	2.7	18.7%
Freshwater Marshes and Wet Prairies	4,216.9	6.6	25.4%
Shrub Swamp	1,760.8	2.8	22.5%
Mixed Wetland Hardwoods	4,537.3	7.1	35.0%
Hardwood Swamp	3,757.3	5.9	48.2%
Saltwater Marshes	3,785.0	5.9	91%
Mangrove Swamps	42,341.0	66.16	100%
Tidal Flats	1,179.0	1.84	100%
Total Acreage of Wetlands	57,168.0	89.33	41.2%

Table 13: Cape Coral/ Fort Myers urbanized area 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 (Trescott and Walker 2009) first met with officials from several counties 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**. EPA'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 EPA 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 Fort 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 EPA'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 EPA 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 can not 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. 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, as in the case of Cape Coral. 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.

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:

Facility Type	**Number in Lee**	**% of Facilities in Region**	**Regional Total**
Boat Locks	1	20%	5
Clinic	1	8%	12
Communication Tower	9	22%	41
Electrical Facilities	7	20%	35
Emergency Medical Services	3	19%	16

Fire Stations	5	11%	45
Government Facilities	5	5%	92
Hospital	1	33%	3
Nursing & Convalescent Facilities	13	48%	27
Police-sheriff Facilities	1	450%	22
Public School	7	18%	39
Sewage Treatment Facilities	7	10%	70
Water Treatment Facility	4	9%	47
Total	**64**	14%	**454**

Table 14: Critical facilities in the study area vulnerable to tropical storm and hurricane flooding and sea level rise

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 Lee County there are three airports, two clinics, nine communication facilities, 14 electrical facilities, three EMS, 19 fire stations, 27 government facilities, one hospital, two landfills, 26 nursing/convalescent centers, three police- sheriff facilities, one Red Cross center, 11 elementary schools, three middle schools, two high schools, one private college, one community college, 43 sewage treatment facilities or transfers, 12 hurricane shelters, one port, and 13 drinking water facilities in hazard of maximum five-10 foot hurricane storm surge.

A listing of identified critical facilities in the City of Cape Coral are 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 in City of Cape Coral subject to sea level rise).

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

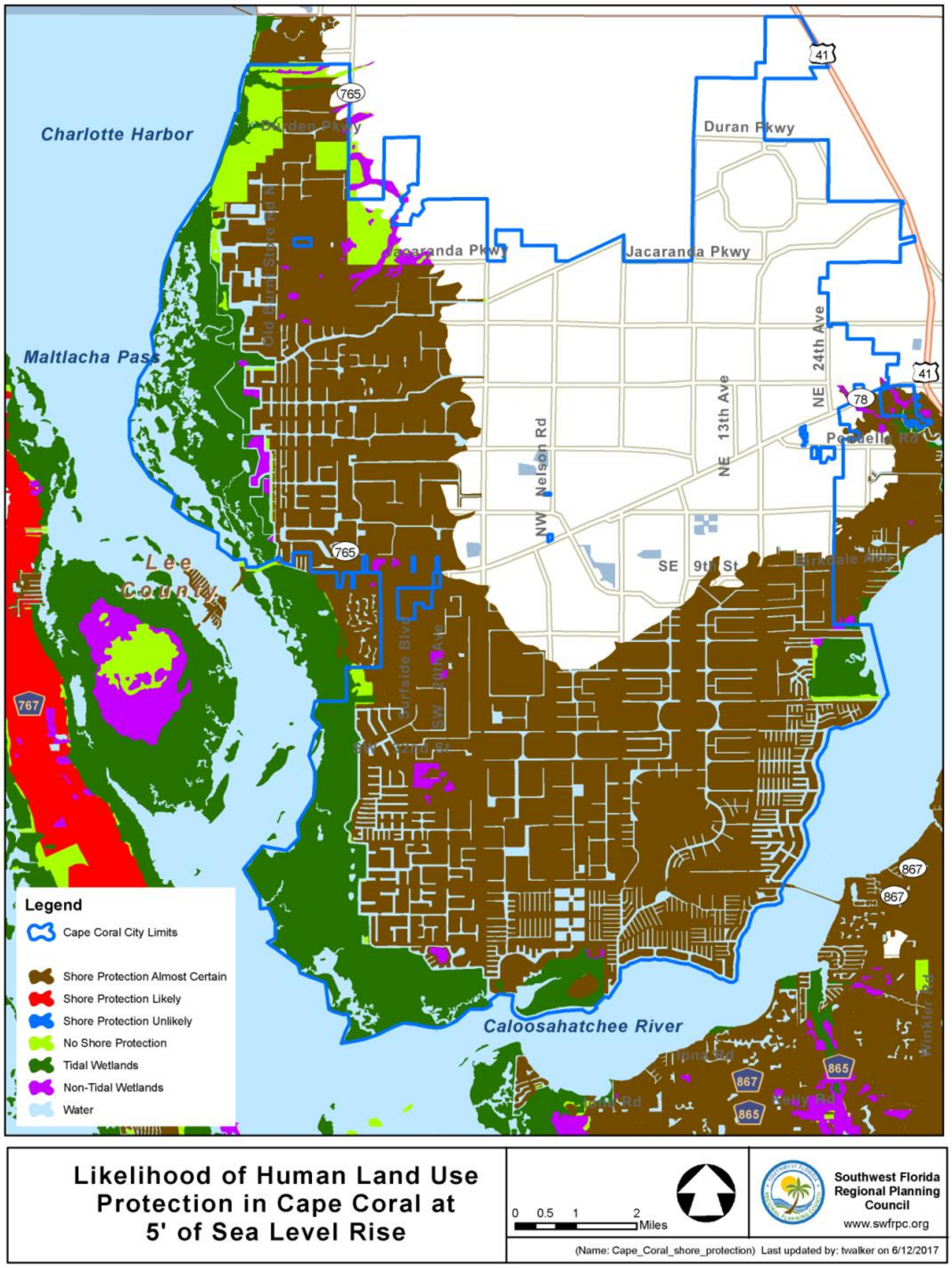


Figure 47: Land use projection map of City of Cape Coral at 5 foot sea level rise

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, streamflow, 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. Sea level rise, together with lower water levels in the surface and groundwater, will result in salt water intrusion.

Increases in precipitation, including heavy and extreme precipitation events, affect all land surfaces and receiving water bodies. Precipitation is expected to increase five to 10% over the levels of the 20th 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 will 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 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 will be affected as well, due to the variation in water recharge cycles. Changes in rainfall patterns will change soil moisture levels which could result in increasing needs 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).

Water conservation measures including grey-water recycling and cistern collection may offset some of the future water use demand, however 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 some for underground storage of freshwater. 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 that $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 other sources (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 million gallons per day (MGD) of freshwater, with costs a little over $3 per 1000 gallons, 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 demand for water through 2050, 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 change 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).

Photograph 2: Aerial view of Charley Pass, a breach of North Captiva Island created by Hurricane Charley on August 13, 2004

Continued sea level rise will exacerbate erosion, 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).

Habitat and Species Changes

Known Habitat and Species Changes and Events that Have Occurred

Corals and Coralline Ecosystems

In Florida, corals are tropical animals already living close to their upper water temperature limits. Corals have a close association with single-celled plants that live inside their cells and that provide energy to the coral by photosynthesis. Corals are said to bleach, or whiten, when those plant cells die. Bleaching events are correlated with local or regional increases in seawater temperature. In the early 1980s, during the first massive coral bleaching event in the Florida Keys, observations of increased coral diseases also began to be reported (Wilkinson and Souter 2008).

Reef-building corals of Florida now are one to1.5°C closer to their upper temperature limits than they were 100 years ago. Corals that are stressed by high water temperature have displayed higher rates of disease and coral bleaching (Wilkinson and Souter 2008; FOCC 2009). Corals stressed by temperature and bleaching are more vulnerable to pathogens on their outer surface, resulting in increases in coral disease (Ritchie 2006; Harvell et al. 2002; Eakin et al. 2005). Coral diseases have increased substantially in the Florida Keys due to an increase in sea surface temperatures (Wilkinson and Souter 2008).

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 Charlotte Harbor 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. Other 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 Charlotte Harbor 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 (Lugo and Snedaker 1974). 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 (Odum and Heald 1972). 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 Cape Coral/ Fort Myers urbanized area coast (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 (Tomlinson 1986). 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 15 ft (5 m) 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 10 to 20 ft (3 to 6 m) 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*), belted 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 snook (*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 (Gore 1994b).

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.

Salt Marshes

The salt marsh community of southwest Florida is perhaps one of the most unique and rare salt marsh systems in the United States. The mild subtropical climate of Florida supports a combination of temperate salt marsh vegetation and tropical mangroves that intermix to form an important transitional ecotone between land and sea. The salt marsh offers numerous ecosystem services including recreational, commercial, and aesthetic values to man. It provides the foundation of life to a variety of resident and transient organisms, especially the six federally-listed and 23 state-listed animal species found there. Although almost 66 percent of the remaining salt marsh habitat is protected in southwest Florida, this habitat continues to be lost to human-induced impacts such as dredge and fill operations, alterations of hydrology, and pollution.

Over 50 percent of the salt marsh habitat adjoining the Charlotte Harbor system has been destroyed since 1945 (Charlotte Harbor NEP 1995). Recent mapping of the Cape Coral/ Fort Myers urbanized area watershed found approximately 1,745 miles of coastal shoreline from Gasparilla Sound to southern Estero Bay in Lee County. Within this area, there are 9,218 acres of salt marsh. Currently, over 55 percent or 962 miles of coastal wetland shorelines have been lost or significantly altered in the Cape Coral/ Fort Myers urbanized area watershed. The most significant coastal wetland losses have been on estuarine rivers and creeks and on barriers islands and include substantial losses of salt marsh.

Mangroves primarily dominate the Cape Coral/ Fort Myers urbanized area open tidal shoreline, although there are patches of transitional salt marsh habitat. Within these zones, dominant species include cordgrass (*Spartina spp.*), saltgrass (*Distichlis spp.*), glasswort (*Salicornia spp.*), and sea purslane (*Sesuvium* spp.) (Drew and Schomer 1984). Monotypic stands of black needlerush (*Juncus roemerianus*) are more common in slightly elevated areas with lower tidal inundation. Cordgrass and needlerush dominate salt marsh communities around the mouths of rivers (e.g., Myakka and Peace Rivers). The interior wetland habitat of Sanibel Island has expanses of salt marsh dominated by Baker's cordgrass (*Spartina bakerii*) and leather fern (*Acrostichum spp.*).

Salt marshes in Charlotte Harbor Estuary have been destroyed or directly impacted by construction activities for residential and commercial purposes including seawalls, drainage ditches for agriculture and mosquito control, boat facilities, and navigation channels. Man-made hydrological alterations have reduced the amount of freshwater flow from some rivers (e.g., Peace River), while artificially increasing the flow through others (e.g., Caloosahatchee). Approximately 400 linear miles of man-made canals were built in the 1950s to 1970s, resulting in a significant loss of salt marsh habitat (Charlotte Harbor SWIM 1993). The interior salt marshes of Sanibel Island were heavily altered from human construction activities, hydrologic changes, and exotic vegetation invasion (Clark 1976).

Limited data are available for determining the long-term trends in the extent of salt marshes. All existing estimates lump the five types of southwest Florida salt marsh into a single unified number. It is estimated that Florida contained approximately 399,152 acres (163,652 ha) of salt marsh coverage prior to European colonization (Cox et al. 1994). Since that time, an estimated 111, 940 acres (45,895 ha) or 28 percent of salt marsh habitat has been lost (Kautz et al. 1993). Of the current 287,212 acres (117,757 ha) of salt marsh habitat in Florida, over 66 percent, or 189,597 acres (77,735 ha), is located in existing conservation areas (Kautz et al. 1993, Cox et al.1994). Twenty percent of all Florida saltmarsh is found in south Florida (Montague and Wiegert 1990); including the Cape Coral/ Fort Myers urbanized area study area.

Southwest Florida salt marshes were not significantly modified by human activities until the early 20th century when many areas were permanently altered to accommodate the speculative real estate development that led to a rapidly growing human population. The common practice of constructing bulkheads and filling salt marsh areas for residential and commercial development destroyed many salt marshes and also altered the natural hydrology. As a result, many salt marsh communities experienced changes in water and soil salinities, water levels, and tidal flushing regimes. Contaminants and pollutants have also been introduced into salt marshes. Exotics are conveyed by a variety of means, including water transport, birds, illegal dumping of vegetation and land clearing. Many exotics initially colonize along roadways or similarly cleared areas. Disturbed or denuded areas are often invaded by exotics such as Australian pine (*Casuarina equisetifolia*) and Brazilian pepper (*Schinus terebinthifolius*) before native salt marsh seedlings can establish themselves.

Unregulated dredging and filling occurred in southwest Florida until the early 1970s when Federal and state governmental policies were implemented to minimize impacts on salt marshes. Current Federal and state regulations normally require some degree of mitigation to offset the alterations or losses of wetland habitat; however, salt marsh habitat continues to be destroyed or altered today as coastal development continues in South Florida.

Efforts to control mosquitoes in southwest Florida began in the early 1930s with the use of ditching, impoundments, and pesticide spraying (Montague and Wiegert 1990, David 1992). Salt marsh plants were killed from the semi-permanent flooding and salinity changes caused by the impoundments. Management efforts to control the population of mosquitoes continue today, although substantial progress has been made to minimize negative impacts on salt marshes.

Natural disturbances on salt marshes include fires, storms and hurricanes, drought, and floods. These events usually have a short-term, localized effect on salt marsh habitat and the community is generally able to recover fairly quickly. However, when these disturbances occur closely together, or are coupled with human-induced impacts, the effects can be catastrophic to the salt marsh community. Fires usually do not permanently affect salt marshes but may temporarily affect soil composition, species composition and biomass (Schmalzer et al.1991, Schmalzer and Hinkle 1992). Most salt marshes are affected by the storm surge more than the flooding or strong winds caused by tropical storms. One of the most significant impacts to salt marshes from hurricanes is the potential for rapid invasion of exotic vegetation into disturbed areas.

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.*), 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 Strand

A narrow band of coastal strand habitat is located between areas of fringing red mangrove forest and immediately adjacent natural grade uplands or spoil-created uplands. The coastal strand community is a combination of tropical and temperate flora that display a level of salt tolerance, such as sea grape (*Coccoloba uvifera*), grey nicker (*Caesalpinia bonduc*), buttonwood (*Conocarpus erectus*), and strangler fig (*Ficus aurea*). These species benefit from the temperature-regulating influence of adjacent estuarine waters. The historic extent of the coastal strand has been abbreviated by the past placement of fill for development in areas of coastal strand and wetlands, including salt marsh, high marsh, and mangrove. This is the area that probably also had southern red cedar (*Juniperus silicicola*) historically. Coastal strand is an important habitat for listed plant species, neotropical migratory birds, butterfly species, and wide-ranging animals such as river otter and raccoon that use the habitat during seasonal food abundance.

Pine Flatwoods

South Florida slash pine (*Pinus elliottii*) is the dominant tree of the pine flatwoods canopy of southwest Florida. The South Florida slash pine is more flood- and drought-tolerant than is the North Florida slash pine. Squillace (1966) concluded that the phenotypic plasticity that allows the South Florida slash pine to accommodate both upland and wetland conditions, fire, and flood is the result of its evolution under the severe environmental factors of south Florida floods and droughts that vary from year to year and fluctuate widely over longer time courses.

While tree densities in pine flatwoods are typically sparse, with canopy coverage typically ranging from 10 to 25%, pines are abundant enough to dominate the apparent landscape view and canopy, but are not close enough to touch each other. Ground cover receives nearly full sunlight (Wade et al. 1980). Mature south Florida slash pine can attain a height of 110 feet, with a diameter at breast height (dbh) of 16 inches (Duever et al. 1976). Mature trees typically attained 10 to 12 inches dbh with 60 to 75 feet of height. Growing season is from February to November, with maximum growth rates attained at the spring and autumnal equinoxes (Langdon 1963).

The type of south Florida pine flatwoods varies with hydrology, elevation, and topography. Xeric pine flatwoods have approximately three feet of well-drained, dry soil above the typical groundwater level, and the water table only attains the surface during unusual precipitation events such as hurricanes. The xeric pine flatwoods have an open understory with bunchgrasses and wiregrass, short clumps of saw palmetto (*Serenoa repens*), and xeric shrub species such as fetterbush (*Leucothoe racemosa*), tarflower (*Bejaria racemosa*), rusty lyonia (*Lyonia ferruginea*), pennyroyal (*Piloblephis rigida*), pawpaws (*Asimina spp.*), and prickly pear cactus (*Opuntia spp.*).
Mesic pine flatwoods are less well-drained and are infrequently and briefly inundated by water only during extremely high levels of precipitation during the rainy season. The mesic pine flatwoods have a relatively closed understory dominated by medium height to tall saw palmetto and occasional shrubs such as wax myrtle (*Myrica cerifera*), fetterbush, pawpaw, cabbage palms, and winged sumac (*Rhus copallinum*).

In contrast, water stands on the surface, inundating hydric pine flatwoods for one or more months per year during the rainy season. The naturally occurring hydric pine flatwoods have standing water for at least one month (30 days) of the year. The hydric pine flatwoods habitat becomes saturated and attains standing water in the middle wet season. The hydric pine flatwoods habitat is dominated by a slash pine canopy with a wetland plant understory. The wetland understory of hydric pine flatwoods is a combination of freshwater slough, freshwater seasonal pond, and high marsh vegetative components. Mid-story plants of hydric pine flatwoods include cabbage palm, wax myrtle, strangler fig, Brazilian pepper, red maple (*Acer rubrum*), dahoon holly (*Ilex cassine*), and buttonbush (*Cephalanthus occidentalis*). The hydric pine flatwoods of southwest Florida is a distinct habitat in dynamic equilibrium between drought and flood that is regularly and predictably perturbed by fire and water (Beever and Dryden 1992).

Nearly all plants and animals of the pine flatwoods are adapted to periodic fires (FNAI 1989). South Florida slash pine is extremely fire tolerant (Ketcham and Bethune 1963). South Florida slash pine seedlings have a grass stage that greatly increases their resistance to fire damage. Fire stimulates slash pine seedlings to sprout, promoting their growth as pioneers of burned land. The herbaceous plant community of the pine flatwoods survives fire by seeding and resprouting from root stock. In natural pine flatwoods communities, the dried herbaceous growth of several prior growing seasons forms the principal fuel for natural fires.

In pre-Columbian times, fires probably occurred in the xeric pine flatwoods every five to seven years, mesic pine flatwoods every two to five years, and hydric pine flatwoods every three to 10 years. While natural fires were numerous, the areal extent of any given fire was probably small (25 acres or less). Most natural fires occurred at the end of the dry season. This pattern of patch fires creates a mosaic of plant and habitat diversity, as opposed to a monopyric, even-aged plant community.

Much of the variation in community structure within a pine flatwoods is probably associated with fire frequency. The longer the period since the last fire, the more developed the understory shrub layer. If the understory is allowed to grow too long without fire, the accumulated needle bed and the height of flammable understory shrubs increases the probability of catastrophic canopy fires (FNAI 1989). If fires are very frequent, slash pine seedling regeneration will not occur, and the pine flatwoods will tend to be dominated by an herbaceous understory with clusters of cabbage palms forming a cabbage palm prairie (Wade et al. 1980).

Less fire-tolerant plant community species have refugia in deep water found in hydric pineland. With overdrainage, fire refugia are lost. This typically results in decreases in the midstory, tropical components of south Florida pine flatwoods with subsequent losses in plant species diversity. If overdrainage is coupled with too-frequent fire, and a melaleuca (*Melaleuca quinquenervia*) seed source is nearby, the pine flatwoods will become dominated by melaleuca monocultures (Wade et al. 1980).

Without regular fires, the pine flatwoods can be expected to succeed into shrub-dominated forests with a closed canopy, eliminating groundcover herbs and shrubs (Alexander 1967, FNAI 1989). After approximately six to 10 years of fire absence, perennial plants that are normally set back by fire attain larger sizes. An increased ground cover results from the presence of fewer, but larger, individual plants. These individual plants are subsequently shaded out by other plant species that would normally be killed by fire. This results in an increase in cover, but a decrease in plant species diversity. In general, fire exclusion from pine flatwoods results in species loss; decreased forage quantity and quality for herbivorous species, and subsequently for their predators; increased danger from wildfires; and decreased pine regeneration (Wade et al. 1980).

Pine flatwoods are an important habitat for a number of vertebrate species, including the pine woods tree frog (*Hyla femoralis*), oak toad (*Bufo quercicus*), box turtle (*Terrapene carolina bauri*), eastern diamondback rattlesnake (*Crotalus adamanteus*), black racer (*Coluber constrictor priapus*), brown-headed nuthatch (*Sitta pusilla*), Bachman's sparrow (*Aimophila aestivalis*), pine warbler (*Vermivora bachmanii*), great horned owl (*Bubo virginianus*), least shrew (*Cryptotis parva*), cotton mouse (*Peromyscus gossypinus*), cotton rat (*Sigmodon hispidus*), and gray fox (*Urocyon cinereoargenteus*) (Layne 1974). Burning to increase habitat value for wildlife is a well-established practice in pine flatwoods. It has been documented to increase habitat values and wildlife habitat

(Komarek 1963, Stoddard 1963, Lewis 1964, Moore 1972, Hughs 1975). Different burn regimes favor different wildlife species. For example, quail (*Colinus virginianus*) are favored by 2-year rotational burns (Moore 1972) and turkeys (*Meleagris gallopavo*) are favored by 3- to 4-year cycles (Stoddard 1963). A diverse pattern of burning, similar to the natural burn conditions for pine flatwoods, can produce the highest species diversity, but fire is often suppressed due to proximity of pine flatwoods to development.

Xeric Oak Scrub

Scrub communities drain rapidly because of their soils. Their typically higher elevation and soil type are suited for development. As such, they are the most endangered of Florida's native upland communities. Scrub communities are ranked by the Florida Natural Areas Inventory (FNAI 1989) as G2 and S2. The G2 designation indicates global imperilment while the S2 designation indicates statewide imperilment. The oak scrub system is a unique habitat of special value to listed species. Scrub habitats contain many uniquely Florida species, including Florida scrub jay (*Aphelocoma coerulescens*), gopher frog (*Rana capito*), Florida mouse (*Podomys floridanus*), invertebrates that are commensal with gopher tortoise (*Gopherus polyphemus*) burrows, and many endemic plant species.

The scrub habitat of southwest Florida tends to be a coastal or riverine scrub (Mulvania 1931) with a canopy dominated by scrub live oak (*Quercus inopina*) and a midstory of xeric shrubs and shorter oaks. The open understory is vegetated with dwarf saw palmetto, wiregrasses, and a sparse herbaceous groundcover. Most of the oldest developed areas of southwest Florida located adjacent to the creeks and rivers were historically oak scrub or an oak scrub flatwoods mixture.

Coastal Zonation

The standard zonation of Charlotte Harbor and 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 48:

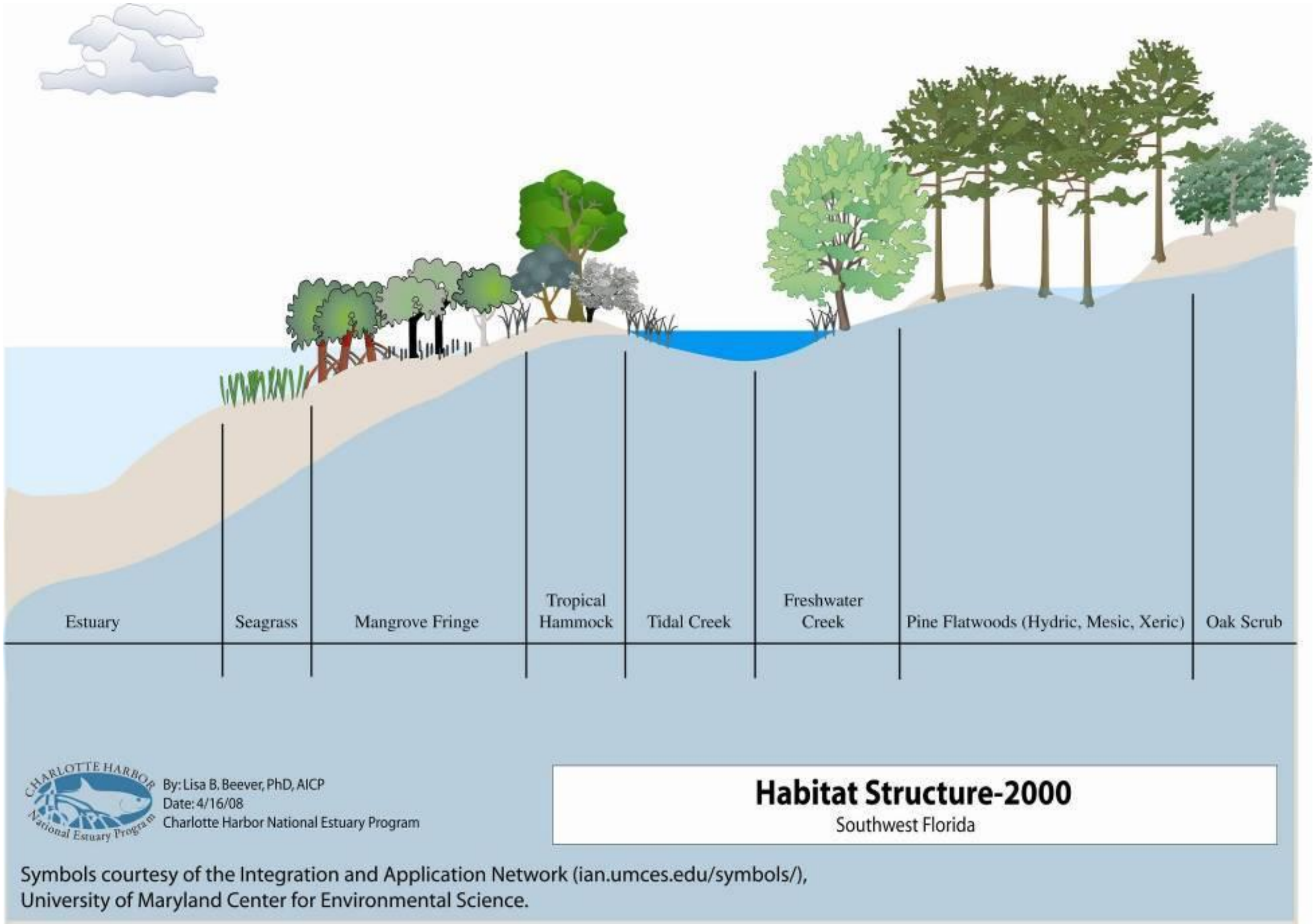


Figure 48 Typical coastal habitat zonation for Charlotte Harbor, Year 2000

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 climate change 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 (90%) 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).

Photograph 3: Caloosahatchee River Algae Bloom resulting from Lake Okeechobee flow management.

Source: J. Cassani 2006

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).

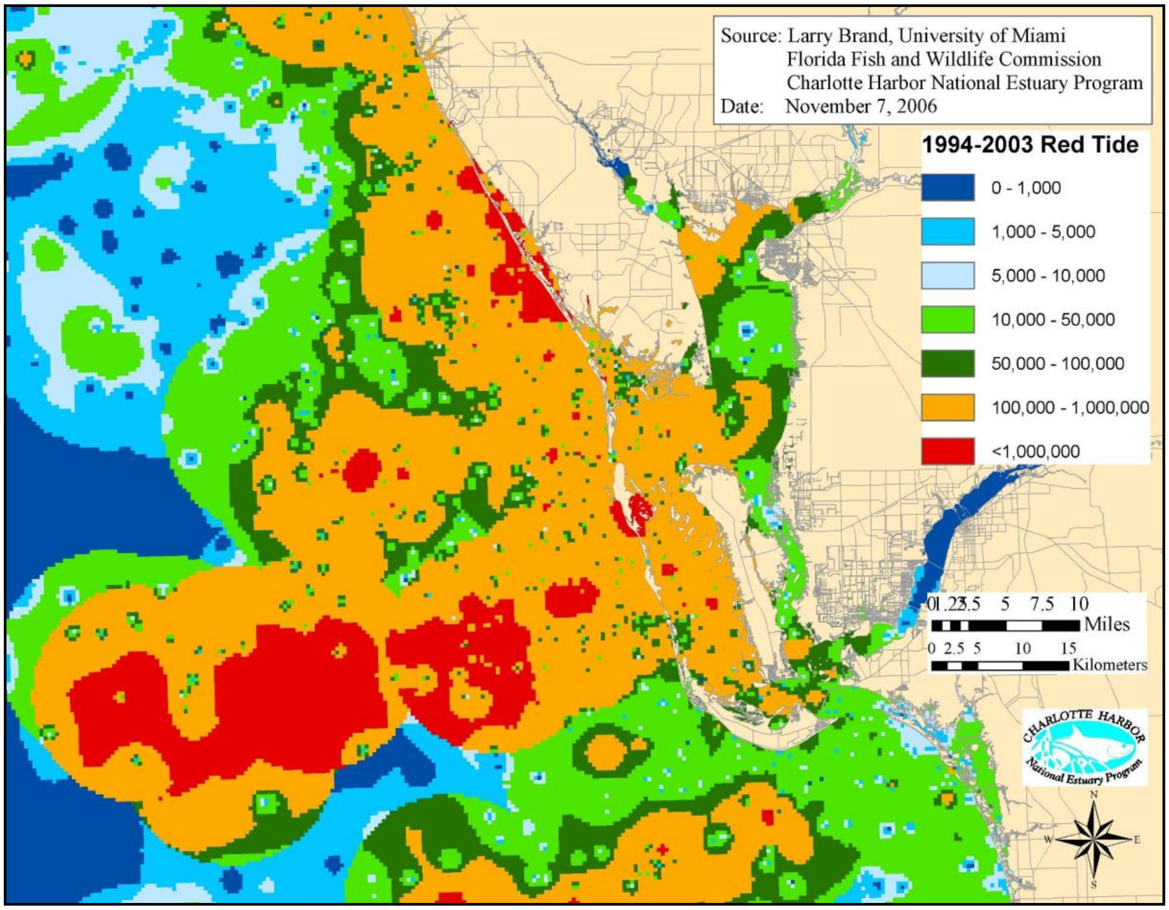


Figure 49: Intensity and location of red tides in Charlotte Harbor and nearshore areas 1994-2003. Source indicated on key.

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 1987, 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 circulation 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.

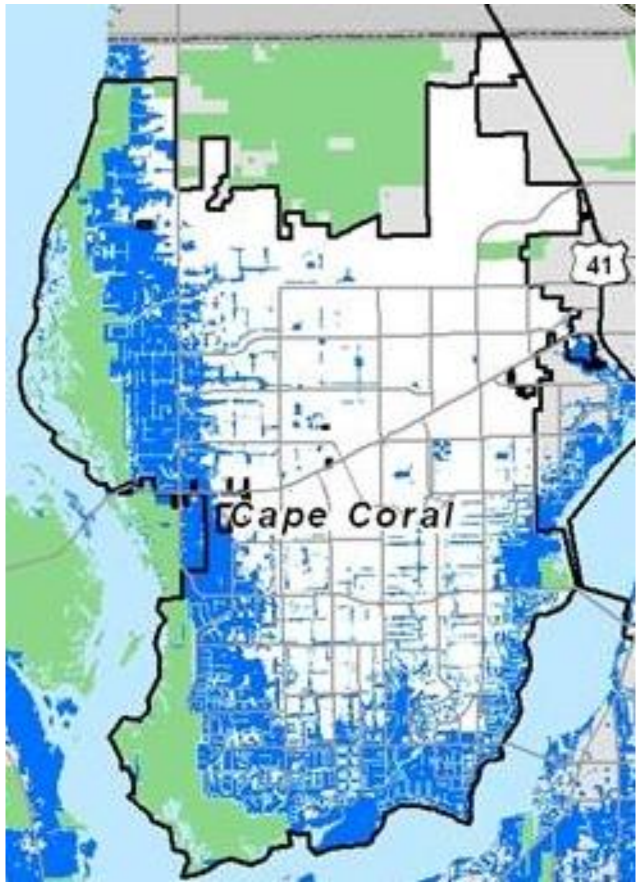


Figure 50: Year 2200 5-Foot Sea Level Rise with Location of Lands Managed for Conservation Southwest Florida

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 Australian pine 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).

Listed Animal Species

As of March 16, 2010 the southwest Florida study area provides habitat for 59 State Listed Species with 22 of these also Federally Listed.

Endangered Species

Florida panther (*Puma concolor coryi*), everglades mink (*Neovison vison evergladensis*), West Indian manatee (*Trichechus manatus latirostris*), Florida bonneted (mastiff) bat (*Eumops floridanus*), sei whale (*Balaenoptera borealis*), finback whale (*Balaenoptera physalus*), North Atlantic right whale (*Eubalaena glacialis*), humpback whale (*Megaptera novaeangliae*), sperm whale (*Physeter macrocephalus*), peregrine falcon (*Falco peregrinus*), wood stork (*Mycteria americana*), snail kite (*Rostrahamus sociabilis plumbeus*), red-cockaded woodpecker (*Picoides borealis*), Bachman's warbler (*Vermivora bachmanii*), Kirtland's warbler (*Dendroica kirtlandii*), Florida grasshopper sparrow (*Ammodramus savannarum floridanus*), American crocodile (*Crocodylus acutus*), green sea turtle (*Chelonia mydas*), leatherback sea turtle (*Dermochelys coriacea*), Kemp's Ridley sea turtle (*Lepidochelys kempii*), hawksbill sea turtle

(*Eretmochelys imbricata*), small-toothed sawfish (*Pristis pectinata*), shortnose sturgeon (*Acipenser brevirostrum*), Atlantic (Gulf) sturgeon (*Acipenser oxyrinchus desotoi*),

<u>State Threatened Species</u>

Big Cypress fox squirrel (*Sciurus niger avicennia*), Sherman's short-tailed shrew (*Blarina carolonensis shermani*), southeastern American kestrel (*Falco sparverius paulus*), Florida sandhill crane (*Grus canadensis pratensis*), roseate spoonbill (*Platalea ajaja*), little blue heron (*Egretta caerulea*), reddish egret (*Egretta rufescens*), tricolored heron (*Egretta tricolor*), black skimmer (*Rhynchops niger*), least tern (*Sterna antillarum*), roseate tern (*Sterna dougallii*), piping plover (*Charadrius melodus*), snowy plover (*Charadrius alexandrinus*), American oystercatcher (*Haematopus palliatus*), white-crowned pigeon (*Columbia leucocephalus*), Florida scrub jay (*Aphelocoma coerulescens*), burrowing owl (*Athene cunicularia floridana*), Audubon's crested caracara (*Caracara cheriway*), eastern indigo snake (*Drymarchon corais couperi*), Atlantic loggerhead turtle (*Caretta caretta*), gopher tortoise (*Gopherus polyphemus*), . Florida pine snake (*Pituophis melanoleucus mugitus*),

<u>State Species of Special Concern</u>

Sherman's fox squirrel (*Sciurus niger shermani*), Sanibel Island rice rat (*Oryzomys palustris sanibelli*), whooping crane (*Grus americana*), American alligator (*Alligator mississippiensis*),

All of the listed species inhabiting southwest Florida can be expected to be impacted by potential climate change effects including habitat losses and translocations of habitat, water quality effects, and decreases in aquatic vegetation and forage fishes. Eleven listed animal species occur in the waters of the marine and estuarine ecosystems of southwest Florida including the manatee, the whales, American crocodile, sea turtles, sturgeons and small-toothed sawfish.

Photograph 4: Small-toothed sawfish (*Pristis pectinata*) in the Caloosahatchee River
Source: FWC 2008

Twenty-three listed species utilize coastal strand habitats of barrier islands and mainland coasts. Problems for shore-nesting species of birds and reptiles, such as least tern, roseate tern, piping plover, snowy plover, American oystercatcher, black skimmer, American crocodile, and the sea turtles will include:

- Increased Sea level
- Increased Storm Frequency and Severity
- Higher-High Tides
- Increased erosion and narrowing of shorefront (beach)
- Increased Harmful Algae Blooms including Macroalgal Drifts
- Shifts in location of food resources to deeper waters
- Changes in beach particle size and compaction if renourishment is employed to detain erosion
- Increased shore-armoring to protect human financial investments in place

Photograph 5: American crocodile at J. N. Ding Darling National Wildlife Refuge, Sanibel Island

Source: H. Greening

Twenty -eight listed animal species utilize the mangrove habitats of southwest Florida including Florida panther, Big Cypress fox squirrel, West Indian manatee, peregrine falcon, wood stork, American crocodile, green sea turtle, leatherback sea turtle, Kemp's Ridley sea turtle, hawksbill sea turtle, small-toothed sawfish , shortnose sturgeon, southeastern American kestrel, least tern, roseate tern, piping plover, snowy plover, white-crowned pigeon, eastern indigo snake, Atlantic loggerhead turtle, roseate spoonbill, little blue heron, reddish egret, , tricolored heron, American oystercatcher, black skimmer, American alligator, and Atlantic (Gulf) sturgeon.

Photograph 6: Female Florida at the Babcock Ranch Preserve, north of the Caloosahatchee River
November 3, 2016 taken with an infra-red triggered camera
Source: FWC 2016

Pine flatwoods, in combination with other forested upland and seasonal wetland habitats, provide critical foraging, breeding, and wildlife corridor habitat for the Florida panther (*Puma concolor coryi*). The documented foraging and breeding territories of radio-collared Florida panthers and documented sightings of Florida panther include large expanses of undisturbed forests (Maehr 1992). The panther utilizes hydric, mesic, and xeric pine flatwoods, and savanna, hardwood hammocks, and mixed swamp forest. Ecotones are particularly important to the panther because they support an increased variety and density of species. Prey animals, including white-tailed deer and wild hog, utilize the plant diversity of edge communities such as the hydric pine flatwoods (Layne and McCauley 1976). Recently burned pine flatwoods provide more prey for panther, and panthers have been documented moving toward fires and staying in areas of recent burns (Belden 1986). Panthers require large territories and abundant prey. Adult male panther territories average 400 square kilometers and adult female territories average 200 square kilometers (Maehr 1992). Panthers may travel up to 19 miles overnight, or stay in the same wooded habitat for a week or more (USFWS 1987). Additionally, forests associated with natural drainage patterns provide the travel corridors essential to the panther for moving between the fragmented foraging areas remaining in Florida. In a 1986 Florida Game and Freshwater Fish Commission (GFC) study, adult male territories averaged 414 square miles, adult female territories averaged 119 square miles, and a juvenile male territory was 269 miles. The hydric and mesic pine flatwoods of southwest Florida provide both the large territories and abundant prey that panthers require. Florida panther are found in the Yucca Pens/Charlotte Harbor Flatwoods at the north of the City of Cape Coral

The Florida black bear (*Ursus americanus floridanus*), listed as threatened by the state, is a forest habitat generalist with seasonal preference for wherever food is most available, such as the seasonal abundances of propagules and insects. Occasionally, fish and carrion are also eaten. Black bears utilize all the natural forested systems of south Florida, with a decided preference for ecotones, including the boundaries between mangroves and other plant communities. Documented movements of radio collared Florida black bears in Lee and Collier counties and documented signs/sightings of Florida black bears in Charlotte, Collier, and Lee counties indicate that the large areas of relatively undisturbed mangrove forest, in combination with mesic forests and the major wetland basins, provide the principal habitat of the black bear in southwest Florida (Maehr 1984, Brady and Maehr 1985, Maehr *et al.* 1988, Maehr and Wooding 1992, Beever and Dryden 1992). Movement by individuals can be extensive and may be related to both mating and food availability. Black bears will swim between mangrove islands in Collier County (Dryden and Beever 1994). Florida black bear are found in the Yucca Pens/Charlotte Harbor Flatwoods at the north of the City of Cape Coral

Tricolored heron, little blue heron, and roseate spoonbill forage and nest in mangroves. Little blue herons and tricolored herons are the most common of the listed wading bird species observed in mangroves in southwest Florida (Beever1992). Diet consists of small fish, crustaceans, insects, frogs, and lizards (Ogden 1978a). Nesting in mangroves typically occurs on overwash islands. They appear to prefer to forage in freshwater habitats even when nesting in saltwater wetlands. The little blue heron forages throughout the wet and dry season in mangroves. Adjacent tidal wetlands are used throughout the year with greater emphasis during low tides on seagrass beds. The snowy egret forages throughout the wet and dry season in mangrove wetlands of the proper depth to allow for their foraging methods. Snowy egrets are the third most abundant listed wading bird observed. Preferred foraging areas are the seagrass beds and mudflats adjacent to the mangroves. Their diet consists of crustaceans, insects, and small fish (Ogden 1978c).

Reddish egrets and roseate spoonbills are obligate mangrove breeders. Reddish egrets forage on the sandbars and mudflats adjacent to mangroves, in an active fashion with spread wings and rapid steps over unvegetated bottoms. Reddish egrets are the least abundant of the listed wading birds associated with mangroves. Reddish egrets utilize a limited set of saltwater habitats that allow for use of their unique foraging method. Diet consists of crustaceans and small fish. Kale and Maehr (1990) indicate that red mangrove rookeries are used during the December through June breeding period. Roseate spoonbills use dry-down pools in the high marsh, and during low tides, adjacent to mangroves. Preferred foraging areas included sheltered coves. They often forage in groups and with other wading birds including wood storks, great egret (*Casmerodius albus*), white ibis, and snowy egret. Roseate spoonbills nest exclusively in mangrove forests, typically on overwash islands, and forage wherever concentrations of small fish and crustaceans allow the birds to utilize their unique bills for feeding (Ogden 1978b).

A wide variety of shorebird species forage on the mudflats of mangrove estuaries. Among the State listed species are the least tern; the black skimmer, and the American oystercatcher. Least terns and roseate terns require open beach or bare substrates for nesting near areas where schools of forage fish concentrate. American oystercatchers utilize oyster bars and mudflat areas in mangroves and nest on bare unvegetated shores. Foraging occurs throughout the year with seasonal movements tracking warmer conditions.

Salt marshes support 21 listed animal species in southwest Florida. Southwest Florida freshwater marsh support 19 listed animal species. Two marsh endemics, the Cape Sable sea-side sparrow and the Sanibel Island Rice Rat, have a limited distribution in coastal marshes of the Everglades and the interior of a barrier island. Both are in the direct path of increased sea levels, increased storm frequency, and increased storm severity. In addition these delimited marshes may be disrupted by climate instability resulting in fire increases and declines in food base and overtopping flooding from increased precipitation during more severe wet seasons. These species may also need relocation to maintain viable populations. Other marsh species that have preferred hydrologic needs for prey item selection include the wood stork, the Everglades mink, the snail kite, and a variety of wading bird with water depth niche partitioning including roseate spoonbill, little blue heron, reddish egret, snowy egret, and tricolored heron.

There will problems for listed species and other wildlife as humans retreat inland from the coast. Most southwest Florida xeric oak scrub is coastal or along rivers and streams. Inland retreat will eliminate the rarest of the upland habitats with endemic animals such as the Florida scrub jay and endemic listed plants. The “Eastward Ho!” paradigm so popular on the east coast of Florida has the reverse effect in southwest Florida since it will push development into the freshwater and the interior pinelands and other uplands that are the last refuge in southwest Florida of the Florida panther, Florida black bear, Sherman's fox squirrel and red-cockaded woodpecker.

SLAM Modeling of Effects on Marshes

With higher tides including higher high tides, higher normal tides, and higher low tides resulting from sea level rise, mangroves and *Spartina* will be unable to establish in water deeper than the ordinary high tide line so an apparent retreat of the waterward edge of the mangrove fringe with occur, along with coastal forest loss is to be expected, including an expected die off of *Sabal palmetto* and other shoreline species (Titus 1998, USEPA CRE 2008). To determine the possible extent of such loss, SLAMM modeling has been employed.

The Sea Level Affecting Marshes Model (SLAMM) was developed with USEPA funding in the mid 1980s (Park et al. 1986), and SLAMM2 was used to simulate 20% of the coast of the contiguous United States for the USEPA Report to Congress on the potential effects of global climate change (Park et al. 1989a, Park et al. 1989b, Park 1991, Titus et al. 1991). Subsequently, more detailed studies were undertaken with SLAMM3, including simulations of St. Mary’s Estuary, FL-GA (Lee et al. 1991, Lee et al. 1992, Park et al. 1991), Puget Sound (Park et al. 1993), and South Florida (Park and Lee 1993). More recently SLAMM4 was applied to all of San Francisco Bay, Humboldt Bay, and large areas of Delaware Bay and Galveston Bay (Galbraith et al. 2002, Galbraith et al. 2003).

SLAMM Version 4.1 is the latest version of the model, developed in 2005 and based on SLAMM 4.0. SLAMM 4.1 provides additional sea level rise scenarios based on the IPCC findings as of the Third Assessment Report (IPCC 2001) and additional data examination tools to ensure that data quality is acceptable. Model flexibility has been improved with respect to accretion rates, and the model now accepts data from the USGS seamless data distribution tool (seamless.usgs.gov). To accurately model erosion in larger sites, maximum fetch is now calculated on a cell-by-cell basis rather than being input as a site characteristic.

SLAMM simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise. A complex decision tree incorporating geometric and qualitative relationships is used to represent transfers among coastal classes. Each site is divided into cells of equal area, and each class within a cell is simulated separately. Earlier versions of SLAMM used cells that were usually 500 by 500 meters or 250 by 250 meters. Version 4.1 uses cells that are 30 m by 30 m, based on NOAA tidal data, Fish & Wildlife Service National Wetland Inventory data, and USGS Digital Elevation Model data that are readily available for downloading from the Web. Map distributions of wetlands are predicted under conditions of accelerated sea level rise, and results are summarized in tabular and graphical form.

Relative sea level change is computed for each site for each time step; it is the sum of the historic eustatic trend, the site-specific rate of change of elevation due to subsidence and isostatic adjustment, and the accelerated rise depending on the scenario chosen (Titus et al. 1991). Sea level rise is offset by sedimentation and accretion using average or site-specific values. For each time step, the fractional conversion from one class to another is computed on the basis of the relative change in elevation divided by the elevational range of the class in that cell. For that reason, marshes that extend across wide tidal ranges are only slowly converted to unvegetated tidal flats. If a cell is protected by a dike or levee it is not permitted to change. The existence of these dikes can severely affect the ability of wetlands to migrate onto adjacent shorelines. Diked wetlands are assumed to be subject to inundation when relative sea level change is greater than 2 m, although that assumption can be changed. In one study, alternate management scenarios involving maintenance of dikes were simulated (Park et al. 1993).

In addition to the effects of inundation represented by the simple geometric model described above, second-order effects occur due to changes in the spatial relationships among the coastal elements. In particular, the model computes exposure to wave action; if the fetch (the distance across which wind-driven waves can be formed) is greater than 9 km, the model assumes moderate erosion. If a cell is exposed to open ocean, severe erosion of wetlands is assumed. Beach erosion is modeled using a relationship reported by Bruun (1962) whereby recession is 100 times the change in sea level. Wetlands on the lee side of coastal barriers are subject to conversion due to overwash as erosion of backshore and dune areas occurs and as other lowlands are drowned. Erosion of dry lands is ignored; in the absence of site-specific information, this could underestimate the availability of sediment to replenish wetlands where accelerated bluff erosion could be expected to occur. Coastal swamps and fresh marshes migrate onto adjacent uplands as a response of the water table to rising sea level close to the coast; this could be modified to take advantage of more site-specific predictions of water table elevations.

Congressional testimony by Park (1991) included predictions of increases and then declines in the brown shrimp catch for the Gulf Coast based on the predicted breakup and loss of marsh habitat (Park 1991). More recently, the model was used to predict loss of habitat for shorebirds (Galbraith et al. 2002, Galbraith et al. 2003).

The model was run given the minimum, mean, and maximum estimates of each of the SRES (Special Report on Emissions Scenarios). A brief description of each of these scenarios can be found in the SLAMM 4.1 technical documentation (Glick 2006); more extensive descriptions are in the IPCC Third Assessment Report (IPCC 2001). For simplicity, this report will focus on the A1 scenario in which the future world includes very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. In particular, the A1B scenario assumes that energy sources will be balanced across all sources.

Significant overwash is predicted for the barrier islands around Charlotte Harbor resulting in major upland loss. Saturation and inundation will also negatively affect uplands that are predicted to decrease by 35-55% depending on whether the mean or maximum scenario is run. Existing tidal flats are also predicted to be all but eliminated by sea level rise. Mangroves are predicted thrive under these scenarios increasing by 75% to 119% provided the sea level rise is gradual.

Habitat	Initial Condition	Percent of Initial	Year 2100	Area Changed	Percent Loss	Percent Loss
	Hectares		Hectares	Hectares	Mean	Maximum
Upland	37,805	23%	24,468	-13,337	-35%	-55%
Hardwood Swamp	5,000	3%	3,196	-1,804	-36%	-51%
Cypress Swamp	31	0%	32	1	3%	5%
Inland Freshwater Marsh	1,261	1%	1,036	-225	-18%	-55%
Transitional Salt Marsh	73	0%	15	-58	-79%	-167%
Saltmarsh	1,384	1%	151	-1,233	-89%	-98%
Mangrove	18,577	11%	32,535	13,958	75%	119%
Estuarine Beach	492	0%	143	-349	-71%	-76%
Tidal Flat	22,835	14%	612	-22,223	-97%	-99%
Marine Beach	97	0%	70	-27	-28%	-100%
Hard bottom Intertidal	3	0%	3	0	0%	0%
Inland Open Water	517	0%	212	-305	-59%	73%
Estuarine Open Water	50,921	31%	74,501	23,580	46%	48%
Marine Open Water	22,691	14%	24,711	2,020	9%	11%
TOTAL	**161,687**		**161,685**			

Table 16: SLAMM 4.1 Predictions of Habitat Fates under Scenario A1B, Mean (Max) for Charlotte Harbor, Florida

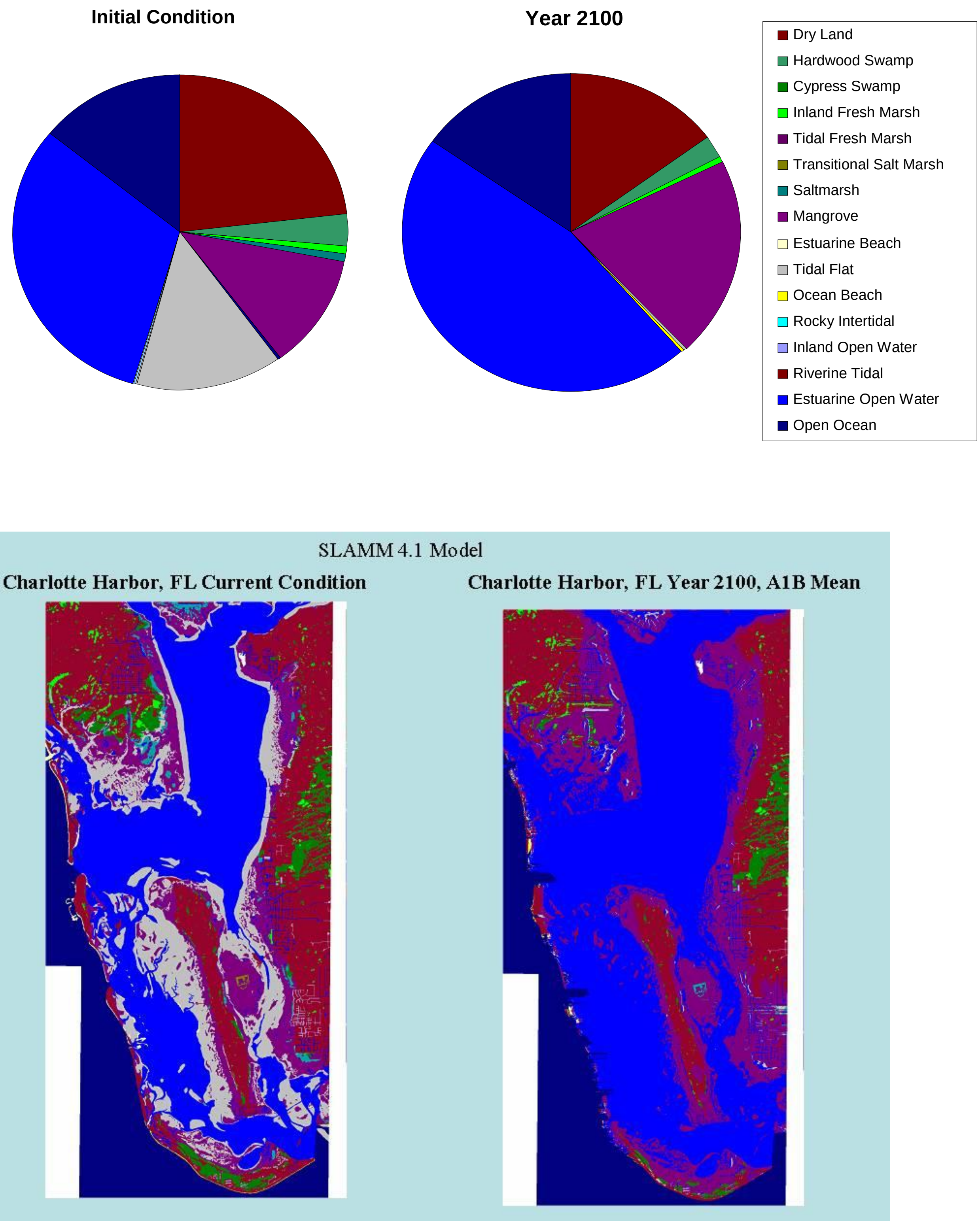


Figure 51: SLAMM Predictions of Habitat Fate under Scenario A1B, Mean for Charlotte, FL

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 43: 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 51: 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.

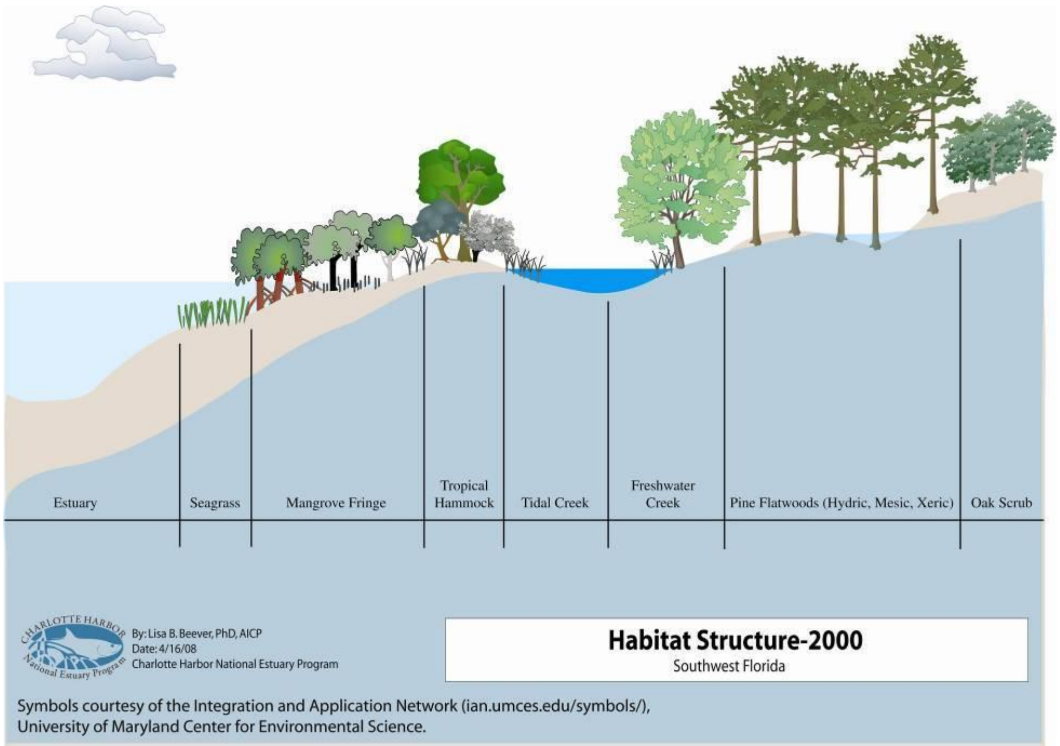


Figure 52: Habitat Structure 2000 Southwest Florida

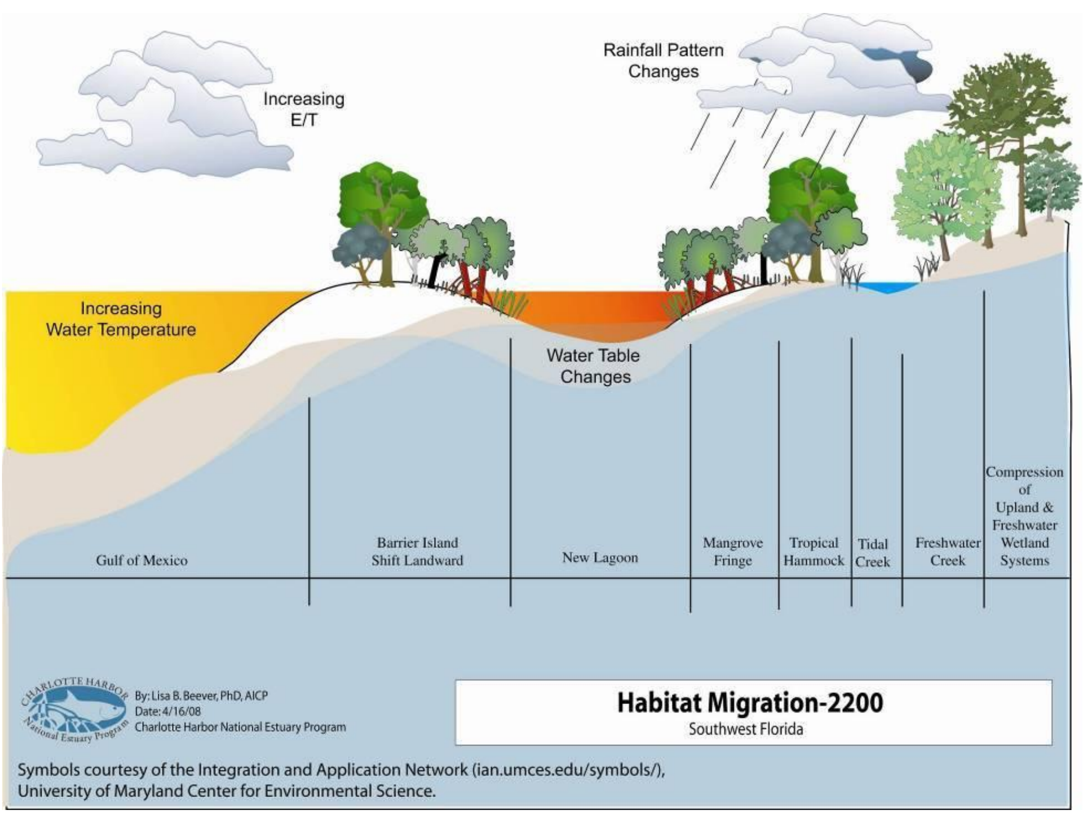


Figure 53: Habitat Structure 2200 Southwest Florida

Land Use Changes

Known Land Use Changes and Events that Have Occurred

Land use projections for Florida

The most important economic and political issue facing Florida over the next decade is land use. Assuming that Florida chooses to participate in mitigation efforts, policy makers will need to make hard choices between urban expansion and alternative land uses associated with greenhouse gas (GHG) mitigation and adaptation. Even assuming a net reduction in immigration to the state, Florida's population will likely increase by at least 50 percent over the next twenty-five years, and may double in fifty years. Urban development, suburban sprawl, transportation pressures, coastal human population densities, habitat fragmentation, and reduced agricultural and forest lands will be the inevitable result of this population increase unless growth is managed wisely with attention to enhancing sustainability (Mulkey 2006).

Seventy-seven percent of Florida's population lives in coastal counties, 31% on the Gulf coast. Population density in shoreline counties is approximately 444 people per square mile, while the density inland was an estimated 170 people per square mile, the differences partially due to large cities along the coast. Inland counties, with smaller population levels, have grown faster than shoreline counties with population and housing growth at approximately 42% during the period 1990-2004. Florida ranks third among the coastal states for shoreline county population and 13th for shoreline county population density (Kildow 2006).

The constraints on land use and natural resources are made ever more critical by the unfolding consequences of climate change, which will impact densely populated coastal regions as sea level rises. The central challenge and opportunity for Florida policy makers is to include the potential for GHG mitigation and adaptation to climate change in this mix of constraints. Since the early 1800s, the history of Florida has been characterized by periodic land speculation, and over the last two decades the urban expansion of the state has been dramatic. A study published by 1000 Friends of Florida shows that, by 2060, an additional 7 million acres will be needed to support growth if it continues at the rate measured through December 2005 (Zwick and Carr 2006).

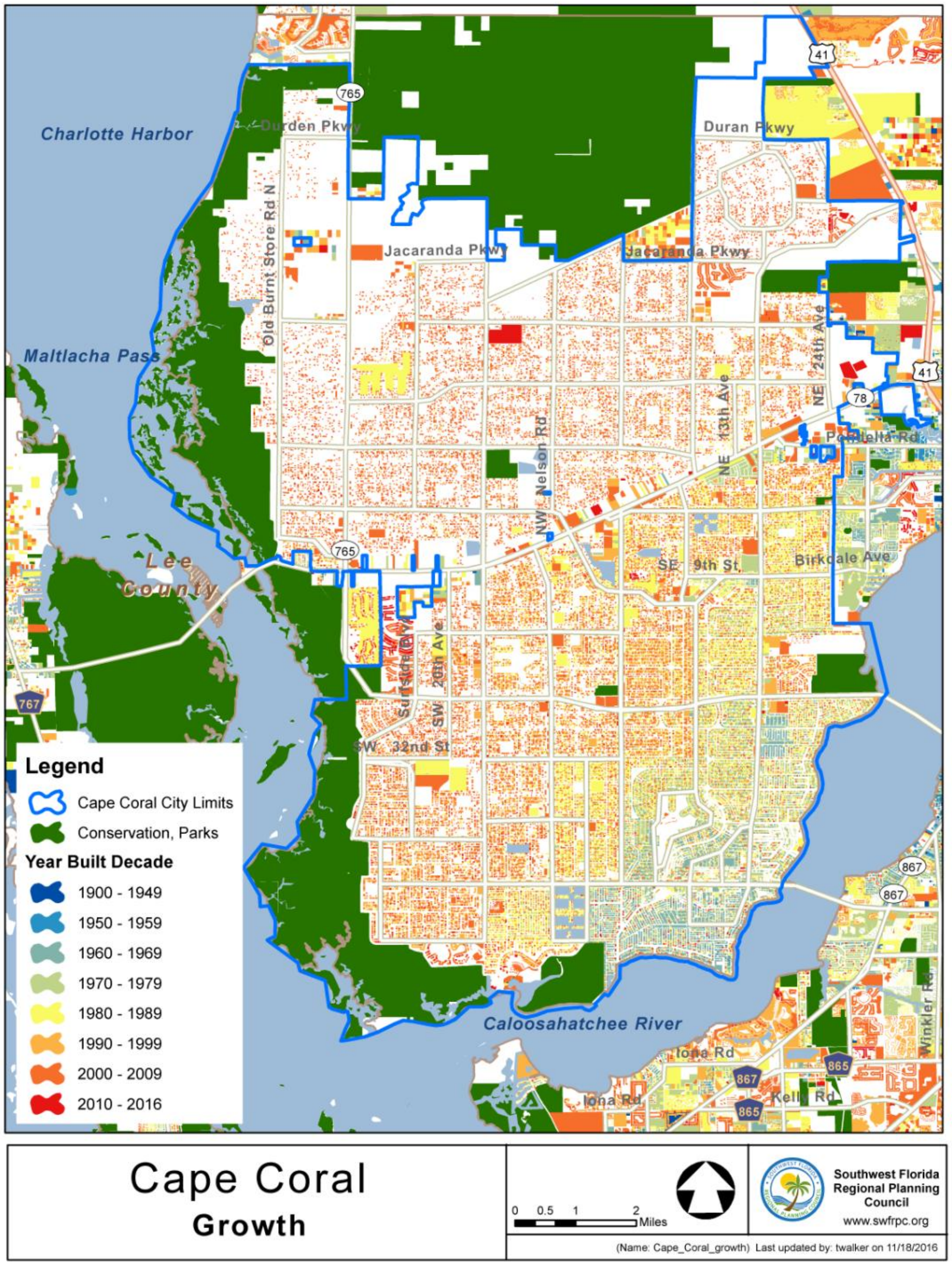


Figure54: Distribution of human development growth in the City of Cape Coral 1900-2016.

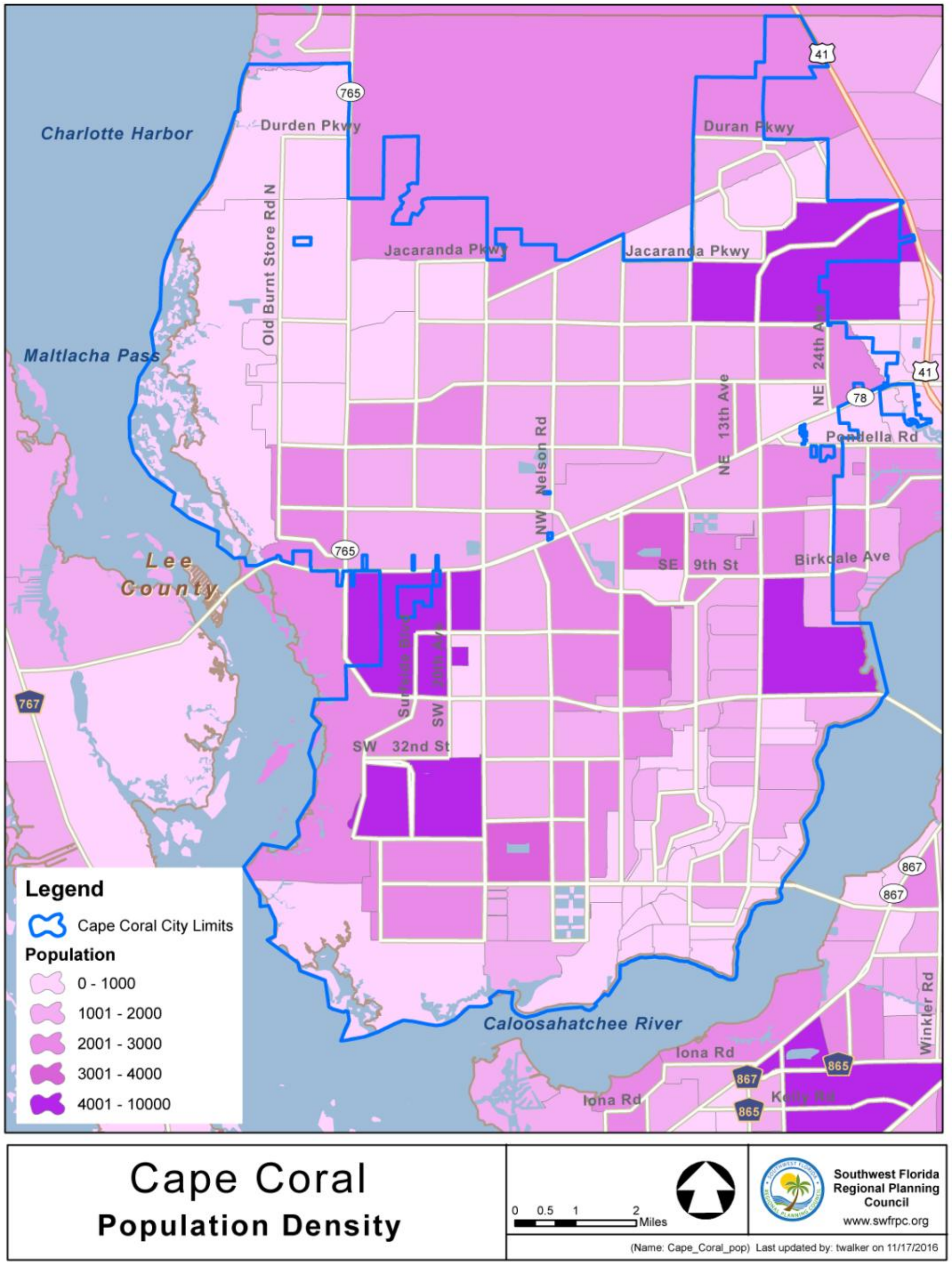


Figure 55: Population Density (by Census Block) in the City of Cape Coral 2016.

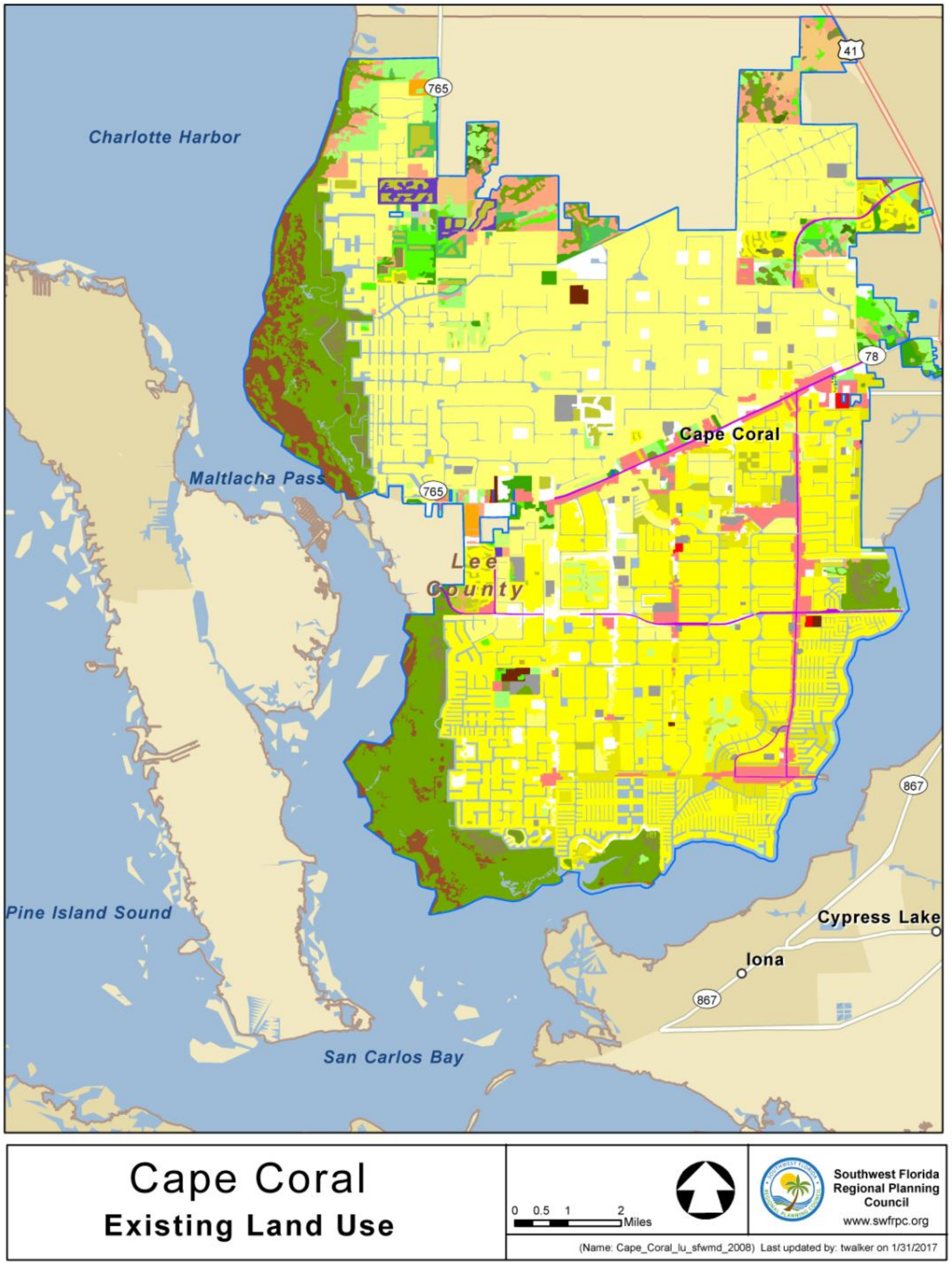


Figure 56: Existing Landuse/Landcover in the City of Cape Coral 2016.

Figure 57: Key to existing Land Use/Land Cover in the City of Cape Coral 2016.

Area of Different Land Uses in the City of Cape Coral	
FLUCCS Designation	Area in Acres
1110 FIXED SINGLE FAMILY UNITS	8,966.40
1120 MOBILE HOME UNITS	0.47
1130 MIXED UNITS - FIXED AND MOBILE HOME UNITS	0.59
1180 RURAL RESIDENTIAL	14,129.74
1210 FIXED SINGLE FAMILY UNITS	17,883.32
1290 MEDIUM DENSITY UNDER CONSTRUCTION	623.01
1320 MOBILE HOME UNITS	10.80
1330 MULTIPLE DWELLING UNITS - LOW RISE	1,572.19
1340 MULTIPLE DWELLING UNITS - HIGH RISE	132.90
1390 HIGH DENSITY UNDER CONSTRUCTION	41.90
1400 COMMERCIAL AND SERVICES	1,608.74
1411 SHOPPING CENTERS	412.57
1480 CEMETERIES	24.10
1550 OTHER LIGHT INDUSTRY	72.02
1700 INSTITUTIONAL	369.65
1710 EDUCATIONAL FACILITIES	584.03
1810 SWIMMING BEACH	1.46
1820 GOLF COURSE	509.97
1840 MARINAS AND FISH CAMPS	11.19
1850 PARKS AND ZOOS	301.40
1900 OPEN LAND	2,202.34
1920 INACTIVE LAND WITH STREET PATTERN	285.10
2110 IMPROVED PASTURES	60.62
2120 UNIMPROVED PASTURES	112.90
2230 OTHER GROVES	0.15
2410 TREE NURSERIES	0.07
2430 ORNAMENTALS	5.13
2610 FALLOW CROPLAND	22.30
3100 HERBACEOUS (DRY PRAIRIE)	570.09
3200 UPLAND SHRUB AND BRUSHLAND	569.12
3210 PALMETTO PRAIRIES	1,158.58
3300 MIXED RANGELAND	722.16
4110 PINE FLATWOODS	1,903.09
4200 UPLAND HARDWOOD FORESTS	86.12
4220 BRAZILIAN PEPPER	23.08
4240 MELALEUCA	702.53
4340 UPLAND MIXED CONIFEROUS - HARDWOOD	335.21
4370 AUSTRALIAN PINE	187.73
5110 NATURAL RIVER - STREAM - WATERWAY	708.04
5120 CHANNELIZED WATERWAYS - CANALS	5,216.89

5300 RESERVOIRS	1,281.22
5410 EMBAYMENTS OPENING DIRECTLY TO GULF OR OCEAN	1,639.55
5420 EMBAYMENTS NOT OPENING DIRECTLY TO GULF OR OCEAN	335.59
5430 SALTWATER PONDS	7.37
6120 MANGROVE SWAMP	7,621.35
6170 MIXED WETLAND HARDWOODS	34.00
6172 MIXED SHRUBS	578.66
6191 WET MELALEUCA	212.94
6200 WETLAND CONIFEROUS FORESTS	2.08
6215 CYPRESS - DOMES - HEADS	16.54
6216 CYPRESS - MIXED HARDWOODS	17.73
6250 WET PINELANDS HYDRIC PINE	58.38
6300 WETLAND FORESTED MIXED	3.89
6410 FRESHWATER MARSHES - GRAMINOID PRAIRIE - MARSH	373.41
6420 SALTWATER MARSHES - HALOPHYTIC HERBACEOUS PRAIRIE	826.04
6510 TIDAL FLATS	24.36
7400 DISTURBED LAND	329.65
7430 SPOIL AREAS	21.50
8140 ROADS AND HIGHWAYS	542.34
8310 ELECTRICAL POWER FACILITIES	22.05
8320 ELECTRICAL POWER TRANSMISSION LINES	11.38
8330 WATER SUPPLY PLANTS - INCLUDING PUMPING STATIONS	66.49
8340 SEWAGE TREATMENT	71.33

Year	Population	Urban Acres	% of Region Acres	Persons per acre	Persons per urban acre
2005	537,180	287,176	55.8	1.04	1.87
2060	1,369,900	514,392	100+	2.66	2.66
Difference	**832,720**	**227,216**	**44.2**	**1.62**	**0.79**

Table 17: Projected Growth in Cape Coral/ Fort Myers urbanized area
Source: FLORIDA 2060: A POPULATION DISTRIBUTION SCENARIO (1000 Friends of Florida 2006)

Year	Population	Urban Acres	% of County Acres	Persons per acre	Person per urban acre
2006	585,608	313,066	60.86	1.14	1.87
2030	1,053,900	514,392	100+	2.05	2.05
Difference	**468,292**	**201,326**	**39+**	**0.91**	

Table 18: Projected Growth in Cape Coral/ Fort Myers urbanized area
Source: Florida Statistical Abstract 2007

Year	Population	Urban Acres	% of County Acres	Persons per acre	Persons per urban acre
2007	615,741	329,175	15	1.2	1.87
2030	1,033,500	514,392	100+	2.01	2.01
2035	1,115,500	514,392	100+	2.17	2.17
Difference '07-'30	**417,759**	**201,326**	**39+**	**0.81**	**0.3**

Table 19: Projected Growth in Cape Coral/ Fort Myers urbanized area
Source: Florida Statistical Abstract 2008

Cape Coral/ Fort Myers urbanized area is expected to reach build-out before 2060 causing an almost continuous band of urban development along the southwest Florida coast and population spillover into adjacent inland counties. Another result will be an almost continuous urban strip linking Ft. Myers to West Palm Beach. Consequently only a few large areas of contiguous open space are likely to remain in the inland counties. The natural systems and wildlife habitat corridors in this region will be fragmented, if not replaced, by urban development. The Southwest Florida region is projected to have the third largest percentage of urban land use (40%) of any region in the state by 2060.

In order to avoid the elimination or extreme fragmentation of natural systems and wildlife habitat, traditional urban development patterns will have to be reevaluated. As illustrated by Table 19 above, each Cape Coral/ Fort Myers urbanized area resident currently creates a demand for 0.5 acres of urban land area. Using the accepted population projections from BEBR and assuming a continuance of low density development, urban land uses will consume 100 percent of Cape Coral/ Fort Myers urbanized area lands by the year 2030.

Forests currently cover approximately 16,718,501 acres in the state of Florida which represents approximately 39.7% of the land area of the state. Comparatively, forests cover approximately 206,567 acres in Cape Coral/ Fort Myers urbanized area which represents approximately 26.9% of the land area of Lee County. In 2002 crop and pasturelands covered approximately 10,414,877 acres of land in the state of Florida. In the same year, crop and pasturelands covered approximately 126,484 acres of Lee County's total 514,392 land acres (2007 Florida Statistical Abstract). By 2030, the projected urban expansion would consume all remaining acreage from both agricultural and native habitat lands, respectively. This vision of the future is not consistent with either the goals of sustainable development or maximizing the opportunity for climate mitigation and adaptation through land management.

Both the Southwest and South Florida Water Management Districts' land use maps use the Florida Land Use and Cover Classification System (FLUCCS). The land use map for 2016 (Figure 56) illustrates the distribution of urban, extractive, agriculture, wetlands and uplands within the City of Cape Coral study area.

Exclusive of urbanization, Florida land cover has been altered extensively in the last century, contributing to changes in temperature trends. While there has been a general trend toward higher mid-summer maximum and minimum temperatures throughout south Florida, the draining of southern wetlands has resulted in an increased severity and frequency of economically damaging frosts for the region between Lake Okeechobee and the Everglades. The thermal inertia of intact wetlands retains heat in the lower atmosphere, while their loss allows dissipation of this heat overnight (Marshall et al. 2003).

Similarly, changes in meteorological parameters (clear sky downward long wave radiation) have been associated with land use change in the subtropical climate of the St. Johns River Water Management District in northeastern Florida (Rizou and Nnadi 2007). This mesoscale, or regional, climate change has been shown to result from human alteration on the landscape. Unlike California, the whole of Florida has not been surveyed for possible effects of land use change on the mesoscale climate. It is likely that the effects of changes in vegetation cover on Florida climate have been extensive during the 20th century.

The urban heat island effect has increased dramatically for many of Florida's growing urban areas over the last century. Buildings (particularly asphaltic roofing materials), parking lots, roads and other paved surfaces of urban areas exhibit greater solar radiation absorption, greater thermal conductivity, and thus a greater capacity for releasing overnight heat that is stored during the day. Thus, urban areas tend to be warmer than surrounding areas in direct relation to the amount of impervious surface present in the landscape.

In a study comparing the urban heat island effect in two metropolitan areas, the urban area of the Tampa Bay watershed was found to have a daytime heating effect, whereas the urban surface in Las Vegas showed a daytime cooling effect. These thermal effects are strongly correlated with urban development densities and percent imperviousness.

Las Vegas may be cooler in part due to the tendency of the arid suburbs to become more vegetated as the city has expanded, but overall there is a greater density of impervious surface in the metropolitan core of Tampa Bay relative to that in Las Vegas (Xian and Crane 2006). A strongly increasing heat island effect has been observed for the Miami metropolitan area as the city has grown, with the number of heat stress nights increasing by more than 24 per year during the period 1950-1999. A similar trend has been documented for Tampa (Physicians for Social Responsibility 2001). The heat island effect has important implications for Florida energy use because, for every 1° F increase in daytime temperature, as much as 225 MW (megawatts) additional power generation is required during periods of peak electricity demand in a large urban area.

Climatologists (Pielke 2005) have argued convincingly that land use change, including urbanization, should be considered a “first order” or primary forcing agent for mesoscale climate. For some regions, over relatively short timescales, this effect can be greater than the climate forcing of the GHGs. Thus, the concept of heterogeneous forcing is the most appropriate paradigm for understanding climate change. The top-down approach inherent in the Global Circulation Models (IPCC 2007) assumes that with sufficient model resolution one can accurately project climate many decades into the future. While this is a reasonable assumption for projections of globally averaged climate under the dominant influence of GHG, it may not be true for regions on a shorter time scale as land use patterns change.

Moreover, because the extremes of weather have important implications for human well being, the average values derived from the Global Circulation Models can be misleading. Land use change often affects meteorological maxima and minima (e.g., Marshall et al. 2004). Based on current knowledge of the importance of land use for climate, it is appropriate that both bottom-up and top-down approaches are utilized when assessing climate change for a region. Climate models incorporating GHGs, land use, and regionally relevant meteorological variables would be useful for predicting climate variability and change for regions the size of the state of Florida and smaller (Pielke et al. 2007). Ideally, mesoscale climate models would operate over timescales consistent with the rate of land use change and allow projections of how specific changes would affect climate. Although such models are being developed, significant resources are needed to advance this science, and there is an urgent need to assess land use impacts on climate given the rapid pace of urbanization of the state (Zwick and Carr 2006).

As natural lands are broken up through the expansion of urban areas, habitats become fragmented. The remaining isolated landscapes are often too small to support breeding pairs of animals and preclude intermixing of breeding populations. Also, the margins of these fragmented natural lands create “edge habitat” that alters species composition and can increase human impacts (CHNEP CCMP 2008). The Lee County study area has lost more than forty-one percent of its original wetland habitat, mostly to agricultural drainage, mining and urban development. Land drained by connector ditches for farming accounts for the largest loss of freshwater wetlands. More recently, wetland conversions to farmland or open water have accelerated, especially in smaller unregulated wetlands. It is not known what the balance in temperature would be between wetland removal and urban heat islands. If a removed wetland is subsequently paved, an even warmer heat island effect outcome could result.

Mining activities have also impacted wetlands. Urban and rural development also destroys wetlands, filling them to provide a more stable substrate for building. Most elimination of wetlands goes through a permitting process with mitigation requirements. However, some wetland losses are currently permitted with no mitigation requirements (CHNEP CCMP 2008; SWFRPC 2007).

Potential Future Climate Changes

There is compelling evidence that not all climate change on a regional scale can be attributed to the atmospheric forcing effect of GHGs. For example, conversion of tropical savanna to grassland has resulted in regional decreases in precipitation in South America, Africa, and Australia (McPherson 2007). A recent survey of California climate variability shows that about half of warming of the state since 1950 can be attributed to global warming through statistical association with increased Pacific Ocean sea surface temperatures. The remaining half of the warming can be attributed to land use change, with large urban areas exhibiting two to five times more warming than the state average (LaDochy et al. 2007). A similar pattern has been shown for the Eastern U.S. (Kalnay and Cai 2003). The urban heat island effect does not account for all of the warming associated with land use change because changes in vegetation cover can significantly affect long wave and short wave emissivity, albedo (reflectivity), boundary layer thickness, potential evapotranspiration, and other factors contributing to local variation in temperature and precipitation (Pielke 2005; McPherson 2007; Waters et al. 2007).

Sea level rise is expected to push most human habitation inland. As larger populations move toward the interior, there are likely to be other changes that complicate effects of climate change. Changes in groundwater use patterns ranging from agricultural cycling to human consumption patterns will exacerbate drought conditions. A decrease in inland water quality may be expected due to increased human habitation combined with fertilizer use, and wastewater and stormwater runoff increases. There will be encroachment of humans into some relatively less-disturbed habitats. This will further reduce the natural areas occupied by wide-ranging listed species such as the Florida panther and Florida black bear. There will be reduced land available for agriculture operations providing food for local and export economies. There will be less interior options for carbon sequestration. There will be competition between people and wildlife for habitat. Under current permitting standards, an extensive loss of short-hydroperiod freshwater wetlands will occur and more of the landscape will become open water from borrow pit operations and creation of stormwater treatment retention areas (USCCSP 2008; Cerulean 2008; Titus 1998; Volk 2008; Bollman 2007).

Sea level rise reduces the amount of land available above the tide line for conservation both by direct physical replacement with submerged habitats and by shifting needs for human habitable and cultivation lands. In balance, this could decrease the amount of land available for conservation (USNOAA 2008; Titus 1998; Volk 2008; USEPA CRE 2008).

Thus, given the conditions of the “business-as-usual” scenario of climate change outlined above, by 2060, 150 square miles of Cape Coral/ Fort Myers urbanized area’s 804 square mile area would be in a vulnerable zone. This amounts to 18.7% of Lee’s land area.

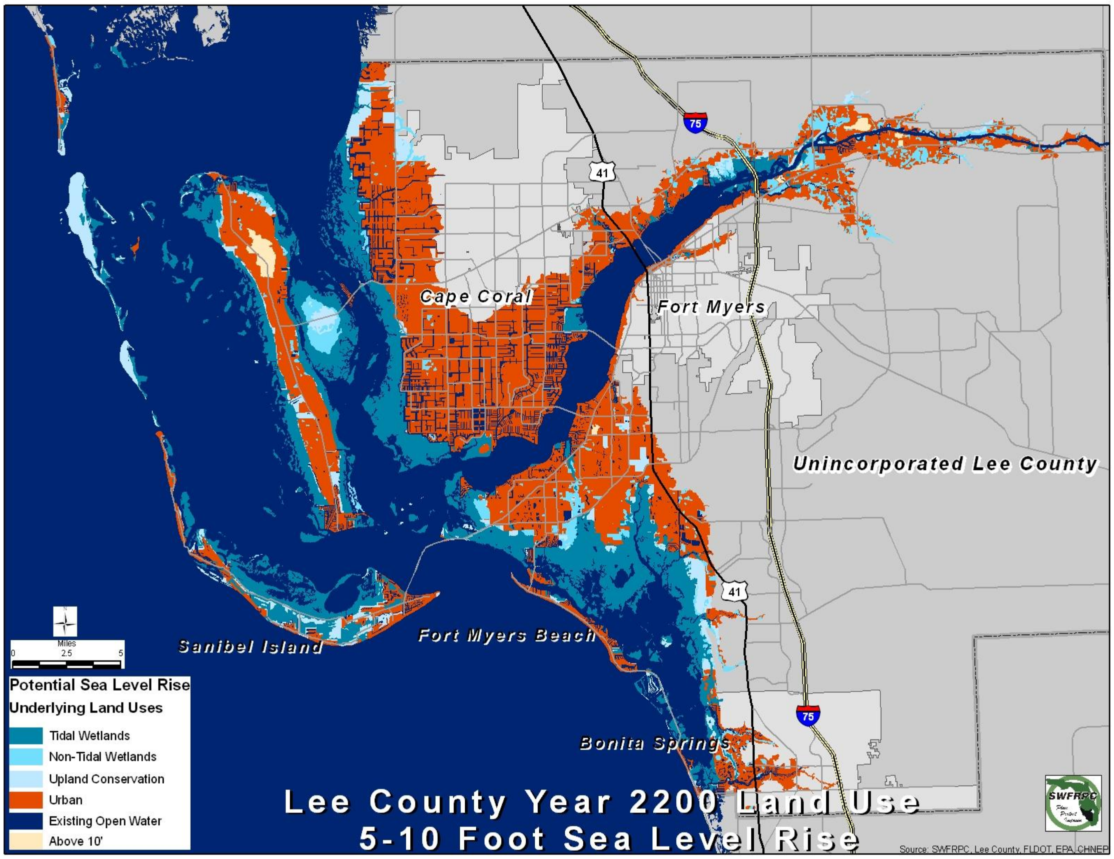


Figure 58: Year 2200 5-10 Foot Sea Level Rise with Location of General Land Use Types Affected in Southwest Florida

The most significant negative short-term effect on mesoscale, or regional, climate will be from changes to urbanization and vegetation cover associated with sprawl and land use change. Efforts at climate mitigation that are most likely to have near-term positive effects should be directed toward managing the state's growth and land use so as to stabilize mesoscale changes in climate.

Because of Florida's rapid human population growth, there is likely less than a decade remaining to avoid significant additional mesoscale climate change from land use. It is still possible, though, to develop and implement best management practices that can mitigate for some of these changes (Mulkey 2007). For example, the forest, agricultural, and natural lands in Florida have yet to be managed for GHG offsets and mitigation, and thus they represent obvious targets for inclusion in a climate action plan for the state

It is important that Florida develop regional climate models capable of modeling heterogeneous atmospheric forcing (climate change derived from more than one source, including land use change) within the three climate zones of Florida. Targeted major funding for climate research groups at the state universities, and collaboration of state agencies with national and international climate modeling groups would help move this effort forward. The results of these models can be integrated into the state's economic projections.

Human Economy

Potential Future Climate Changes

Climate change will affect Florida's economy. The economic and financial costs associated with such change can be direct or indirect. Some costs are called "hidden" because they are difficult to identify and quantify. Many environmental and human costs cannot be measured in dollars. These include the effects on human quality of life and the destruction of ecosystems that currently provide essential ecological functions at no cost. Some sectors of the economy may actually benefit from climate change, and some of the costs of climate change may be offset by mitigation efforts. However, the net costs of climate change are likely to exceed the benefits. A recent national study, sponsored by the Center for Health and the Global Environment at Harvard Medical School, indicates that the economic impacts of climate change will be felt throughout the United States (Center for Integrative Environmental Research (CIER) 2007). These impacts will be unevenly distributed across regions and society, and negative impacts will outweigh benefits for most sectors that provide goods and services. The impacts will place immense strains on public sector budgets. The secondary impacts of climate change may include higher prices, reduced incomes, and job losses.

The CIER study (2007) predicts that major impacts on the southeast United States (including Florida) will be felt most acutely in coastal infrastructure. Forests, agriculture and fisheries, water supplies, water quality, and energy sources may be subject to considerable change and damage. Many of these sectors are closely linked. For example, energy supply depends on cooling water availability to power plants; emergency preparedness depends on transportation, energy supply, water availability, and more. Only a few of these interrelationships typically enter economic impact and cost assessments. These indirect links need to be considered as well as the economic cost assessments.

Stanton and Ackerman's study (2007), mentioned in detail above, indicates the cost of inaction as being the difference between a business-as-usual scenario and a rapid stabilization scenario. For just four categories of economic activity— tourism, hurricanes, electric power, and real estate—the cost of inaction ranged from $27 billion by 2025 (or 1.6 percent of the projected gross state product) to $354 billion in 2100 (about 5 percent of the projected gross state product). If estimates include other sectors, such as agriculture, fisheries, insurance, transportation, water systems, and ecosystem damages, the cost of inaction is even greater.

If climate change results in reduced runoff and lower groundwater levels for parts of the year, the consequence could be a shortage of water to satisfy both ecosystem needs and the growing and competing human demands, resulting in wetland loss. Wetland loss will continue to convert land to open water, threatening the region's enormously valuable fisheries, aquaculture and coastal agriculture, as well as navigation and other industries located near the coast. Future wetland loss rates could increase as sea level rise accelerates in the latter part of the 21st century (Twilley et al. 2001).

Changes in estuarine water quality will affect ecosystem services which are provided by the environment at no investment cost, but which greatly enhance the Florida economy. These include sediment stabilization, water quality treatment, nursery functions for fisheries, and watchable wildlife (Peterson et al. 2007; USEPA CRE 2008).

Increases in drought-related fires would have severe impacts on managed forests and the timber-based economy of the region and would also pose substantial risks to nearby human development. Most southern pine plantations are not managed regularly with prescribed burns because of management costs and legal liabilities, despite awareness of the need to reduce fuel loads. High fuel loads will increase the risks of wildfire, especially if the climate becomes more favorable to intensified fire cycles (Twilley et al. 2001).

In contrast, wildfires are critical for maintaining grassland communities such as coastal prairies, where woody plants typically invade prairies that are not mowed or burned. Increased fire frequency should help prairie conservation and the maintenance of gazing lands (Twilley et al. 2001).

Warmer average temperatures and milder winters are likely to result in a higher incidence of damage by agricultural and forestry pests such as the Southern Pine bark beetle (Twilley et al. 2001).

Plant growth and productivity could increase with higher atmospheric concentrations of carbon dioxide (CO_2) and modestly warmer temperatures, as long as rainfall is not reduced. However, increased plant growth in response to higher CO_2 varies among species and higher CO_2 could drive changes in the mix of species and interactions within communities. Further, gains in plant productivity due to increased CO_2 could be countered by other climate-driven changes such as reduced moisture availability, higher ultraviolet-B radiation, limited nutrient availability, increased water stress, increases in pests and fires, and air pollution. For example, certain agricultural crops such as corn, sorghum, and rice could become more productive with higher CO_2 concentrations, assuming other stresses do not counter the fertilizer effects of CO_2 (Twilley et al. 2001). However, if the climate of the Gulf Coast turns drier overall, cotton, soybean, rice, and sorghum productivity could drop without irrigation and citrus production may shrink moderately in Florida (Twilley et al. 2001).

As rising sea temperatures cause a 5 to 10% increase in hurricane wind speeds, storm events will result in increased coastal erosion and there will be increases in insurance rates due to more severe wind-related hurricane damage to dwellings and other buildings, agriculture and public infrastructure. This will discourage creation and maintenance of dwelling units, public investment and utilities in coastal high hazard areas (USNOAA 2008; FOCC 2009; USEPA CRE 2008). Increasing population growth and increasing wealth structure has already vastly raised the potential financial damage a storm can inflict (USNOAA 2008).

Climate change will have other economic consequences including regional water shortages, increased ocean acidity affecting sport/commercial fishing, and increased salinity of drinking water supplies will make potable water more expensive. There will be road and infrastructure damage. Coastal cities' expenses will increase. Beachfront property will be lost. Coastal business expenditures will increase. The state may become less desirable to tourists. (USCCSP 2008; USNOAA 2008; USEPA CRE 2008).

It should be noted that adaptations to climate change effects will have consequences of their own. Short-term climate change adaptations implemented in the coastal zones by humans including canals, floodgates, levees, etc. may actually reduce the ability of coastal wetlands to deliver valuable ecosystem services. These structures cause changes in water availability for wetlands reducing their ability to store, distribute and purify water. Construction of bulkheads eliminates upslope vegetative transition zone migrations, causes loss of seaward habitat, and causes the loss of the ability of all habitat types to migrate inland with rising sea level (Ebi et al. 2007; Peterson et al. 2007; USEPA CRE 2008).

Tourism

Each year visitors make 85 million trips to Florida's scenic beaches, rich marine ecosystems and abundant amusement parks, staying for an average of five nights per trip. Of these trips to Florida, 78 million are taken by domestic U.S. travelers —one trip per year for every fourth U.S. resident — and seven million trips by international visitors, one third of which are Canadian. A further 13 million Florida residents take recreational trips within Florida, and many more travel on business within the state, or participate in recreational activities near their homes (VISITFLORIDA 2007a; b).

In 2006, almost a tenth of the state economy — 9.6 percent, or $65 billion, of Florida's gross state product (GSP) — came from tourism and recreation industries including restaurants and bars; arts, entertainment and recreation facilities; lodging; air transportation; and travel agencies.

Tourism is the second biggest contributor to Florida's economy, after real estate (in 2007). As Gross State Product (GSP) grows six-fold over the next century, Stanton and Ackerman (2007) project that, in the rapid stabilization case, tourism and its associated taxes will remain a steady 9.6 percent of total GSP. Under these assumptions, Florida's tourism industry will bring in $317 billion in revenues in 2050. Today, approximately 980,000 people make their living in Florida's tourism and recreation sector, 6 percent of the state's population. If the same share of state residents is still employed in tourism in 2050, 1.9 million Floridians will draw paychecks from restaurants, amusement parts, hotels, airports, and travel agencies (VISITFLORIDA 2007a; b).
The gradual climate change under the rapid stabilization case should have little impact on tourism, however, sea level rise and higher temperatures will alter the state's tourist economy to some degree. Negative impacts to state and local economies, individuals'

livelihoods, and commercial/sport fishing could be expected. Erosion and/or destruction of beaches may greatly decrease tourist activity in those areas. Declines in fisheries may decrease sport fishing. Impacts to reefs may decrease interest in scuba diving and related activities (Fiedler et al. 2001; Lee County Visitor and Convention Bureau 2008).

In the Stanton and Ackerman (2007) worst case scenario, the future of Florida's tourism industry is clouded. By this estimation, Florida's average temperature increases 2.5°F by 2025, 5°F by 2050, and 10°F by 2100. In January, warmer temperatures are unlikely to deter many tourists, but in July and August, when the average high temperature on Miami Beach will rise from 87°F to 97°F over the next century, and the July heat index (temperature and humidity combined) will increase by 15 to 20°F, Florida's already hot and sticky weather is likely to lose some of its appeal for visitors.

In the Stanton and Ackerman (2007) worst case scenario, sea levels in 2050 will have risen by 23 inches, covering many of Florida's sandy beaches. In theory, these beaches could be "renourished" by adding massive amounts of sand to bring them up to their former elevation, or the new coastline could be converted to beach recreation use, but only if residential and commercial properties in the zone most vulnerable to sea level rise are not "shored up" by sea-walls or levees.

With 45 inches of sea level rise over the next century, a Florida nearly devoid of beaches in 2100 is a possibility. Many of the marine habitats that bring divers, snorkelers, sport fishers, birdwatchers and campers to Florida will also be destroyed or severely degraded over the course of the next century. Tourists are also attracted by Florida's natural environments and wildlife, but sea level rise will drown the Everglades and with it the American crocodile, the Florida panther, and many other endangered species. As Florida's shallow mangrove swamps and seagrass beds become open water (unless wetland ecosystems are permitted to migrate inland by allowing Florida's dry lands to flood) manatees and other aquatic species that rely on wetlands for food, shelter and breeding grounds will die out. Similarly, Florida's coral reefs will bleach and die off as ocean temperature and acidity increases.

Tourists are unlikely to come to Florida to see the dead or dying remnants of what are today unique treasures of the natural world.

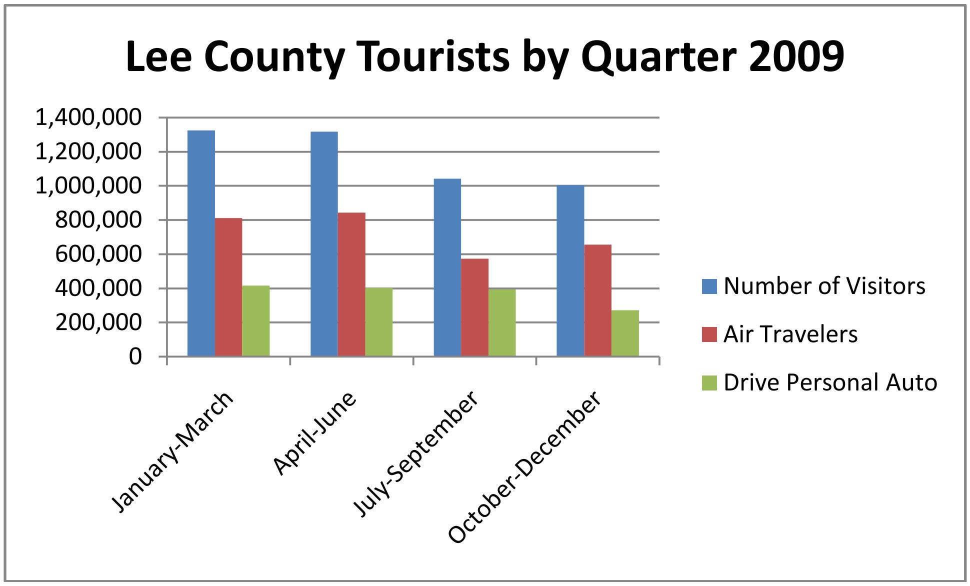


Figure 59: Cape Coral/ Fort Myers urbanized area tourists by quarter 2009
Source: Lee County Visitor and Convention Bureau

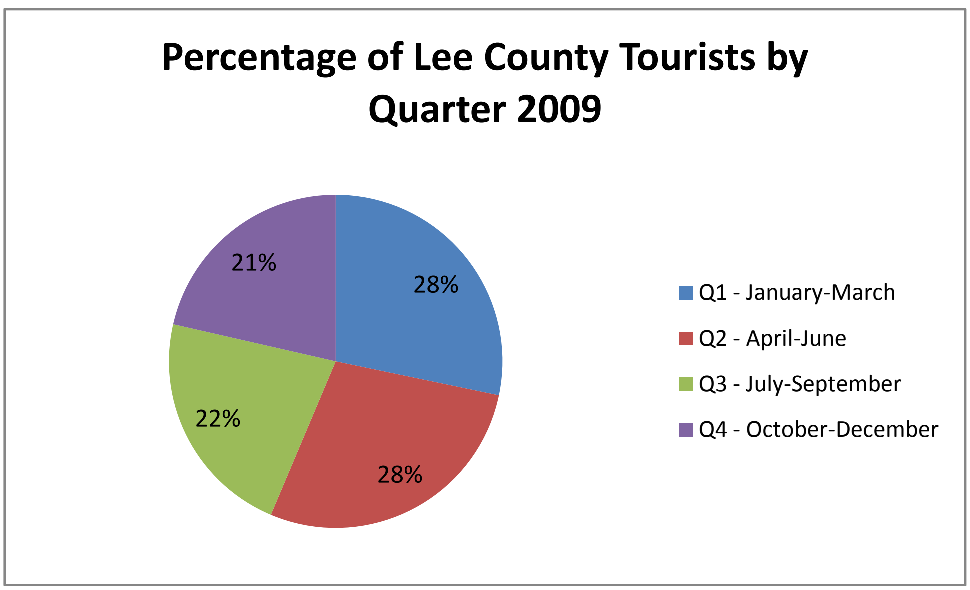


Figure 60: Percent of Cape Coral/ Fort Myers urbanized area tourists by quarter 2009
Source: Lee County Visitor and Convention Bureau

Estimates of the direct impact of hurricane damage on Florida's economy are dealt with in a separate section of this report, but there are also important indirect effects on Florida's reputation as a vacation destination. As the intensity of storms increases in the worst case, fewer visitors are likely to plan trips to Florida, especially during the June-to-November hurricane season. The possibility of being caught in a storm or forced to evacuate to a storm shelter will become a greater concern for tourists as the effects of climate change are featured more frequently on the evening news. Under these conditions, Florida's tourism industry is almost certain to suffer; the exact decline in future revenues and employment is, however, nearly impossible to estimate with any certainty. The calculations that follow are, therefore, a rough estimate based on a broad interpretation of existing data. Because Florida received 19 percent of its tourists in October through December in 2007, the fewest visitors of all four quarters, Stanton and Ackerman (2007) infer that the lowest number of trips to Florida in any month is about five million (VISIT FLORIDA 2007a; b). Stanton and Ackerman (2007) consider this to be the base rate for Florida's tourism at present; and assume it is the rate that is insensitive to weather: regardless of hurricanes and sweltering summers, at least five million people come to Florida each month. Some come for business, some to visit amusement parks (many of which are air conditioned, though outdoor areas, including waiting lines, obviously are not), and some, despite rain, humidity, and scorching heat, to the beach. This projection implies that three-quarters of all tourists would still come to Florida despite the worst effects of climate change, while one-quarter would go elsewhere or stay home.

Stanton and Ackerman (2007) make the same assumption for Florida residents' share of tourism and recreation spending: for one out of four recreational activities that Florida families would have taken part it, they will instead choose to stay in their air conditioned homes. They assume that under the worst case scenario, tourism and recreational activities decline gradually to 75 percent of the rapid stabilization case level by 2100. Midway through that decline, in 2050, Florida's tourism industry will be bringing in $40 billion less in annual revenue and employing one million fewer people than it would in the rapid stabilization case, a loss of 1.2 percent of GSP. The annual cost of inaction reaches $167 billion in 2100 — 2.4 percent of GSP.

Agriculture

The mix of crop and livestock production in a state is influenced by climatic conditions and water availability. As the climate warms, some production patterns will shift northward. Increases in climate variability could make adaptation by farmers more difficult. Warmer climates and less soil moisture due to increased evaporation may increase the need for irrigation. However, these same conditions could decrease water supplies, which also may be needed by natural ecosystems, urban populations, and other economic sectors. Most studies have not fully accounted for changes in climate variability, water availability, and imperfect responses by farmers to changing climate. Including these factors could substantially change modeling results. Analyses based on changes in average climate and which assume farmers effectively adapt suggest that aggregate U.S. food production will not be harmed, although there may be significant regional changes.

Florida is one of the leading states in terms of cash revenue from farming, with irrigated cropland accounting for the high value of farm production. Yields of citrus fruits could decrease with warmer temperatures in the southernmost part of the state because of a lack of a sufficient dormant period. Changes in cotton and sorghum production are unclear — increasing CO_2 levels and rainfall would be likely to increase yields, but the shortened growing season brought on by increasing temperatures could result in plants producing fewer or smaller seeds and fruit, which would decrease yields. Increases in temperature (about 6°F) and rainfall (10%) are projected to reduce corn yields by 14% (USEPA 1997).

Due to increases in precipitation of five to 10% over levels of the 20th century, including heavy and extreme precipitation events, in some areas of the state, certain crops, such as corn, soybeans, sorghum and peanuts could be reduced in their yields by as much as 20%. (Mulkey 2007)

Despite its profitability and importance to the state and the nation, Florida's agriculture faces serious constraints even in the best case scenario. Currently, there is little land remaining for expansion of agriculture. There is likely to be continued pressure on existing agricultural land from population growth, residential development, and sprawl. Florida's citrus industry will continue to suffer from citrus canker, a bacterial disease that causes fruit and leaves to be shed prematurely, and from citrus greening.

The citrus canker bacteria can be spread quite rapidly by wind-blown rain; hurricanes have transported the disease beyond the quarantine zones set up by farmers. The 2004 hurricanes led to the infection of 80,000 acres of commercial citrus; Hurricane Wilma in 2005 caused the disease to spread to an additional 168,000 to 220,000 acres (Schubert et al. 2001; Anderson et al. 2004; FDACS 2006a; d; 2007a). The increases predicted in wind speeds and storm intensities under various climate change scenarios could result in the further spread of this disease.

Even greater pressure on agriculture will result from the scarcity of water in the state. Florida's agricultural sector is already heavily dependent on irrigation: 80 percent of all farmed acres (excluding pasturelands) are irrigated (Marella 2004). In 2000, just under half of all freshwater withdrawals were used for agriculture. Citrus and sugarcane commanded 47 and 22 percent of agricultural water withdrawals, respectively; all vegetables, including tomatoes, used just over 10 percent; greenhouses and nurseries about 5 percent; and livestock less than 1 percent (FDACS 2003; Marella 2004).

In the worst case scenario, Florida's climate changes much more quickly: the state will become hotter and drier, and hurricanes and other extreme weather events will become more frequent. Temperatures climb four times as quickly in the worst case; as a result, impacts that don't arise until 2100 in the rapid stabilization case become important by 2025 in the business-as-usual case. The warmer weather and increased carbon dioxide levels that come with climate change could, at first, have some short-term benefits for Florida agriculture. Even in Florida, farmers can face heavy damages when temperatures dip below freezing, and these losses result in higher fruit and vegetable prices across the country. Rising temperatures would, on average, mean fewer winter freezes, a welcome change for many farmers.

In addition, some types of plants can photosynthesize more productively when levels of carbon dioxide are somewhat higher than at present. All the major crops grown in Florida, except sugarcane, fall into this category. The magnitude of this effect, however, is uncertain and by the end of the century, under the worst case scenario, carbon dioxide levels well beyond those which have been tested on plants will have been reached.

But reduced damages from freezing and benefits from carbon dioxide fertilization are not the only effects on agriculture in the worst case, and most of the other impacts are detrimental. As temperatures increase, citrus production in South Florida will begin to decline as periods of dormant growth, necessary to the fruit's development, are reduced (EPA 1997). Optimal temperatures for citrus growth are 68-86°F; at higher temperatures, citrus trees cease to grow (Ackerman 1938; Morton 1987). Production of tomatoes, too, will begin to decrease before the end of the century, as Florida's climate moves above their mean daily optimal temperature range of 68-77°F (Sato et al. 2000; U.S. Global Change Research Program 2001; Lerner 2006). Sugarcane may also suffer a reduction in yield; it belongs to a class of plants that benefit little from higher levels of carbon dioxide in the air, and it will have to compete with carbon-loving weeds (IPCC 2007a). If farmers increase herbicide use as a result, their production costs will increase accordingly, as will the environmental impacts of herbicide use. Sugarcane will also grow more slowly in the hotter, worst case climate; the optimal average growing temperature for sugarcane is 77–79°F (Vaclavicek 2004).

Due to the increased presence of pests, spraying is already much more common in warmer areas than in cooler areas (Karl et al. 2009). For example, Florida sweet corn growers spray their fields 15 to 32 times a year to fight pests such as corn borer and corn earworm, while New York farmers average zero to five times (Hatfield et al. 2008).

Even those agricultural commodities that thrive in higher temperatures and higher concentrations of carbon dioxide are at risk from other consequences of climate change, including the northward shift of some pest insects and weed species (IPCC 2001a). Flooding from sea level rise is another concern. With 27 inches of sea level rise in 2060, 4,500 acres of current pasture, 7,000 acres of citrus groves and 26,000 acres of other farmlands will be inundated.

Florida also has a long history of severe crop damage from hurricanes, and more intense storms may cause still greater losses. The 2004 hurricane season, for example, caused extensive damage to citrus groves, decreasing yields by 17 percent in the following year. In Indian River County, where Hurricanes Francis and Jeanne both struck, citrus production dropped by 76 percent and several other counties lost 40 to 50 percent of their crop (FDACS 2006b). Sugarcane is another vulnerable crop: flooding from hurricanes can easily damage sugarcane roots when moisture levels become too high (NRDC and Florida Climate Alliance 2001).

Climate change's biggest threat to Florida agriculture, however, may be increased water requirements for irrigation of crops and for livestock, accompanied by a decreased supply of freshwater. In addition to the water problems discussed above, higher temperatures will result in greater irrigation needs, as more water is lost to increased evaporation from the soil and transpiration from plants, while five to 10 percent less rainfall reaches plants in the Stanton and Ackerman (2007) worst case. In a statistical analysis of USDA data, Florida citrus and sugarcane was found to require approximately five and seven percent more water, respectively, for each degree (Fahrenheit) of mean temperature increase (USDA 2003).

Human Health

Current Relationship of Human Health to Climate Changes

Existing changes in climate patterns and extreme climatic events have already had a wide range of negative effects on human health and well-being in the United States and around the world. For example, severe heat waves, hurricanes, and floods have resulted in many deaths and injuries (Epstein 2005; Patz et al. 2006). In addition, stormwater discharges carry nutrients, toxins, and fecal contaminants from the landscape into receiving waterbodies. Pulses of fecal contaminants in stormwater runoff have caused the closure of beaches and shellfish beds and affect humans through recreational exposure (Dowell et al. 1995). Storm-induced increases in fertilizer runoff from agricultural and residential areas could affect the frequency, intensity, and duration of toxin producing red tides or harmful algal blooms, and promote the emergence of previously unknown toxic algae (Harvell et al. 1999). In other parts of the world, increases in waterborne diseases, such as cholera, have been directly linked to warming and extreme weather outbreaks. In the future, the potential exists for the reintroduction of mosquito-borne diseases, such as malaria and dengue fever, into areas where they do not currently exist, such as warmer regions of the United States, including Florida (Colwell 1996). Threats to ecosystems rich in biodiversity, such as coral reefs, mangroves, and seagrasses, will result in the loss of marine algae and invertebrates, some of which are sources of chemicals with disease-fighting properties (Epstein and Mills 2005).

The ability of the health care system to reduce these health risks in the face of climate change is an important consideration in any projections of vulnerability during the 21st century (Twilley et al. 2001).

Clear effects of climate change have now been established for several human infectious diseases, including malaria (Pascual et al. 2006; Hay et al. 2002), cutaneous leishmaniasis (Chaves and Pascual 2006), cholera (Koelle et al. 2005), plague (Stenseth et al. 2006; Snall et al. 2008), and dengue (Gazelles et al. 2005), as well as for diseases afflicting livestock (Gubbins et al. 2008), wildlife (Harvell et al. 2002), and coral (Harvell et al. 2002; Bruno et al. 2007). The complexities of these systems pose enormous challenges for the detection of climate effects, and for the isolation and integration of climatic and non-climatic effects. Most of the studies cited were able to detect a climate signal because they obtained high-quality data over long time (Ostfeld 2009).

Increased temperatures will affect the occurrence, extent and virulence of disease and parasitism in human, animal and plant populations. Increased parasite survival, increases in development rate, increases in geographic range, increased transmission, increased host susceptibility, compromised physiological function of hosts, decreased host immunity, and decreased survival of obligate symbiotes, such as the coral/algae symbiosis, are all to be expected (Peterson et al. 2007; FOCC 2009; USEPA CRE 2008). Gastrointestinal diseases, respiratory diseases, and skin, ear, and eye infections can result from eating contaminated fish and shellfish and can be acquired during the recreational use of coastal waters. Since temperature, rainfall, and salinity all influence the risk of waterborne infectious diseases, this risk may increase with climate change (Twilley et al. 2001). Most of the germs that cause water-borne disease, such as viruses, bacteria, and protozoa, survive longer in warmer water. Bacteria also reproduce more rapidly in warmer water. Increasingly intense rainfall projected for Florida could also increase the prevalence of water-borne disease. Outbreaks of two of the most common forms of water-borne diseases, *Cryptosporidium parvum* and *Giardia lamblia*, have been found to occur after heavy rainfall events and cause contamination of drinking water (Rose et al.2001). For most healthy people, an infection from a water-borne disease will cause diarrhea for a limited time and go away with no treatment needed. However, in the elderly, infants, pregnant women, and anyone with a weakened immune system, waterborne diseases can be very serious and even fatal. There are some water-borne diseases, such as hepatitis, that can cause serious and long-lasting illness even in previously healthy people (NRDC 2001).

Hotter temperatures, extreme rainfall and increased runoff can increase populations of disease carrying insects and boost the potential for transmission of diseases such as malaria and dengue fever. But actual incidences of these diseases will depend primarily on the responsiveness of the public health system and on the adequate maintenance of water-related infrastructure (Twilley et al. 2001). Vector-borne diseases are spread by mosquitoes, rodents, ticks, and other insects and animals. Malaria, encephalitis, and dengue fever are three examples of vector-borne diseases, as is the mosquito-transmitted West Nile Virus, which has recently caused several deaths in Florida. Rising temperatures could expand the range of many vectors, and can play a role in transmission of the disease itself. Each vector and disease will respond differently to temperature and other factors, including efforts at control. Because of high standards of living and better health infrastructure in Florida, vector-borne disease is less of a problem than elsewhere in the world (Balbus and Wilson 2001). Close monitoring and vigilance will be needed to ensure that diseases such as malaria, encephalitis, dengue fever, and West Nile Virus do not become more widespread problems in Florida (NRDC 2001).

Lafferty (2009) has asserted that early reviews about climate change exaggerated claims that diseases will increase in the future (Randolph 2009). Commentaries from ecologists with considerable expertise in infectious diseases illustrate several examples and case studies which correlate increases in infectious disease with existing climate variation, though alternative explanations exist for many of these patterns (Dobson 2009; Harvell et al. 2009; Ostfeld 2009; Pascual and Bouma 2009; Randolph 2009).

Although we need to focus control efforts on areas where diseases may expand with climate change (Dobson 2009; Pascual and Bouma 2009), it would not be appropriate to then build a general theory of climate change and infectious disease around the one-tailed prediction that climate change will increase the problem of infectious diseases (Randolph 2009). A neutral starting hypothesis is that the ranges of infectious diseases will likely shift with climate change, but not necessarily expand or contract (Lafferty 2009). While public health officials might view this as callous, conservation biologists might find it overly generous.

The shift in the habitat suitability for malaria illustrates the rich set of interacting factors that make it difficult to predict net outcomes in the geographic range of disease and the number of infected humans. Exposure to malaria induces temporary immunity (Dobson 2009) and, over evolutionary time scales, has led to adaptations to reduce infection or increase tolerance (e.g., sickle-cell trait; Allison 1954). If the range of climate suitability for malaria transmission shifts, then newly exposed human populations will be more susceptible to infection and likely suffer greater morbidity (Dobson 2009, Pascual and Bouma 2009). This is particularly relevant for moderate-scale shifts in transmission that could occur within the present poverty prone areas where malaria is endemic (Ostfeld 2009). Whether malaria will disappear from areas where it becomes too hot or arid may depend on how human societies respond to climate change, particularly with respect to damming and irrigation practices to compensate for drought (Pascual and Bouma 2009). In contrast, larger-scale shifts in habitat suitability into wealthier nations at higher latitudes are likely to be countered by control efforts, urbanization, and lack of suitable habitat for vectors (Randolph 2009). Table 20 includes information on climate related disease occurrence in the study area.

County	Dengue and dengue haemorrhagic fever	Malaria	West Nile Virus	Yellow Fever	Encephalitis including St. Louis, California	Equine Encephalitis (Eastern & Western)	Lyme Disease (Borrelia burgdorferi)	Rocky Mountain Spotted Fever	Ehrlichiosis	Typhus Fevers	Plague (Yersinia pestis)	Rabies (possible exposures)	Hantavirus	Tularemia (Francisella tularensis)
Lee 92-08	5	31	5	0	17	0	37	6	2	2	2	624	0	0
2009-2010	1	1	1	0	0	0	11	2	1	0	0	158	0	0
Totals	6	32	6	0	17	0	48	8	3	2	2	782	0	0

mosquito-borne | tick-borne | flea-borne | mammal-borne

Table 20: Tropical diseases occurrence in Cape Coral/ Fort Myers urbanized area, Florida

Higher temperatures poses potential health threats of several kinds: direct health stresses, increased prevalence of disease, and potentially increased smog formation. Although these effects cause concern, there is considerable uncertainty in the level of harm that will occur and some specialists believe that increased threats could be handled adequately by the healthcare system (Natural Resources Defense Council (NRDC) 2001).

Given the make-up of Florida's population, the state is particularly vulnerable to health impacts of climatic warming. In general, the elderly, the young and other segments of the population with impaired health will be most affected. Low-income populations may also be at risk because they typically have less access to high quality healthcare (NRDC 2001).

Increased heat stress could result in increased human mortality, particularly for the elderly, ill and less wealthy in the population and those that exercise strenuously in midday heat such as athletes, exterior construction workers, and children. Southwest Florida is vulnerable to increased frequencies of heat waves, which could increase the number of local heat-related deaths and the incidence of heat-related illnesses, particularly among the large numbers of older residents and visitors (Twilley et al. 2001). Projected changes in the heat index for Florida are the most dramatic in the nation: an increase of eight to 15°F is likely during the next century (United States Global Change Research Program 2001).

The elderly are particularly vulnerable to severe heat-related illness and death. Seniors over 65 years old today constitute about 18 percent of Florida's population, and that figure is forecast to climb to over 26 percent by 2025 (U.S. Census Bureau 2004b). At the same time that Florida's climate is increasingly affected by global warming, the population of the most severely affected age group is growing rapidly. Many factors combine to put Florida's 2.8 million senior citizens at greater risk of suffering a heat-related illness or death (NRDC 2001):

- Impaired ability to disperse heat through the body's physiological mechanisms
- Greater risk of having underlying diseases
- Greater risk of taking medications that may contribute to heatstroke
- Limited mobility
- Compromised temperature perception

Others vulnerable to heat stress are persons working or exercising in the heat, such as construction workers, farmers, theme park workers, and even tourists themselves (Kilbourne 1998). Low-income households are less likely to have air conditioning and may be at higher risk than the general population. One study projected that the number of people dying each year from heat stress in Tampa would more than double by the year 2020 (Kalkstein 1997). However, Florida is well adapted to high temperatures compared to more northern regions, and may be able to adjust without substantial harm. Additional research is required to draw more certain conclusions about heat-related deaths (NRDC 2001).

Sea level rise will also affect the availability and distribution of high-quality freshwater available for drinking because many Gulf Coast aquifers are susceptible to saltwater intrusion. Drinking water supplies taken from surface waters for coastal communities such as Punta Gorda and Fort Myers will be more frequently threatened by saltwater intrusion caused by a combination of sea level rise, land subsidence, and periodic low river flows (Twilley et al. 2001).

The concentration of air pollutants such as ozone is likely to increase in Gulf Coast cities. Ground-level ozone has been shown to reduce lung function, induce respiratory inflammation, and aggravate chronic respiratory diseases like asthma, obstructive pulmonary disease (Twilley et al. 2001). Higher temperatures that increase the rate of smog formation will result in cardiovascular diseases, chronic respiratory diseases like asthma or obstructive pulmonary disease and reduced lung function (Fiedler et al. 2001; SCCP 2005). Increased use of fossil fuels could increase a range of air pollutants. Ground-level ozone, which is a major component of smog, is formed from nitrogen oxides and volatile organic compounds. With warmer temperatures and sunlight, this reaction proceeds faster and forms more smog. Higher temperatures also cause more evaporation of volatile organic compounds when refueling and operating vehicles, further contributing to smog formation. Smog formation is also influenced by rain and wind patterns, not just temperature, and increased rainfall and stronger winds could actually decrease smog formation. Predictions of changes in air quality as a result of global warming are very difficult to make, because global warming will affect rainfall and wind patterns in uncertain ways (NRDC 2001).

Fossil-fuel use is projected to increase under the scenarios considered. In fact, there may even be an increase in energy consumption to power air conditioners as people adapt to warmer temperatures. Without improvements in technology, this would lead to increased amounts of air pollutants, such as sulfur oxides, nitrogen oxides, volatile organic compounds, and particulate matter. However, increased air pollution could be avoided by technological developments and more stringent regulations that would increase energy efficiency and further control air pollutants. In the absence of controls, carbon monoxide, sulfur oxide, and nitrogen oxides aggravate existing cardiovascular diseases, and may produce lung irritation and reduced lung function. As with heat effects, seniors, the young, and those with existing health problems are particularly at risk. Seniors over the age of 65 are more apt to have underlying conditions exacerbated by air pollution and therefore are at higher risk of suffering the consequences of air pollution (NRDC 2001).

Potential Future Climate Changes

Heat waves are considered to be events in which there are temperatures greater than 90°F for several days in a row with warm, stagnant air masses and consecutive nights with higher-than-usual low temperatures. Heat waves are expected to increase in severity and frequency as a result of climate change. Heat waves are already the cause of the most weather-related deaths in the U.S. Studies suggest that, if current emissions hold steady, excess heat-related deaths in the U.S. could climb from an average of about 700 each year currently, to between 3,000 and 5,000 per year by 2050. The elderly are especially vulnerable (CDC, Heat waves, 2009). Higher temperatures and increased frequency of heat waves may increase the number of heat-related deaths and the incidence of heat-related illnesses. Recent scientific work suggests that 28 people die every year in Tampa from heat-related causes during the summer. Even if people adjust to climate change, a 3°F warming could more than double this figure; as many as 68 additional heat-related deaths could occur every year in Tampa during the summer. The elderly, particularly those living alone, are at greatest risk (USEPA OPPE 1997).

There is concern that climate change could increase concentrations of ground-level ozone. For example, specific weather conditions, strong sunlight, and stable air masses, tend to increase urban ozone levels. While Florida is in compliance with current air quality standards, increased temperatures could make remaining in compliance more difficult. Ground-level ozone has-been shown to aggravate existing respiratory illnesses such as asthma, reduce lung function, and induce respiratory inflammation. In addition, ambient ozone reduces agricultural crop yields and impairs ecosystem health (USEPA OPPE 1997). Ozone and airborne particulate matter have well-documented human health effects that may be exacerbated with the increases in their concentrations that will likely occur with climate change. Fine particulate matters are associated with respiratory and cardiovascular diseases, including asthma, COPD, and cardiac dysrhythmias, and are responsible for increased school and work absences, emergency department visits, and hospital admissions (CDC, Air quality and respiratory disease, 2009).

Changing climate conditions also may affect human health through impacts on terrestrial and marine ecosystems. In particular, warming and other climate changes may expand the habitat and infectivity of disease-carrying insects; increasing the potential for transmission of diseases such as malaria and dengue fever. Although dengue fever is currently uncommon in the United States, conditions already exist in Florida that makes it vulnerable to the disease. Warmer temperatures resulting from climate change could increase this risk (USEPA OPPE 1997).

Sea surface warming and sea level rise could increase health threats from marine-borne illnesses and shellfish poisoning in Florida. Warmer seas could contribute to the increased intensity, duration, and extent of harmful algal blooms. These blooms damage habitat and shellfish nurseries, can be toxic to humans, and can carry bacteria like those causing cholera. In turn, algal blooms potentially can lead to higher incidence of water-borne cholera and shellfish poisoning. Acute poisoning related to the consumption of contaminated fish and shellfish has been reported in Florida (USEPA OPPE 1997).

Increased ambient temperatures and humidity along with increased ground-level carbon dioxide will result in increased plant metabolism and pollen production, fungal growth and spore release. Pollen and mold spores can aggravate allergic rhinitis and several other respiratory diseases including asthma. Allergic diseases are already the sixth leading cause of chronic disease in the U.S. Aero-allergens can also combine with pollutants to worsen respiratory diseases (CDC, Aero-allergens, 2009).

Climate change is likely to affect insects and animals that spread diseases, much the same as it will wildlife. Increased temperature is likely to speed up the metabolisms and life cycles of disease-spreading organisms such as mosquitoes and ticks and allow increases in ranges for species that have been confined to tropical environments. Mosquitoes'' metabolism and consumption of blood meals speeds up with increased temperatures, up to a certain point which varies with species. Lyme disease and hantavirus have shown evidence of seasonality, thus the ranges of those diseases could change with climate change. Flooding from more intense rain events may introduce standing water in which mosquitoes can breed, while increased drought may improve conditions favorable to ticks.(CDC, Vector-borne and zoonotic disease, 2009)

Experts estimate water- and food-borne diseases already cause more than 210 million cases, 900,000 associated hospitalizations, and 6,000 deaths annually, caused by bacteria, viruses and parasites. Several water- and food-borne diseases show seasonal patterns, suggesting that they are subject to environmental influences, in terms of pathogen replication, survival, and persistent rates; transmission rates; and disease ranges overall. Temperature and precipitation, both of which will increase with climate change, will affect the spread of water- and food-borne diseases, resulting in higher pathogen replication, persistence, survival, and transmission for bacterial pathogens, and having mixed effects on viral pathogens. Higher temperatures seem to produce a greater number of water- and food-borne parasitic infections. Overall, increased precipitation is associated with increased burdens of disease for bacteria, viruses, and parasites, though the causes of these increases differ by pathogen and ecologic setting. (CDC, Water- and food-borne diseases, 2009)

Indirect health effects include injuries or death from wildfires resulting from more frequent and prolonged drought; conflict over water and other scarce resources; mass population movement; and increased ocean acidity resulting in severe stress on ocean ecosystems, particularly in the tropics. Adaptation to climate change may also increase the risk of certain health conditions, including adoption of new fuels, shifting to other energy sources such as nuclear power, and new methods of reclaiming and purifying waste-water for human consumption. (CDC, Other indirect health effects, 2009)

Other circumstances may interact with climate change in varying ways. Geologic and political limitations on the supplies of fossil fuels; increasing worldwide population; decreased freshwater availability worldwide; worldwide migration to urban areas; and increasing worldwide cost of food and resulting food shortages, among other factors may have effects on human health worldwide. (CDC, Interacting trends, 2009)

Infrastructure

Potential Future Climate Changes

Much of Florida's infrastructure, water, power, telecommunications, transportation, and buildings, were constructed to last at least 75 years. Infrastructure longevity was thus based on past environmental design criteria and specifications, many of which may have been exceeded already by aspects of climate change (Alvarez 2008). Much of this infrastructure will need to be replaced or improved during the time course of ongoing climate changes. An opportunity exists to relocate, harden, and adapt the infrastructure to conditions in ways that avoid or mitigate the potential effects of climate change. (Victorian Climate Change Program (VCCP) 2008)

Climate change is likely to have a significant impact on human infrastructure, particularly at the coasts (FOCC 2009). Sea level rise will stress this infrastructure (buildings, roads, bridges, etc) physically, as salinity changes may affect the structural integrity and/or functionality of physical materials that comprise the features of roads, ports, airports, rail systems, increasing fatigue, reducing effective functional life and requiring accelerated maintenance (USNOAA 2008; SCCP 2005; USEPA CRE 2008). More frequent flooding and erosion will occur. Bridges may be too low for new water levels (USCCSP 2008; University of Washington 2007; US NOAA 2008; Volk 2008; SCCP 2005; USEPA CRE 2008). Increased flooding will affect human-inhabited areas and result in more roadway washouts (USNOAA 2008; USEPA CRE 2008).

Whether or not global warming increases the number or intensity of hurricanes, future storm damages are likely to rise substantially because of the increasing amount of development in harm's way and the aggravating impacts of higher sea levels and degraded coastal ecosystems. Predictions of future wave and storm surges accompanying severe hurricanes (categories 3-5) indicate that significant wave heights (between three and six feet) could reach further inland if barrier islands and wetlands are lost as buffers (Twilley et al. 2001).

With 88 % of all structures in Southwest Florida vulnerable to tropical storms hurricanes and surge events; debris management capacity (as has been observed in Hurricane Charley and other devastating storm events) is a key critical vulnerability and the capability to manage this level of debris and damage, some of which will be hazardous will need to be considered. While solid (and hazardous) waste facilities and landfills are considered as critical facilities in local government's local mitigation strategies many of the facilities in southwest Florida are located in low-lying wetland areas and within the storm surge and 100 year floodplains. There was significant difficulty with managing the debris from the 2004 and 2005 hurricane seasons in southwest Florida with the need to designate temporary staging areas and no long term plan other than to expand existing facilities in place in vulnerable locations. To date, significant waste and debris is found in the estuary and associated wetlands and native uplands where little official effort, other than volunteer efforts, was undertaken to remove anthropogenic materials of all types, including hazardous material, from non-navigable waters and wetlands.

Photograph 7: Raccoons take shelter under building debris post Hurricane Charley, Matlacha Pass, mangroves, Lee County.
Source: L. Beever CHNEP 2004

Energy Infrastructure

The state's electricity market is growing rapidly. These increasing demands on the energy sector are expected to be strained by global climate change, at significant cost to Florida's consumers. Among the impacts of climate change projected in the IPCC 2007 report, several will affect electricity demand, generation, and distribution capacity in Florida, including warmer and more frequent hot days and nights; an increase in the frequency of heat waves; more intense hurricanes; possible coastal flooding from storms surges and sea level rise; and changes in the availability of water for cooling processes.

Additional regulation of energy providers (power plants) is likely to increase consumer costs. There will possibly be greater variability in energy availability depending upon the local conditions that make solar, wind, hydrologic and geothermal sources available. Development of new technologies could offset the costs and decreases in reliability when completed but there will be a period of transition with concomitant inefficiencies that will translate as costs (USEPA CRE 2008).

While much of Florida experiences over a half year of comfortable temperatures between 70 and 85°F, the state has the warmest daily average temperatures in the nation, and summers are hot and humid (O'Brien and Zierden 2001). In 2005, 74 days had highs of 90°F or more, while winter highs dropped below 70°F on only 19 days. Higher atmospheric temperatures will mean that air conditioners run through more of the year, power plants will use significant energy to cool equipment, and power lines will operate less efficiently than they would in a cooler climate. Rising temperatures will dramatically increase demand and further degrade system-wide efficiencies.

The state's older population, highly dependent on air conditioning, will ensure that energy demand remains tightly coupled to temperature. With more frequent heat waves, there may be a need for costly emergency energy infrastructure to reduce heat-related injuries or illness. Without mitigation, the increasing number of Florida customers will stretch current infrastructure, particularly when power demands peak.

Electricity demand projections

In the rapid stabilization case outlined previously, electricity demand will rise mostly due to rapid demographic growth and increasing demands for electricity from residential and commercial consumers; climate change will play only a minor role. The Florida Public Service Commission recorded an increase in residential use per capita of 7 percent between 1995 and 2005, and has projected future increases of 0.84 percent per year (Murelio 2003). The Energy Information Administration (EIA) (2007) projects a 0.76 percent annual increase in commercial use per capita until 2030. Residential housing, amongst the fastest growing sectors in the state, will consume increasing amounts of electricity for lighting, air conditioning, and entertainment. The EIA estimates that, after lighting, the largest use of residential electricity is for air conditioning, a factor which is expected to grow through 2030 at nearly 1 percent per year (EIA 2007). Coupled with Florida's projected rapid demographic growth, the Florida Reliability Coordinating Council (FRCC) expects an annual compounded growth rate of 2.4 percent in summer peak demand and 2.8 percent in total state energy consumption between now and 2015.

Based on this picture of a rapidly growing state population and economy, Stanton and Ackerman (2007) project average annual growth in electricity demand, from 2005 through 2100, of 1.54 percent before considering any effects of temperature changes. A review of Florida's electricity generation by hour indicates that it is closely correlated with temperature (EPA 2007c; NOAA 2007b). Power generation increases at both low and high temperatures to meet heating and cooling demand, respectively, and is lowest at approximately 67°F. In 2005, 85 percent of the hours of the year were above 67°F, a percentage that will rise to 93 percent by 2050 and to 96 percent by 2100. All other things being equal, therefore, we would expect a steep increase in electricity demand in line with warming. In the worst case scenario, average annual temperatures rise by more than 9.7°F by 2100, causing a much more noticeable impact on the electricity system.

On the one hand, this will ease the pressure of winter demand for heating, surprisingly a major factor in Florida's electricity use at present. The highest peak hour demand for electricity in any year is typically a weekday morning hour in winter month. The primary reasons for this peak hour occurring during winter is 1) the number of seasonal residents (single and multi-family homeowners) who winter in Florida; 2) residents who heat their pools with heat pumps; and ,perhaps most importantly, 3) the number of homes with electric resistance heating strips incorporated into central ventilation systems which serves to heat the home. These resistance heat strips are highly inefficient, consuming great quantities of electricity in order to heat residential spaces (Durrett 2010). In 2003, winter demand prompted the state to issue an advisory while local utilities asked consumers to conserve power (Murelio 2003). On the other hand, air conditioning demand on scorching days in the summer will quickly push up against the limits of system capacity. In 2005, 74 days had highs exceeding 90°F. This may climb to more than 90 days a year by 2020, 150 days by 2050, and nearly two-thirds of the year by 2100. In the rapid stabilization case, where a temperature increase of only 2.2°F is expected by 2100, warming will add only 0.07 percent to electricity demand growth each year, for a combined annual growth rate of just over 1.6 percent. By 2100, Stanton and Ackerman (2007) project Florida's total electricity demand will be about 4.5 times as large as in 2005.

For the worst case scenario, Stanton and Ackerman (2007) project that warming will add an average of 0.34 percent to the growth of electricity demand each year, for a combined annual growth rate of 1.88 percent. By 2100, they project Florida's total electricity demand will be about 5.9 times as large as in 2005. There is a large gap between the sizes of the electricity system in the two scenarios: by 2100 the difference between the two scenarios amounts to 1.4 times the total amount of electricity the state produced in 2005.

Electricity supply projections

Unfortunately, the same high temperatures that cause electricity demand to spike also impair the efficiency of power system components, including central generating stations as well as transmission and distribution equipment.

Due to their inability to cool components as quickly, thermal generators have lower efficiency at higher ambient temperatures. When air temperatures rise above design expectations, they are unable to produce as much power. For example, in gas turbines, performance decreases with increasing temperatures, and power output drops off significantly at temperatures over 100°F. In Florida's current system, gas and oil systems lose approximately one percent of efficiency for every 4°F temperature increase (EIA 2007). Florida relies heavily on seawater to cool power plants, thus increases in ocean temperature will reduce the cooling efficiency, and thus impair generation efficiency. At a New York nuclear plant, generation efficiency drops rapidly if river water used for cooling rises above 50 to 60°F; output drops by as much as 2 to 4 percent when water temperatures reach 85°F (Powers 2003). While these declines in efficiency may appear relatively small, the losses can have dramatic consequences across the system, particularly during heat waves when these resources are needed most urgently.

There is a high likelihood that water shortages will limit power plant electricity production in many regions (Karl et al. 2009), and future water constraints on electricity production in thermal power plants are projected for Florida by 2025 (Bull et al. 2007).

When the amount of electricity carried over transmission lines increases (for example on a hot day when many people are using air-conditioning), power lines heat up, stretch, and sag. An overloaded power line can sag so much that it comes in contact with a tree, or comes close to the ground, creating a short-circuit as electricity is discharged, and potentially leading to power outages. Higher ambient temperatures also decrease the maximum current carrying capacity of transmission and distribution lines.

The effect of high temperatures on power system components was highlighted during the widespread power system outages in the summer of 1999. On July 6th, a heat wave with sustained temperatures of 100°F caused overloads and cable failures, knocking out power to 68,000 customers (U.S. Department of Energy 2000). Outages in New York City were due to heat-related failures in connections, cables and transformers. In the South Central region, power plants were not able to produce as much power as predicted, leading to system failures. Small inefficiencies at multiple power plants added up to losses equivalent to 500 megawatts.

To calculate costs for the two scenarios (rapid stabilization and business-as-usual), Stanton and Ackerman (2007) constructed a simple simulation of electricity demand and supply in Florida to 2100. The model accounts for changes in population, per capita demand, and temperature, but holds fuel prices and the cost of new power plants constant (EIA 2007). For the rapid stabilization scenario, the simulation assumes a slowly changing fuel mix, migrating towards increasing efficiency measures and use of renewable energy sources such as wind power, while phasing out oil and coal. With increasing petroleum scarcity, adoption of policies to reduce greenhouse-gas emissions, and resulting demand for better efficiency and widespread renewable energy sources, Stanton and Ackerman (2007) envision a cleaner portfolio with coal use falling steadily by 2100 and use of oil for electricity generation discontinued by 2050. In place of fossil fuels, the cleaner portfolio relies on rigorous new conservation measures that will reduce demand by 40 percent, along with expanded renewable electricity production, supplying 30 percent of electricity demand by 2100.

Such changes are entirely in line with Governor Crist's Executive Orders on climate change of July 2007; indeed, in order to meet the governor's targets for reduced greenhouse gas emissions, as set out in those orders, a massive shift to energy efficiency and renewable energy sources will be necessary. A June 2007 report from the American Council for an Energy-Efficient Economy (ACEEE) argues that Florida can afford to do even more than the cleaner portfolio used in the simulation (Eliott 2007).

For the worst case, on the other hand, Stanton and Ackerman (2007) assumed that the state will satisfy the growing demand for electricity by maintaining the current fuel mix. In this scenario, Florida will need to build approximately five gas plants, four oil plants, and one coal plant in Florida *every year* for the foreseeable future. Even assuming that it was possible to obtain regulatory approval for all these facilities, and to site and construct them and the associated transmission lines, it is uncertain where adequate cooling water would be obtained. And the costs of securing those approvals, and siting and constructing those plants and transmission lines, would inevitably lead to price increases.

Stanton and Ackerman (2007) estimate that in the worst case, the *annual* cost of power in Florida will rise to $43 billion in 2050 and to $78 billion by 2100 (see Table 19). A substantial portion of this growth can be attributed to booming population and energy demand, and is required even in the rapid stabilization case, but the difference between the two scenarios accounts for an added $18 billion a year by 2100. By the end of the century, every additional degree Fahrenheit of warming will cost electricity consumers an extra $3 billion per year.

According to the simulation, the increasing population and demand for power in the business-as-usual scenario will require an untenable 1,500 new sources of generation, nearly 400 more than would be required in the rapid stabilization case (EIA 2007). Significant new construction may be required in any case to supply electricity for Florida's growing economy, but the costs will be much higher under the worst case scenario than under the rapid stabilization scenario.

	2025	**2050**	**2075**	**2100**
Best Case	22.4	37.6	48.1	60.2
Worst Case	23.5	42.5	58.4	78.2

Table 21: Electricity Sector: Costs of Climate Change in billions of 2006 dollars

In the worst case scenario, the electric system has to adapt not only to gradual average temperature increases, but to increasing temperature variability as well, presenting additional challenges and expenses to the energy sector. Highly variable temperatures require a greater number of expensive "peaking" power plants to be online, that sit idle most of the time, but provide enough electrical generation capacity to meet peak demand for cooling on hot summer afternoons. As a result, both the costs of generation and the overall size of the power grid in Florida will be larger than would be needed in the absence of climate change.

	2004 Hurricanes				**2005 Hurricanes**			
	Charley	Frances	Ivan	Jeanne	Dennis	Katrina	Rita	Wilma
Hurricane Category	4	2	3	3	3	2	2	3
Florida sustained winds (mph)	145	105	130	120	120	80	62	125
Number of Utility Restoration Personnel	19,860	21,172	6,430	27,320	5,353	14,820	546	19,121
Customer Power Outages (thousands)	1,800	4,500	400	3,500	500	1,200	25	3,551

Table 22: Hurricane Impacts on Florida's Electric Utilities
Sources: Florida Division of Emergency Management, Hurricane Impact Report (Florida Division of Emergency Management 2004); Florida Division of Emergency Management, Draft Hurricane Impact Report (Florida Division of Emergency Management 2007).

Cape Coral/ Fort Myers urbanized area is home to two electrical generation facilities. Lee County's primary power plant is the Florida Power and Light plant located at 10650 Palm Beach Boulevard. The facility produces 1,400 megawatts (MW)/day from the combustion of natural gas. The plant receives its fuel source via an underground pipeline. The facility is located in the Category 2 storm surge zone. Lee County's secondary electrical generation facility is the waste-to energy-plant which is located at 10500 Buckingham Road. The facility produces an average of 65 MW/day from the residential and commercial waste stream. The facility is located in the Category 4/Category 5 storm surge zones.

Infrastructure vulnerability to storm damage has already been keenly felt in Florida during the 2004 and 2005 hurricane seasons. The four hurricanes that struck the state during each of those two years resulted in damage restoration costs for Florida's privately owned electric utilities of over $1.2 billion in 2004 and $0.9 billion in 2005.

Currently there are 15 plants, representing 22 percent of Florida's total generation capacity (13 gigawatts (GW)) located in storm surge zones for Category 1 hurricanes, and up to 36 plants (over 37.8 percent of capacity) are vulnerable to Category 5 hurricanes. Some of Florida's largest coastal resources are also the most vulnerable, as estimated from the state's "surge zones" (Florida State Emergency Response Team 2006).

Transportation and Other infrastructure

Climate change and sea level rise deserves consideration in the transportation planning process due to the high costs associated with public investments in transportation infrastructure, and the long-term nature of these investments, even if potential risks seem to be in the distant future and the threats to infrastructure are not immediate. From project concept, adoption into an areas' long range transportation plan through environmental studies, design and engineering and construction phases can take 10-25 years. The resulting transportation facilities may have a service life exceeding 100 years, and will influence the location of other public and private investments as well as growth and development patterns (Transportation Research Board 2008).

Climate change and variability is expected to affect transportation infrastructure through temperature changes, precipitation changes, accelerated sea level rise, and increase storm surge and intensity. (Savonis 2009)

Increases in precipitation of five to ten percent over levels of the 20th century, including heavy and extreme precipitation events, will result in increased flash flooding, thereby affecting road washouts (UWCES 2007; USNOAA 2008; SECCP SDRT LCCP 2005, FOCC 2009, USEPA CRE 2008).

Sea level rise, combined with high rates of subsidence in some areas, will make much of the existing transportation infrastructure more prone to frequent or permanent inundation; 27 percent of the major roads, nine percent of the rail lines, and 72 percent of the ports in the southeastern United States are built on land at or below four feet in elevation, a level within the range of worst case projections for relative sea level rise in this region in this century. Increased storm intensity may lead to increased service disruption and infrastructure damage (Karl et al. 2009). More than half of the southeastern United States' major highways (64 percent of interstates, 57 percent of arterials), almost half of the rail miles, 29 airports, and virtually all of the ports, are below 23 feet in elevation and subject to flooding and damage due to hurricane storm surge. These factors will merit consideration in today's transportation decisions and planning processes (Kafalenos et al 2008).

Transportation infrastructure in Florida will be damaged by the effects of sea level rise, particularly in combination with storm surge (Stanton and Ackerman 2007). Many types of transportation infrastructure, including port facilities, airport runways, railways, and especially roads, are at risk. Docks and jetties, for example, must be built at optimal heights relative to existing water levels, and more rapid sea level rise may force more frequent rebuilding. Roads, railroads, and airport runways in low-lying coastal areas all become more vulnerable to flooding as water levels rise, storm surges reach farther inward, and coastal erosion accelerates. Even roads further inland may be threatened, since road drainage systems become less effective as sea levels rise. Many roads are built lower than surrounding land to begin with, so reduced drainage capacity will increase their susceptibility to flooding during rainstorms (Titus 2002).

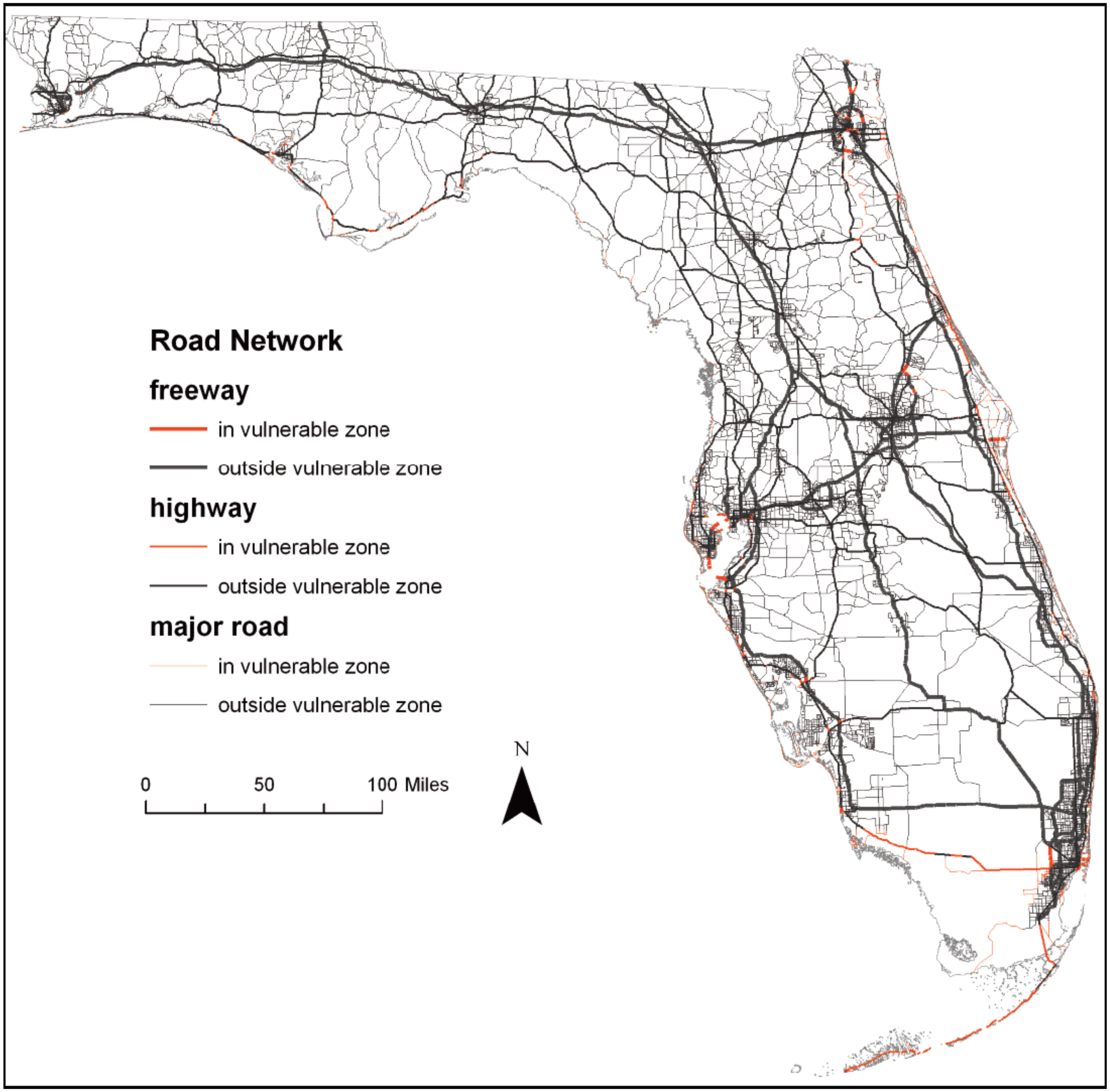

Road Network
freeway
in vulnerable zone
outside vulnerable zone
highway
in vulnerable zone
outside vulnerable zone
major road
in vulnerable zone
outside vulnerable zone
0
50
100 Miles
N

Figure 61: Roads and Railroads in Areas Vulnerable projected worst case sea level rise to 27 Inches of Sea level Rise

Sources: road network data from U.S. Streets Dataset (Environmental Systems Research Institute 2005) and Rail Network dataset (Federal Railroad Administration and Research and Innovative Technology Administration's Bureau of Transportation Statistics 2006); vulnerable zones data from NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).Note: Limited access highways are accessed via a ramp and/or numbered exits, like all Interstates and some intrastate highway

As illustrated in the figures below, access to barrier islands and through low-lying areas such as Hancock Bridge Parkway in North Fort Myers bridges are examples of the most vulnerable transportation infrastructure in the City of Cape Coral by 2050. Bridges generally are a strategic asset, and may be affected if bridge approaches are low-lying, even under best-case scenarios. Even relatively high ground may be vulnerable to erosion (Titus 2002). The City of Cape Coral hurricane evacuation routes are also highly vulnerable to significant impacts to transportation and other infrastructure that occur elsewhere in the State; for highways including Burnt Store Road, this is primarily all bridges on I-75 and on the US 41 corridors. .

While this report is not intended to provide detailed and precise projections of transportation system vulnerabilities in the years 2050, 2100 and 2200, the analyses provide a reasonable basis for developing general expectations of which facilities are likely to be impacted before others, and for developing a planning framework for resiliency strategies. The maps below are provided with the understanding that they are intended for this purpose, not to predict the future status of a specific street or location.

Roadway elevation for the City of Cape Coral Sea Level Rise Vulnerability/Resiliency project was created by using two layers: an elevation polygon and roadway polyline files. The roads were created in segments where the entire length of a given roadway is not one continuous line feature, but many connected pieces. The road line file was laid on top of the elevation polygon. Next, a selection was performed to isolate the desired elevation to study, and, further, to select all intersecting roadway segments. This new roadway selection was exported as a new file that was classified as those roadway segments which intersect a location of low elevation that is highlighted in this study for a given sea level rise scenario. These segments were then used to calculate the linear distance of roadway subject to potential inundation within a given sea level rise scenario. It should be understood that only intersecting segments were exported for further calculation, not the entire roadway. Furthermore, for any portion of a roadway segment that intersects the elevation under review, the length of the entire segment is calculated. This method provides a relatively general understanding of those roadways that are vulnerable to sea level rise. Future project analyses would include an expanded methodology that would provide a more specific understanding of vulnerable roadways.

Sea-Level Rise Scenario	US, State, County, and Interstate Highways(miles)	Other Major Roads (miles)	All Roads(miles)	Railroads (miles)
Lee County 2050 at 1.5 feet	46	145	191	0.8
Lee County 2100 at 3 feet	97	679	776	2.5
Lee County 2200 at 9 feet	255	2783	3038	11
Florida Total at 2.25 feet (from Stanton and Ackerman 2008)	466.3	1972.4	2438.7	181.3

Table 23: Roads and Railroads in Areas Vulnerable to 27 Inches of Sea level Rise
Sources: road network data from U.S. Streets Dataset (Environmental Systems Research Institute 2005) and Rail Network dataset (Federal Railroad Administration and Research and Innovative Technology Administration's Bureau of Transportation Statistics 2006); vulnerable zones data from NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

By 2050, the worst-case analysis indicates approximately 230 miles of roadway in Cape Coral/ Fort Myers urbanized area is below 1.5 ft. in elevation and is likely be directly impacted by sea level rise. This includes 26 miles of major highway roads, and 36 miles of named state routes. Access roads connecting to Pine Island; the bridges to Fort Myers; and across Hancock Creek are among the most vulnerable roadways in the City of Cape Coral to sea level rise and storm surge inundation. Local roads near the Caloosahatchee River; northward along the Burnt Store Road corridor and in low parts of western Cape Coral are subject to precipitation accumulation flooding.

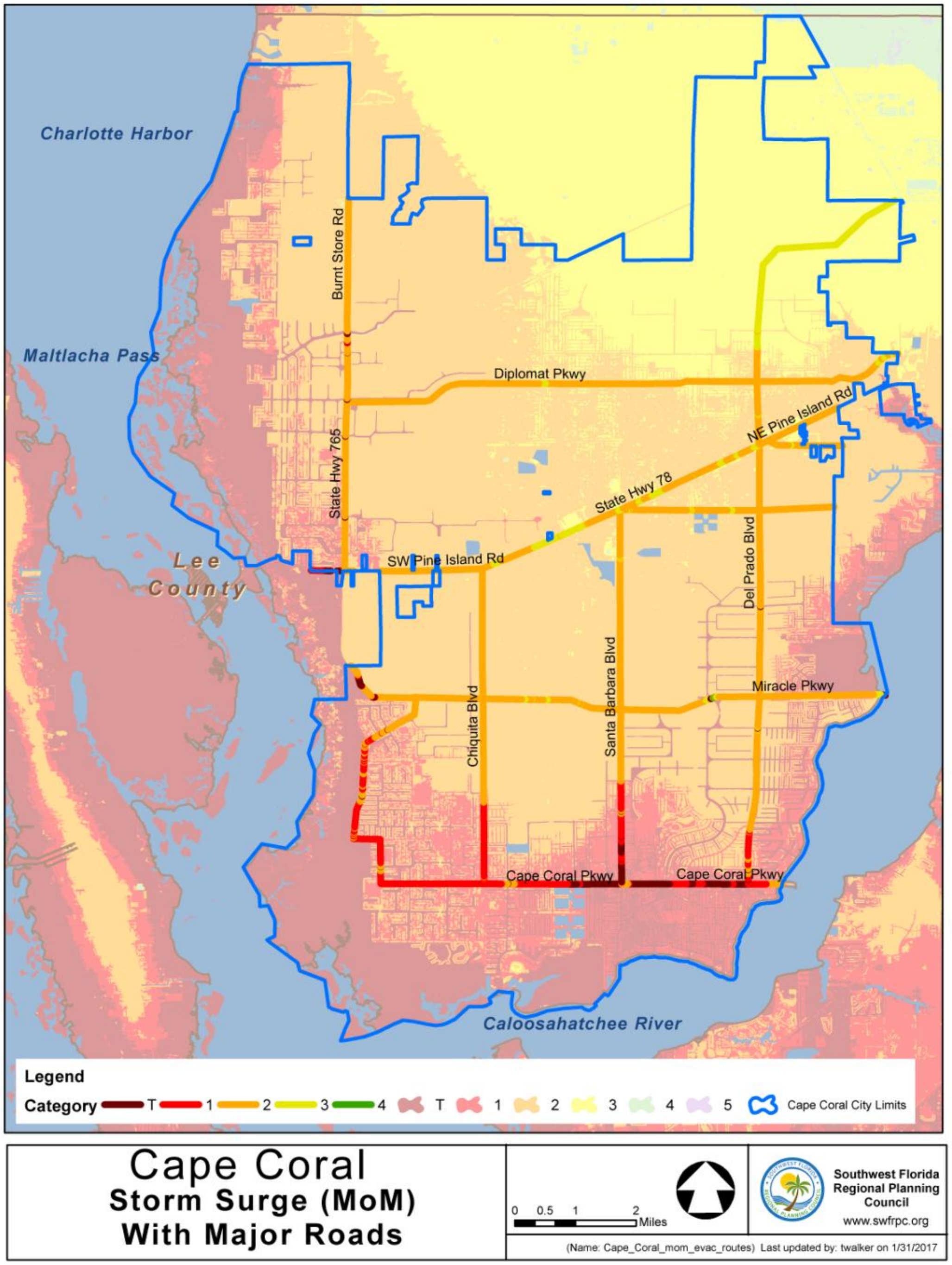


Figure 62: Major Roads in Areas Vulnerable to MoM storm surge and sea level rise

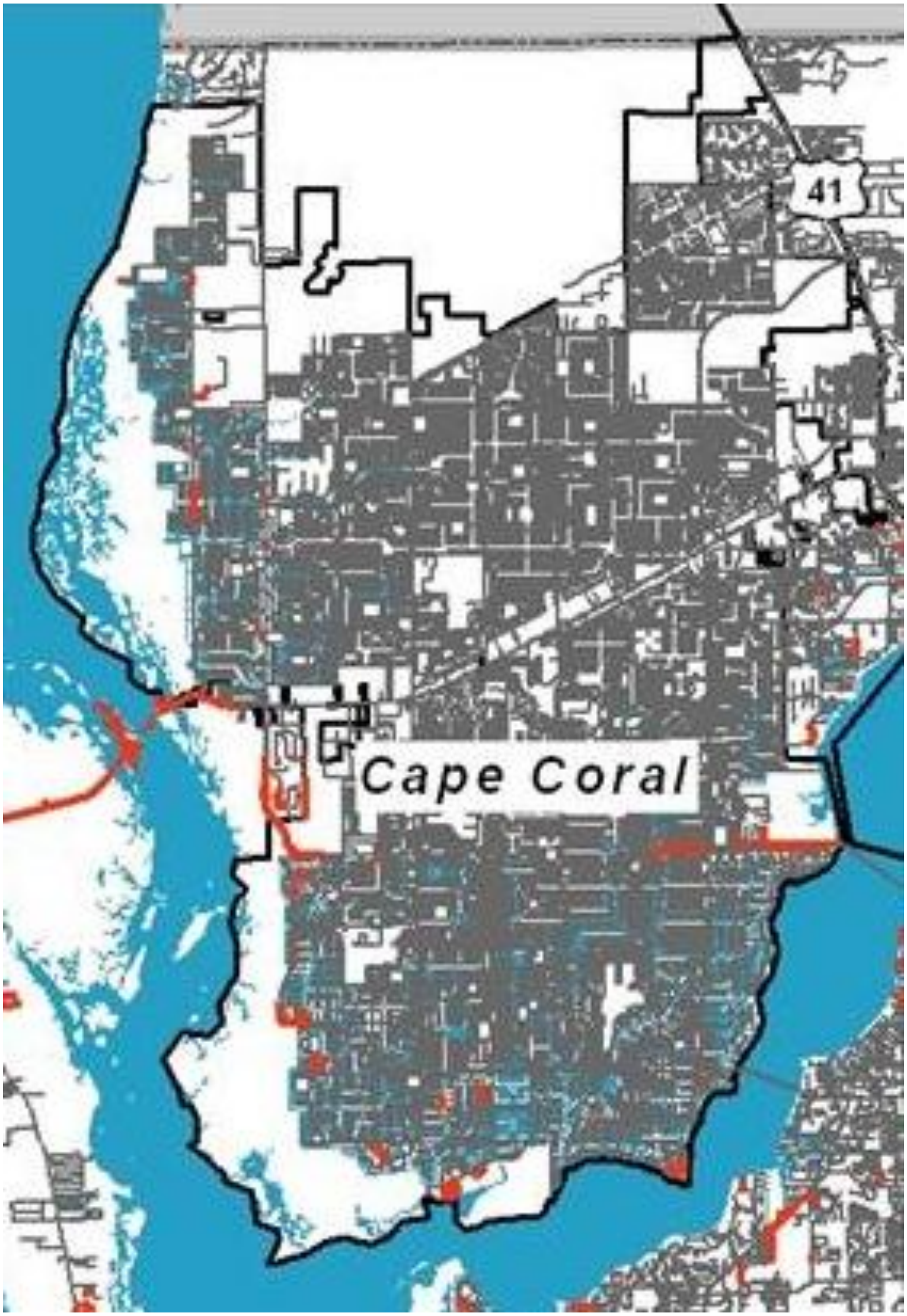


Figure 63: Major roads vulnerable to projected worst case sea level rise year 2050 at 1.5 feet inundation

By 2100, significantly more roads and transportation infrastructure are at subject to inundation if sea level rises by three feet. Approximately 862 miles of roadway are at or below 3 feet, including 44 miles of primary highways and 36 miles of named state routes. Nearly all but the highest areas of all local barrier islands may be inundated, along with significant portions of Cape Coral, and much of South Fort Myers west of U.S. 41, San Carlos west of U.S. 41 and portions of Bonita Springs and Estero primarily but not exclusively west of U.S. 41. More of the roads along both sides of the Caloosahatchee River will be inundated in Cape Coral, Fort Myers, North Fort Myers and up the river. Roads and facilities near other major drainages are also at risk. In many neighborhoods where roads are higher than home sites, inundation is likely to affect housing and commercial property even before roads are affected

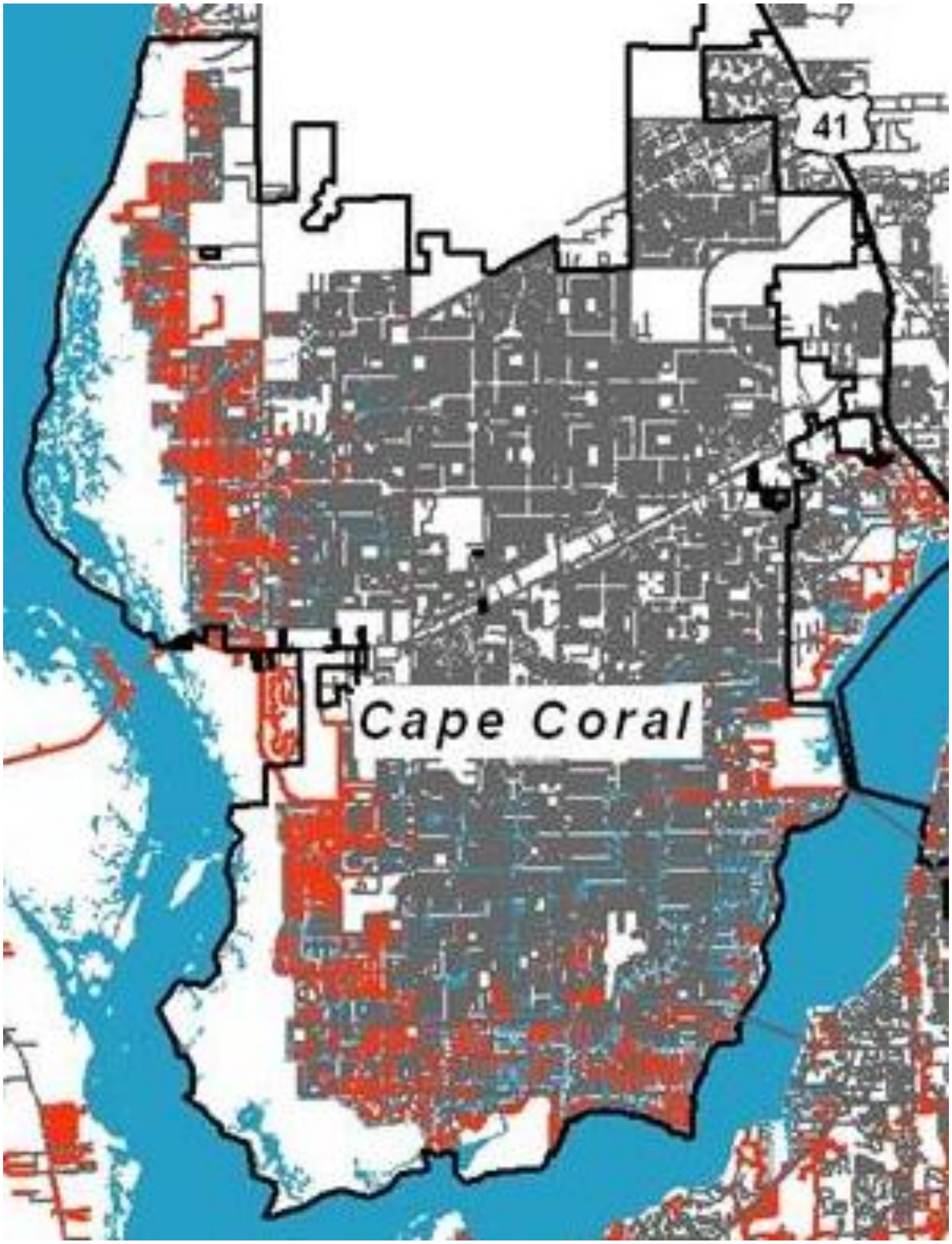


Figure 64: Major roads vulnerable to projected worst case sea level rise year 2100 at 3 feet inundation

By 2200, the worst-case scenario included in this analysis indicates a much greater risk of inundation from sea level rise in Lee County, with the majority of roads in heavily developed southern Cape Coral being affected.

Another finding is the need for additional research, since there are few rigorous quantitative climate change studies of potential transportation impacts, especially focusing on operations and network and performance issues for U.S. locations. Transportation-focused interdisciplinary research can help produce better data and decision tools. (Savonis 2009). Lee County's extensive inventory of transportation assets maintained in Geographic Information Systems (GIS) formats will enable analyses of various scenarios and should contribute to better and easier decision-making by policy-makers. Ensuring that GIS data includes elevation attributes will facilitate development of decision tools related to climate change vulnerabilities.

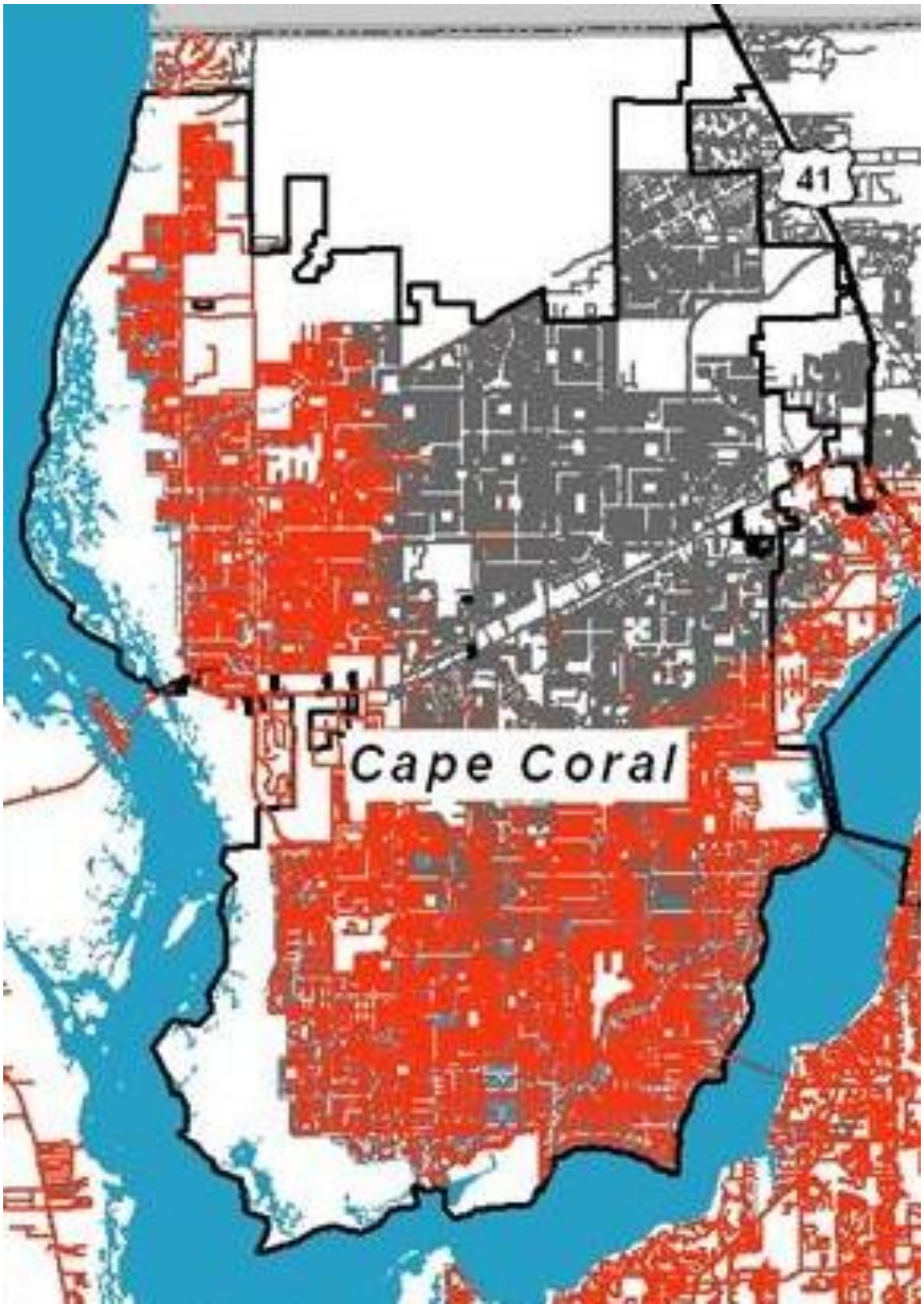


Figure 65: Major roads vulnerable to projected worst case sea level rise year 2200 at 9 feet inundation

Variable Risk and Property Insurance

Known Variable Risk Changes and Events that Have Occurred

Insurance companies are designed to operate assuming *predictable* risks. *Variable* risk is a significant danger to their profitable operation. Insurance companies make their profit based upon their ability to accurately predict the risks associated with the objects or persons they are insuring and by obtaining a fee or premium that is greater than the amount that is expended in claims for damages accrued.

The Florida insurance industry has made mistakes at times by setting premiums too low to cover claims, and at other times charging more than their customers can afford. Under the best case scenarios, hurricane damages will continue to vary widely from year to year, and the industry will need to take a long-term perspective to avoid bouncing between very low and very high rates.

Under the median case scenarios, about the same number of hurricanes will occur but more of them will be Category 4 or 5, and damages will be higher on average and more variable from year to year. Worst case scenarios include more severe storms with a higher frequency of storm events. With greater uncertainty (higher variable risk) the insurance companies will be more likely err in either direction, either under- or over-collecting premiums. It will become harder for homeowners, businesses, and governments to pay the increased average cost of insurance. Greater and greater public subsidies will be required as private insurers raise their rates, or leave the market. Currently, many of the largest national insurance firms in the country have left or are planning to leave the riskiest parts of the Florida market after the strong hurricanes of recent years. Smaller, state-based insurance firms, an increasingly important part of the industry, do not have the resources to provide adequate coverage for hurricane damages on their own. As a result, the state and federal governments have been drawn into subsidizing Florida property insurance. Florida's property insurance industry is second only to California's in value of premiums sold (Florida Office of Insurance Regulation 2006).

In Florida, property insurance is provided by leading private companies such as State Farm and Allstate, as well as smaller companies active only in Florida; by a state-created not-for-profit insurer called Citizens' Property Insurance Corporation; and by the federal government's National Flood Insurance Program (NFIP). Homeowners living on the coast often have one policy from a private insurer covering general threats such as theft or fire, another from Citizens' to cover wind risk from hurricanes, and a third from NFIP for flood damage. There is a $250,000 limit to NFIP, so either additional private coverage is obtained or the property owner suffers exposure to uninsured damages.

Before Hurricane Andrew hit in 1992, many property insurers, eager to increase their market shares, were charging rates that proved too low to pay for the claims filed after the storm. These low rates made high risk areas look misleadingly attractive and affordable, encouraging investment in real estate. As a result of Andrew, Florida insurers faced $15.5 billion in claims, and 12 insurance companies went bankrupt (Florida Office of Insurance Regulation 2006; Scott 2007). Premiums went up an average of 82 percent across the state (Wilson 1997). For the companies that remained in the state's insurance industry, rates increased enough to restore financial health. From 1996 to 2006, the loss ratio for Florida insurers was less than 70 percent of all premiums collected, meaning that insurers paid less than seventy cents in claims out of every dollar of premiums paid by consumers. Florida's loss ratio was only two percentage points higher than the average for all insurers nationwide (Florida Office of Insurance Regulation 2007a; Hundley 2007). Insurance companies were somewhat better prepared for the massive storms of 2004 and 2005. One large Florida-based insurer, Poe Financial Group, was bankrupted, and many other companies dropped their policies in vulnerable parts of Florida to limit their exposure to future storms. Rate increases after these storms roughly doubled the average premium charged across the state, according to a spokesperson for the Florida Office of Insurance Regulation (Kees 2007). These increases brought the loss ratio down to 45 percent in 2006, allowing insurers to rapidly recoup their losses from 2004 and 2005 (Florida Office of Insurance Regulation 2007b). But despite the higher rates, several of the larger insurance companies continued to move out of the Florida market: the two largest insurers, State Farm Group and Allstate Insurance Group, reduced their share of the market from 50.9 percent in 1992 to 29.9 percent in 2005 (Grace and Klein 2006). Although a few large national firms remain in Florida, 12 of the state's top 15 insurers sell only Florida residential property insurance (Florida Office of Insurance Regulation 2006).

The state government plays an active role in Florida's insurance markets, and has expanded its involvement in response to recent hurricane activity. One key role of the state is to regulate insurers' activities to prevent sudden abandonment of policyholders or unfair premium hikes. All rate increases are subject to public hearings and require regulatory approval; companies wishing to cancel policies must provide 90 days' notice and some assurance that their withdrawal is "not hazardous to policyholders or the public" (Florida State Legislature 2006; Kees 2007). Companies have pursued a strategy of dropping the policyholders with the riskiest properties, which allows them to reduce their risk and improve their expected level of profitability without requiring state approval for rate increases (Grace and Klein 2006; Florida Office of Insurance Regulation 2007b). The state has also played an ever-growing role as an insurer of last resort for homeowners who cannot find private insurance. Prior to Hurricane Andrew, the state acted as an insurer of last resort through the Florida Windstorm Underwriting Association (FWUA), but only to a limited set of customers. When thousands of customers were dropped after Andrew, a new insurer of last resort was set up called the Residential Property and Casualty Joint Underwriting Association (JUA), which grew to 936,000 policies by September of 1996, before shrinking again as new private insurers moved into the state (Wilson 1997). The FWUA and JUA merged in 2002 to become Citizens' Property Insurance Corporation, partly in response to private insurers' demands that the government assume some of their wind risk. After the 2004 and 2005 storms, many more customers were dropped by private insurers and picked up by Citizens', raising the number of its policyholders to over 1.3 million. In June 2007, a new bill was passed which froze Citizens' rates until January 1, 2009 and allowed policyholders of private companies to switch to Citizens if their private insurer charged 15 percent more than the state’s rates. With these changes, the number of properties insured by Citizens was projected to reach 2 million by the end of 2007 (Liberto 2007).

The state has also increasingly taken on the role of providing reinsurance for private insurance companies. After the wave of bankruptcies following Hurricane Andrew, the state government set up the Florida Hurricane Catastrophe Fund or CAT Fund for short, to provide a limited level of reinsurance to private insurers, which would cover a portion of their claims in the event of a hurricane. The rates charged were below private market rates for reinsurance, especially after the storms of 2005 nearly doubled private reinsurance rates (Florida Office of Insurance Regulation 2007a). In January 2007, the state injected more money into the CAT fund, expanding it from $16 billion to $28 billion, and required private insurers to purchase more reinsurance through them, and to pass on the savings to customers through lower rates (Florida Office of Insurance Regulation 2007a). The projected savings, however, did not materialize.

One impact of this expanded government role in insurance markets is that the state’s potential liability in the event of a large hurricane has increased. In 2005, the state had to bail out Citizens’, which had a $1.4 billion deficit. This was done through a combination of a charge to all insurance companies, which were passed on to policyholders and a payment from the state budget of $750 million (Kees 2007). With the expansion of Citizens’ and the increase in subsidized reinsurance, the state could be left with an even larger bill in the event of another big storm.

All these changes have increased the amount that the state government effectively subsidizes property insurance rates. Citizens’ rates may not appear artificially low to policyholders, but according to a spokesman for the organization, the rates necessary for the premiums of homeowners in high risk coastal areas to cover their own claims would be entirely prohibitive (Scott 2007). In addition, the federal government provides flood insurance through NFIP that is often pegged at rates too low to break even with claims. The nationwide effects of Hurricane Katrina left NFIP bankrupted 10 times over by the $16 billion it paid in flood claims.

The estimates for sea level rise under the business-as-usual case diverge in scale somewhat from the U.S. Geological Survey (USGS) maps. Geographic Information System (GIS) technology makes it possible to show an approximation of Florida’s coastline at 27 inches of sea level rise, which is projected to be reached by around 2060 in the business-as-usual case. This is equivalent to the 80% probable sea level rise predicted in the IPCC’s Fourth Assessment Report (2007). For simplicity, Stanton and Ackerman (2007) refer to the land area that would be inundated in Florida with 27 inches of sea level rise as the year 2060 “vulnerable zone.” The 2060 vulnerable zone includes nine percent of Florida’s current land area, or some 4,700 square miles. Absent successful steps to build up or otherwise protect them, which will be expensive and in some areas is likely impossible, these lands will be submerged at normal high tide. Almost one tenth of Florida’s current population, or 1.5 million people, already live in this vulnerable zone.

Statewide, the vulnerable zone also includes residential real estate now valued at over $130 billion, half of Florida's existing beaches, and 99 percent of its mangroves, as well as the following significant structures statewide (among many others):

Statewide Critical Facilities Vulnerable to a 27-inch Sea Level Rise
2 nuclear reactors
3 prisons
37 nursing homes
68 hospitals
74 airports
82 low-income housing complexes
115 solid waste disposal sites
140 water treatment facilities
171 assisted livings facilities
247 gas stations
277 shopping centers
334 public schools
341 hazardous-material cleanup sites, including 5 Superfund sites
1,025 churches, synagogues, and mosques
1,362 hotels, motels, and inns
19,684 historic structures

Table 24: List of Statewide Critical Facilities Vulnerable to a 27-inch Sea Level Rise

Potential Future Climate Changes

Changing climate conditions and trends from increased atmospheric and aquatic temperatures together with sea level rise will cause current risk models to become obsolete. It is not possible to develop forecasting for an uncertain climate-changed future from an actuarial table based upon prior performance under a more stable climate with less severe storms and less harsh climatic conditions. Changes in risk modeling may not keep up with changes in climate with financial ramifications to the insurance industry and the consumer (USEPA CRE 2008).

In Florida's insurance industry, an already bad situation will be made much worse if climate impacts intensify. Under the rapid stabilization scenario, continuing the current frequency and intensity of storms, the industry might be able to muddle along with the current arrangements, premiums, and state and federal subsidies. Under the worst case scenario, with more intense storms as well as higher sea levels that will increase the height of storm surges, the insurance crisis will become more severe. Either premiums or subsidies, or likely both, will have to increase to cover the rising average costs of storm damages. As storms intensify, private firms are likely to continue withdrawing from the market for Florida property insurance, leaving the government, and the taxpayers, with an increasingly expensive drain on public resources. The cost of hurricane damages will be borne by property owners through increased premiums and/or reduced coverage and by state and federal governments through subsidies to insurance companies. Increased insurance costs and increased storm damages will contribute to a decline in property values, worsening climate damages to the real estate industry. (Stanton and Ackerman 2007)

Despite a growing awareness of the threats posed by climate change, there are relatively few organizations already preparing to adapt to these changes. For example, many states acknowledge sea level rise as a concern in their coastal zone management assessments, but have not yet developed a comprehensive strategy to deal with it. Part of this failure to act can be traced to institutional barriers to changes in management and individuals' behavior (Martinich 2008). Some of the primary institutional barriers to adaptation in estuarine systems include policy biases and decision paralysis due to uncertainty.

Established policies often favor one type of response over another, causing institutional biases. Policies at the federal level tend to favor shore protection over retreat in developed areas, and retreat over shore protection in undeveloped areas. Hard structures tend to be favored over living shorelines in some longstanding federal policies, but more recent state policies (e.g., Maryland) favor living shorelines that rely on less-constructed solutions such as rebuilding an eroded marsh or bay beach (Martinich 2008). Uncertainty surrounding impacts, the relative benefits of different adaptation options, and how others respond to climate change stressors all may lead to failure to decide whether and how to protect or abandon resources that cannot be saved. The specific effects of climate change stressors on specific systems are still highly uncertain, as are the expected responses that will result from implementing adaptation strategies. Decision makers are hesitant to act in the face of an uncertain future. Furthermore, interdependent agencies manage various estuarine systems; not knowing how other decision makers will respond to stressors makes it difficult to decide what actions to take (Martinich 2008).

Prioritizing Climate Change Effects

This report assesses significant potential climate changes in air and water and the effects of those changes on climate stability, sea level, hydrology, geomorphology, natural habitats and species, land use changes, economy, human health, human infrastructure, and variable risk projects, in southwest Florida.

Depending upon the method of prioritization utilized, some climate change effects will be experienced more proximally in time and location; others with longer time lines will be more costly in terms of total cumulative habitat impact or in human economic terms. There are a number of planning actions that, if undertaken now, could significantly reduce negative climate change effects and their costs in the future while providing positive environmental and financial benefits in the near term.

Many of the anticipated consequences of climate change occur via mechanisms involving interactions among the stressors and variables, and therefore may not be widely appreciated by policy makers, managers, stakeholders, and the public. 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.

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, inter-tidal littoral, and wetland habitats if continued as climate changes and sea level rises.

There are crucial areas where adaptation planning and implementation will be needed to avoid, minimize, mitigate, and adapt to the anticipated effects to the natural and man-altered areas of southwest Florida. Some effect such as air temperature and water temperate will be experienced throughout the region. Others such as sea level rise and habitat shifts will occur in specific geographic and clinal locations. In the course of this project, we identified 246 climate change management adaptations (Beever et al. 2009) that could be utilized to address the various vulnerabilities identified for the region. Future adaptation plans will identify the management measures best suited for each geographic location.

When examined in consideration of what climate change effects would *most imperil the implementation of the goals of the City of Cape Coral Comprehensive Plan*, the following prioritization is derived (where 1 is top priority and others follow in order):

1) Storm Severity/Climate Instability
2) Altered Hydrology
3) Sea Level Rise
4) Human Economy
5) Infrastructure Impacts
6) Habitat and Species Change
7) Water Temperature and Chemistry Changes
8) Human Health
9) Air Temperature and Chemistry Changes
10) Geomorphic (Landform) Changes

11) Land Use Changes

12) Variable Risk

When examined in terms of the climate change *effects currently experienced in the City of Cape Coral* (i.e. what effects with perceived negative effects are occurring now and in the nearer future vs. what changes will occur later), the prioritization of effects is (where 1 is top priority and other follow in order):

1) Altered Hydrology

2) Storm Severity/Climate Instability

3) Variable Risk

4) Habitat and Species Changes

5) Geomorphic (Landform) Changes

6) Human Health

7) Air Temperature and Chemistry Changes

8) Infrastructure Impacts

9) Human Economy

10) Land Use Changes

11) Sea Level Rise

12) Water Temperature and Chemistry Changes

When examined in terms of what climate change effects will have the most severe impacts on the coastal portion of Cape Coral in terms of *habitat loss in the estuary, on barrier islands and nearshore mainland*, the prioritization of effects is (where 1 is top priority and other follow in order):

1) Altered Hydrology

2) Sea Level Rise

3) Storm Severity/Climate Instability

4) Land Use Changes

5) Habitat and Species Changes

6) Water Temperature and Chemistry Changes

7) Geomorphic (Landform) Changes

8) Air Temperature and Chemistry Changes

9) Infrastructure Impacts

10) Human Economy

11) Human Health

12) Variable Risk

When examined in terms of what climate change effects will have the most severe impacts on the interior portion of City of Cape Coral in terms of *habitat loss in the watersheds*, the prioritization of effects is (where 1 is top priority and other follow in order):

1) Altered Hydrology

2) Storm Severity/Climate Instability

3) Water Temperature and Chemistry Changes

4) Habitat and Species Changes

5) Geomorphic (Landform) Changes

6) Land Use Changes

7) Human Health

8) Air Temperature and Chemistry Changes

9) Infrastructure Impacts

10) Human Economy

11) Variable Risk

12) Sea Level Rise Sea Level Rise

Combining the rankings provides the following priority matrix for climate change vulnerabilities:

Prioritization	Cape Coral Comprehensive Plan Goal Implementation	Proximity in Time	Habitat Loss in the Estuary	Habitat Loss in the Watersheds	Sum of Scores	Average Rank
Air Temperature and Chemistry	9	7	8	8	32	8.0
Altered Hydrology	2	1	1	1	5	1.3
Climate Instability	1	2	3	2	8	2.0
Geomorphic Changes	10	5	7	5	27	6.8
Habitat and Species Changes	6	4	5	4	19	4.8
Sea Level Rise	3	11	2	12	28	7.0
Water Temperature and Chemistry	7	12	6	3	28	7.0
Human Economy	4	9	10	10	33	8.3
Human Health	8	6	11	7	32	8.0
Infrastructure	5	8	9	9	31	7.8
Land Use Changes	11	10	4	6	31	7.8
Variable Risk	12	3	12	11	38	9.5

Table 25: Prioritization of climate change effects in southwest Florida

The resultant prioritization ranking is:

1) Altered Hydrology
2) Climate Instability/ Storm Severity
3) Habitat and Species Changes
4) Geomorphic (Landform) Changes
5) Sea Level Rise and Water Temperature and Chemistry Changes

6) Infrastructure Impacts and Land Use Changes

7) Air Temperature and Chemistry Changes and Human Health

8) Human Economy

9) Variable Risk

Conclusions

The primary focus of this project is the vulnerability of the City of Cape Coral to climate change. This project includes an assessment of significant potential effects of climate change on the human and native ecosystems of the City of Cape Coral, 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 in Cape Coral.

This project lays the groundwork for the development of a resiliency plan for the local government, local government guidance resolutions, and comprehensive planning.

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".

In the absence of effective avoidance, mitigation, minimization and adaptation, climate-related failures will appear in all of the important management goals identified by the City of Cape Coral in its comprehensive plan.

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 (Speybroeck, et al. 2006).

Many of the anticipated consequences of climate change occur via mechanisms involving interactions among the stressors and variables, and therefore may not be widely appreciated by policy makers, managers, stakeholders, and the public. 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.

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.

Salt marsh and mangrove ecosystems of Cape Coral are particularly threatened by climate change. Based on available evidence, of all the climate change outcomes, relative sea level rise may be the greatest threat to mangroves (Gilman et al.2008). 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 and where there is limited area for landward migration. There is less certainty over other climate change outcomes and mangrove responses. More research is needed on assessment methods and standard indicators of change in response to effects from climate change, while regional monitoring networks are needed to observe these responses to enable educated adaptation. Proper adaptation measures can offset anticipated mangrove losses and improve resistance and resilience to climate change. Appropriate coastal planning can facilitate mangrove migration with sea level rise (Doyle et. al. 2003). Management of activities within the catchment that affect long-term trends in the mangrove sediment elevation, better management of other stressors on mangroves, rehabilitation of degraded mangrove areas, and increases in systems of strategically designed protected area networks that include mangroves and functionally linked ecosystems through representation, replication and refugia, are additional adaptation options.

Many management adaptations to climate change to preserve estuarine services can be achieved at all levels of government at a known, measured expense. One major form of adaptation involves recognizing the projected consequences of sea level rise and then applying policies that create buffers to anticipate associated consequences. An important example would be redefining riverine flood hazard zones to match the future projected expansion of flooding frequency and extent. Other management adaptations can be designed to build resilience of ecological and social systems. These adaptations include choosing only those sites for habitat restoration that allows natural recession landward, providing resilience to sea level rise. Hardening of infrastructure will address both the consequences of climate variability while improving degraded infrastructure with more long-lasting durable structures.

Management adaptations to climate change can occur on three different time scales:

a. reactive measures taken in response to observed or encountered negative impacts;

b. immediate development of plans for adaptive management to be implemented later, either when an indicator signals that delay can occur no longer, or in the wake of a disastrous consequences that provides a window of financially and socially feasible opportunities; or

c. immediate implementation of proactive mitigations, minimizations and adaptations.

The factors determining which of these time frames is appropriate for any given management adaptation include balancing costs of implementation with the magnitude of risks of injurious consequences under the status quo of management; the degree of reversibility of negative consequences of climate change; recognition and understanding of the problem by managers and the public; the uncertainty associated with the projected consequences of climate change; the timetable on which change is anticipated; and the extent of political, institutional, physical and financial impediments.

Monitoring of the effects and results of climate changes will be necessary to assess when and where adaptive management needs to be and should be applied. A critical goal of this monitoring is to establish and follow indicators that signal approach toward an ecosystem threshold that, once passed, puts the system into an alternative state from which conversion back is difficult to impossible. Avoiding conversion into such less-desired alternative states is one major motivation for implementing proactive management adaptation. This is especially critical if the transition is irreversible or very difficult and costly to reverse, and if the altered state delivers dramatically fewer valued ecosystem services. Work to establish environmental indicators are already being done by the Charlotte Harbor National Estuary Program (CHNEP) and will be used to monitor climate change impacts.

One critically important management challenge for southwest Florida is to implement actions to achieve an orderly relocation of human infrastructure and development from shorelines that are at high risk of erosion and flooding, or to preclude development of undeveloped shorelines at high-risk from sea level rise and climate variability effects. Such proactive management actions have been inhibited in the past by:

a. uncertainty over or denial of climate change and its implications;

b. failures to include the true economic, social, and environmental costs of present policies that encourage, allow and subsidize such risky development; and

c. legal tenets of private property rights.

One possible proactive management option would be to establish and enforce “rolling easements” along estuarine shorelines as sea level continues to rise, thereby sustaining the current public ownership of tidal lands. Management adaptations may include ending public subsidies that now encourage and support risky development on coastal barrier and estuarine shores at high risk of flooding and storm damage as sea level rises further and intense storms become more common. Although the flood insurance system as a whole may be actuarially sound, current statutes provide people along the water’s edge in eroding areas of highest risk with artificially low rates, subsidized by the flood insurance policies of people in relatively safe areas. Ending such subsidization of high-risk developments would represent a market-based, free enterprise form of management adaptation to sea level rise. The federal Coastal Barriers Resources Act provides some guidance for eliminating such subsidies for public infrastructure and private development, although this act currently applies only to a specific list of undeveloped coastal barriers and would require extension to all barrier islands and to estuarine mainland shorelines to enhance its effectiveness to protect human and natural resources.

It will be important to include climate change sensitivity, resilience, and adaptation responses as priorities on all relevant government funding programs at local, state and federal levels. In the absence of such actions, for example, climate impacts on estuarine wetlands will likely violate the national "no-net-loss of wetlands" policy (which stems from the current application of the Clean Water Act) in two ways: (a) wetland loss due to climate change will increasingly compound the continuing loss of wetlands due to development and inadequate mitigation; and (b) structural measures used to protect coastal human infrastructure from climate impacts will prevent wetland adaptation to climate change as ecotones are compressed to non-existence.

All federal, state, and local programs need to be reviewed to assess whether projected consequences of climate change have been considered adequately, and whether adaptive management needs to be applied to achieve programmatic goals. For example, Jimerfield et al. (2007) conclude that "There clearly needs to be [a] comprehensive approach by federal agencies and cooperating scientists to address climate change in the endangered species recovery context. The current weak and piece-meal approach will waste precious resources and not solve the problem we are facing."

Cape Coral/ Fort Myers urbanized area's growing population and development are replacing natural habitat. Without the proper habitat, plant communities and wildlife disappear. Florida is one of North America's most important reserves of biological diversity. Occupying an important transitional zone between tropical and temperate climates, more than 1,300 fish and wildlife species and about 3,500 plant species can be found in Florida. Preserving this biodiversity requires protection and restoration of regional fish and wildlife habitat. High rates of land conversion and habitat modification create a critical need for regional wildlife habitat planning in Cape Coral/ Fort Myers urbanized area (CHNEP CCMP 2008).

A diversity of restored habitats will be needed to restore and maintain listed-species biodiversity in the face of the identified anticipated climate changes. Concentration on protecting coastal wetlands alone will not serve upland species, upland-dependent wetland species, marine species, or indeed, the coastal species as ecotones and habitats shift up-gradient. It will be vital to protect refugia, latitudinal and elevational gradients, habitat heterogeneity, and gene flow/population connectivity. Species will benefit from reducing other non-climate stresses (e.g. invasive species, pollution, etc), protection of freshwater surface sources, and hydrologic restoration, with riverine and landscape scale migratory corridors, such as the one that is being established from Charlotte Harbor across north Lee County through four landscape scale acquisitions, including the Yucca

Pen Creek, Yucca Pens Unit of the Charlotte Harbor Flatwoods, Pinelands Preserve, and Babcock Ranch.

The likely effects of climate change and particularly sea level rise on the City of Cape Coral and southwest Florida ecosystems and infrastructure development are too great for policymakers, property owners, and the public-at-large to stand by and wait for greater evidence before considering strategies for adaptation. It is essential to plan and act now to avoid, mitigate, minimize, and adapt (AMMA) to the negative effects of climate change, and to examine the possibilities of providing benefits to human and natural systems by adapting to the changing climate.

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Appendix 1: City of Cape Coral Critical Facilities Subject To Sea Level Rise

FACILITY TYPE	FACILITY	CITY	ELEVATION/PROTECTION
CHURCH	SAINT ANDREW CATHOLIC CHURCH IN CAPE CORAL	CAPE CORAL	5'-10' Protection Definite
CHURCH	METHODIST UNITED CH CAPE CORAL	CAPE CORAL	5'-10' Protection Definite
CHURCH	LUTHERAN CHRIST CHURCH	CAPE CORAL	5'-10' Protection Definite
CHURCH	BAPTIST CHURCH FIRST	CAPE CORAL	5'-10' Protection Definite
CHURCH	CHRISTIAN FIRST CHURCH OF	CAPE CORAL	5'-10' Protection Definite
CHURCH	CHURCH ON THE ROCK	CAPE CORAL	5'-10' Protection Definite
CHURCH	EPIPHANY EPISCOPAL CHURCH	CAPE CORAL	5'-10' Protection Definite
CHURCH	MESSIAH LUTHERAN CHURCH	CAPE CORAL	5'-10' Protection Definite
CHURCH	TEMPLE BETH SHALOM	CAPE CORAL	5'-10' Protection Definite
CHURCH	ABIDING LOVE LUTHERAN CHURCH	CAPE CORAL	5'-10' Protection Definite
CHURCH	CAPE CORAL CHURCH OF CHRIST	CAPE CORAL	5'-10' Protection Definite
CHURCH	HOPE PARSONAGE	CAPE CORAL	5'-10' Protection Definite
CLINIC	CAPE CORAL SURGERY CENTER	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	CAPE CORAL POLICE DEPARTMENT TOWER	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	FT MYERS BROADCASTING CO	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	G T E MOBELNET OF TAMPA INC	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	G T E MOBILNET OF TAMPA INC	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	SPRINT-FLORIDA INC	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	UNITED TELEPHONE CO OF FL	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	VANDERLINDEN DIRK TR	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	UNITED STATES POSTAL SERVICE	CAPE CORAL	5'-10' Protection Definite
COMMUNICATION	TOWER CITY POLICE	CAPE CORAL	5'-10' Protection Definite
ELECTRICAL	LEE CO ELECTRIC COOP EL DORADO BL SUBSTATION	CAPE CORAL	5'-10' Protection Definite
ELECTRICAL	LEE CO ELECTRIC COOP DEL PRADO	CAPE CORAL	5'-10' Protection Definite

	SUBSTATION		
ELECTRICAL	LEE CO ELECTRIC COOP BURNT STORE SUBSTATION	CAPE CORAL	5'-10' Protection Definite
ELECTRICAL	LEE CO ELECTRIC COOP INDUSTRIAL SUBSTATION	CAPE CORAL	5'-10' Protection Definite
ELECTRICAL	LEE CO ELECTRIC COOP CC SUBSTATION	CAPE CORAL	5'-10' Protection Definite
ELECTRICAL	LEE CO ELECTRIC COOP WEST CC SUBSTATION	CAPE CORAL	5'-10' Protection Definite
ELECTRICAL	LEE CO ELECTRIC COOP SOUTH CAPE SUBSTATION	CAPE CORAL	5'-10' Protection Definite
EMERGENCY MEDICAL SERVICES	EMERGENCY MEDICAL SERVICE-AMBULANCE MEDIC 4	CAPE CORAL	5'-10' Protection Definite
EMERGENCY MEDICAL SERVICES	EMERGENCY MEDICAL SERVICE-AMBULANCE MEDIC 12	CAPE CORAL	5'-10' Protection Definite
EMERGENCY MEDICAL SERVICES	EMERGENCY MEDICAL SERVICE-AMBULANCE MEDIC 14	CAPE CORAL	5'-10' Protection Definite
FIRE STATION	CAPE CORAL FIRE STATION #1	CAPE CORAL	5'-10' Protection Definite
FIRE STATION	CAPE CORAL FIRE STATION #3	CAPE CORAL	5'-10' Protection Definite
FIRE STATION	CAPE CORAL FIRE STATION #4	CAPE CORAL	5'-10' Protection Definite
FIRE STATION	CAPE CORAL FIRE STATION #6	CAPE CORAL	5'-10' Protection Definite
FIRE STATION	CAPE CORAL FIRE STATION #7	CAPE CORAL	5'-10' Protection Definite
GOVERNMENT BUILDING	Lee County ANNEX, CAPE CORAL	CAPE CORAL	5'-10' Protection Definite
GOVERNMENT BUILDING	CAPE CORAL POST OFFICE	CAPE CORAL	5'-10' Protection Definite
GOVERNMENT BUILDING	CAPE CORAL PUBLIC LIBRARY	CAPE CORAL	5'-10' Protection Definite
GOVERNMENT BUILDING	CAPE CORAL POST OFFICE	CAPE CORAL	5'-10' Protection Definite
GOVERNMENT OFFICES	CAPE CORAL CITY HALL	CAPE CORAL	5'-10' Protection Definite
HAZARDOUS MATERIAL SITE	CITY OF CAPE CORAL-UTILITIES COLLECTIONS DIST.	CAPE CORAL	5'-10' Protection Definite
HAZARDOUS MATERIAL SITE	CITY OF CAPE CORAL YACHT CLUB COMPLEX	CAPE CORAL	5'-10' Protection Definite
HAZARDOUS MATERIAL SITE	K MART STORE 7277	CAPE CORAL	5'-10' Protection Definite
HAZARDOUS MATERIAL SITE	SPRINT CAPE CORAL CENTRAL OFFICE	CAPE CORAL	5'-10' Protection Definite
HAZARDOUS MATERIAL SITE	CAPE CORAL GOLF AND TENNIS RESORT LIME PLANT	CAPE CORAL	5'-10' Protection Definite
HAZARDOUS MATERIAL SITE	EVEREST WASTEWATER RECLAMATION FACILITY	CAPE CORAL	5'-10' Protection Definite

HAZARDOUS MATERIAL SITE	SW WASTEWATER TREATMENT FACILITY	CAPE CORAL	5'-10' Protection Definite
HOSPITALS	CAPE CORAL HOSPITAL	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	CAPE CORAL HOSPITAL HELISTOP	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	STORM FOOTBALL COMPLEX	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	MULTI SPORTS COMPLEX	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	CAMELOT	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	NORTHWEST SOFTBALL	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	CITY HALL	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	JASON VERDOW MEMORIAL	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	PELICAN FIELDS	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	PELICAN SOCCER	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	VETERANS PARK	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	FOUR FREEDOMS	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	JAYCEE	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	CAPE CORAL YACHT CLUB & ROTINO SENIOR CENTER	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	ECOLOGY PARK	CAPE CORAL	0' to 5' Protection Not Recommended
LANDING ZONE	HORTON	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	KOZA/SALADINO	CAPE CORAL	5'-10' Protection Definite
LANDING ZONE	ADMIN. & ART STUDIO	CAPE CORAL	5'-10' Protection Definite
MISCELLANEOUS	CAPE CORAL GOLF & TENNIS	CAPE CORAL	5'-10' Protection Definite
MISCELLANEOUS	CASA LOMA MOTEL	CAPE CORAL	5'-10' Protection Definite
MISCELLANEOUS	EVANGELICAL PRESBYTERIAN CHURCH	CAPE CORAL	5'-10' Protection Definite
MISCELLANEOUS	QUALITY INN	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	CAPE CHATEAU	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	COURTYARD VILLAS	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	THE MILLER HOME	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	MILLIE'S CONVALESCENT CARE	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	OUR HOUSE ALF	CAPE CORAL	5'-10' Protection Definite

NURSING/CONVALESCENT CENTERS	PERIDOT PLACE OF CAPE CORAL	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	PERIDOT PLACE OF CAPE CORAL	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	WESTBAY ASSISTED LIVING	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	SUNRISE #12	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	SUNRISE CAPE CORAL CLUSTER	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	REHABILITATION AND HEALTHCARE CENTER OF CAPE CORAL	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	STERLING HOUSE	CAPE CORAL	5'-10' Protection Definite
NURSING/CONVALESCENT CENTERS	HEARTLAND HEALTH CARE	CAPE CORAL	5'-10' Protection Definite
POLICE DEPARTMENT	CAPE CORAL POLICE DEPARTMENT	CAPE CORAL	5'-10' Protection Definite
POLICE DEPARTMENT	CAPE CORAL POLICE DEPARTMENT SOUTH SUB.	CAPE CORAL	5'-10' Protection Definite
SCHOOL	CAPE ELEMENTARY	CAPE CORAL	5'-10' Protection Definite
SCHOOL	GULF ELEMENTARY	CAPE CORAL	5'-10' Protection Definite
SCHOOL	PELICAN ELEMENTARY	CAPE CORAL	5'-10' Protection Definite
SCHOOL	GULF MIDDLE SCHOOL	CAPE CORAL	5'-10' Protection Definite
SCHOOL	TRAFALGAR MIDDLE SCHOOL	CAPE CORAL	5'-10' Protection Definite
SCHOOL	CAPE CORAL HIGH SCHOOL	CAPE CORAL	5'-10' Protection Definite
SCHOOL	CAPE CORAL	CAPE CORAL	5'-10' Protection Definite
SEWAGE TREATEMENT FACILITY	EVEREST RECLAMATION FACILITY METER #153472	CAPE CORAL	5'-10' Protection Definite
SEWAGE TREATEMENT FACILITY	SOUTHWEST WATER RECLAMATION FACILITY P MCC-1 BUILDING	CAPE CORAL	5'-10' Protection Definite
SEWAGE TREATEMENT FACILITY	SOUTHWEST WATER RECLAMATION FACILITY P MCC-2 BUILDING	CAPE CORAL	5'-10' Protection Definite
SEWAGE TREATEMENT FACILITY	SOUTHWEST WATER RECLAMATION FACILITY P BIO-SOLIDS BUILDING	CAPE CORAL	5'-10' Protection Definite
SEWAGE TREATEMENT FACILITY	SOUTHWEST WATER RECLAMATION FACILITY P MAINTENANCE BUILDING	CAPE CORAL	5'-10' Protection Definite
SEWAGE TREATEMENT FACILITY	TWISTY TREET	CAPE CORAL	5'-10' Protection Definite
SEWAGE TREATEMENT FACILITY	CAPE CORAL WATER RECLAMATION	CAPE CORAL	5'-10' Protection Definite
SHELTERS	ABIDING LOVE LUTHERAN CHURCH	CAPE CORAL	5'-10' Protection Definite

SHELTERS	CAPE CORAL FIRST UNITED METHODIST CHURCH	CAPE CORAL	5'-10' Protection Definite
WATER TREATEMENT FACILITY	SW R/O PLANT	CAPE CORAL	5'-10' Protection Definite
WATER TREATEMENT FACILITY	LIME PLANT STORAGE AND REPUMP STATION	CAPE CORAL	5'-10' Protection Definite
WATER TREATEMENT FACILITY	REVERSE OSMOSIS WATER TREATMENT FACILITY METER #150940	CAPE CORAL	5'-10' Protection Definite
WATER TREATEMENT FACILITY	GREATER PINE ISLAND WATER	CAPE CORAL	5'-10' Protection Definite