The Charlotte Harbor National Estuary Program (CHNEP) is a partnership of citizens, scientists, elected officials, resource managers and commercial and recreational resource users who are working to improve the water quality and ecological integrity of the CHNEP study area. A cooperative decision-making process is used within the program to address diverse resource management concerns in the 4,700-square-mile CHNEP study area.

February 19, 2010
# Charlotte Harbor National Estuary Program

**March 2008**

## Policy Committee

<table>
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<tr>
<th>CITIES</th>
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Table of Contents

Contents
About this Report iv
Executive Summary v
Climate Change Context 1
Climate Change Overview
   Climate Change Drivers 3
   Climate Change Stressors 5
   Three Climate Change Scenarios 8
Climate Change Impacts
   Critical Facilities 16
   Economic Activities 22
   Cultural Resources 28
   Human Health 29
   Water Resources 33
   Coastal Resources 36
   Wildlife and Ecosystems 39
Conclusions
   Summary of Significant Vulnerabilities 44
   Challenges and Opportunities 46
   Our Further Efforts 46
Cited References 47
Abbreviations 55
Appendix 1: Grouped Vulnerabilities 56
Appendix 2: SLAMM Predictions of Habitat Fates 58

List of Figures
   Figure 1: Sea Level Changes during Cenozoic Era 1
   Figure 2: Florida Shelf Sea Level Changes 1
   Figure 3: Atlantic Sea Surface Temperatures 2
   Figure 4: Key West Tide Gauge Records 2
   Figure 5: Historic Calendar of Hurricanes 2
   Figure 6: Greenhouse Effect 3
   Figure 7: Climate Change Drivers and Stressors 4
   Figure 8: Hurricanes within 50 miles of Fort Myers 5
   Figure 9: Intense Wildfires can burn Wetlands 6
   Figure 10: A new inlet (Charley Pass) 7
   Figure 11: Sea Level Rates (6000 years) 8
   Figure 12: Global Sea Level Rise 1860-2009 8
   Figure 13: Charlotte Harbor Regional Temperatures 9
   Figure 14: Fort Myers Average Temperature 11
   Figure 15: Arcadia Average Temperature 11
   Figure 16: Days per Year with over 90o -Southeast 12
   Figure 17: Days per year over 90o (1901-2008) 12
   Figure 18: Average Water Acidity 12
   Figure 19: Annual Rainfall (1901-2008) 13
   Figure 20: Rainfall Delivered June thru September 13
   Figure 21: Tide Gauge Trends 14
   Figure 22: Systems Impacted by Climate Summary 16
   Figure 23: Charlotte Regional Medical Center 18
   Figure 24: Debris in Mangroves 18
   Figure 25: Shell Creek Reservoir 19
   Figure 26: Widening I-75 over the Peace River 20
   Figure 27: Citrus Grove with road and drainage 24
   Figure 28: Cypress Logging at Babcock Ranch 24
   Figure 29: Red Drift Algae on Sanibel 25
   Figure 30: Mangroves Damaged by H. Charley 26
   Figure 31: Lake Hancock Lake Level and MFLs 34
   Figure 32: Comparison of Flows to Estero Bay 35
   Figure 33: Flooding in Punta Gorda 37
   Figure 34: Habitat Migration Conceptual Diagram 40
   Figure 35: SLAMM Prediction Maps 41
   Figure 36: SLAMM Prediction Charts 41
   Figure 37: Dry Bed in the Upper Peace River 44
   Figure 38: Restored Salt Marsh at Island Park 45

List of Maps
   Map 1: CHNEP and SWFRPC Jurisdictions vi
   Map 2: Projected 2100 Sea Level Rise 15
   Map 3: Emergency Facilities and Communications 17
   Map 4: Water Supply and Wastewater Treatment 19
   Map 5: Transportation Facilities 20
   Map 6: Electrical Generation Facilities 21
   Map 7: Agriculture and Forestry 23
   Map 8: Mining 27
   Map 9: Historic Structures and Lighthouses 28
   Map 10: Critical and Non-critical Beach Erosion 36
   Map 11: Flood Zones 37
   Map 12: Storm Surge 38
   Map 13: Seagrass Migration 42

List of Tables
   Table 1: Climate Change Scenarios 10
   Table 2: Economic Activities 22
   Table 3: Tropical Disease Occurrence 30
   Table 4: Storm Surge Elevations 38
In 2008, the Charlotte Harbor National Estuary Program (CHNEP) updated its Comprehensive Conservation and Management Plan (CCMP). The last new priority action added to the draft plan was under the Priority Problem “Stewardship Gaps” or “SG”. The new priority action is:

SG-Q: Build capacity for communities and their local leadership to mitigate and adapt to the effects of climate change through joint efforts.

Subsequent to the addition of the draft priority action, the Environmental Protection Agency, Region 4 representing the southeastern United States, offered funding assistance to accomplish the first step of implementing the strategies of CHNEP’s new action, a vulnerability assessment.

CHNEP’s host agency, the Southwest Florida Regional Planning Council (SWFRPC), has a two decade history of preparing planning tools to improve the region’s resiliency to severe storms. Its storm surge map, critical facilities assessments and hurricane evacuation scenarios have improved infrastructure investments, land use decisions, and land conservation choices providing for increased severe storm resiliency. In 2000, SWFRPC partnered with EPA to assess sea level rise associated with climate change, building on its history of planning for climate.

Based on this history and its relationship to the CHNEP, the EPA Region 4 directed its funding assistance to SWFRPC in order to review the literature and regional data and to develop a comprehensive assessment of climate change vulnerabilities in southwest Florida.

This report crystallizes the southwest Florida climate change vulnerability. This assessment has the added benefit of helping to implement CCMP priority action:

SG-K: Present scientific information in a form readily understood by the majority of people.

The CHNEP has a rich history of communicating technical scientific products for the general public. The quarterly newsletter Harbor Happenings and the website www.chnep.org are the major vehicles for communicating to the public. Documents such as the CCMP and this report provide CHNEP opportunities to present significant and extensive information, with bright compelling graphics that attract people to pick up and peruse.

**Relationship of the Assessment to other Projects**

Following the EPA Region 4 award to prepare the climate change vulnerability assessment, EPA named CHNEP as one of six “Climate Ready Estuary” (CRE) pilot projects. The pilot for CHNEP was to develop an adaptation plan for a small city in its study area. The SWFRPC vulnerability assessment has provided a foundation for this work. Moreover, this foundation has provided a base for:

- City of Punta Gorda Climate Change Adaptation Plan developed through the first round of EPA Climate Ready Estuaries (CRE) pilot projects;
- EPA Region 4 Wetland Program Development Grant Salt Marsh Vulnerability Assessment and Adaptation;
- Lee County Climate Change Vulnerability Report and Climate Change Resiliency Plan; and
- A second round of EPA CRE assistance to develop CHNEP environmental indicators for climate change and model ordinances.
The Charlotte Harbor Region is located within southwest Florida. The region is currently experiencing climate change. The natural setting of southwest Florida coupled with extensive development 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 effects of a changing climate.

Even in the 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 of infrastructure; and
- Increased uncertainty regarding risk.

Maintaining the status quo in the management of estuarine ecosystems 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 Charlotte Harbor National Estuary Program (CHNEP) Comprehensive Conservation and Management Plan (CCMP): hydrologic alteration, water quality degradation, fish and wildlife habitat loss, and stewardship gaps.

This assessment examines the past and current climate in the Charlotte Harbor Region along with three future scenarios of climate change to the year 2200. These scenarios include:

1) **Lower**: a condition that involves a future in which significant mitigative actions are undertaken to reduce the human influence on climate change,

2) **Intermediate**: a scenario which falls within various forecasts, and

3) **Upper**: a future in which few actions are taken to address climate change and the most recent projections of more significant impacts are used, including those related to glacial ice melting.

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 projections, in the Charlotte Harbor Region.

The most significant vulnerabilities facing the Charlotte Harbor region are changes related to drought, flood, hurricane severity, land area, habitats, biological cycles, and uncertainty in environmental models.

The sectors that are most vulnerable to the effects of climate change include interests that are in competition for water (public water supply, agriculture, mining, flood control and the environment), beaches and associated tourism that can be impacted by the geomorphic changes brought by sea-level rise and other climate change effects, low-lying facilities that are subject to sea-level rise (such as lighthouses, US17 and medical facilities in Punta Gorda, 14 wastewater treatment facilities and 17 public water supply facilities), public health (especially in the relatively high elderly population), seagrass extent, freshwater wetland extent, extent of native uplands and biological cycles of native species.
The Charlotte Harbor National Estuary Program (CHNEP) and the Southwest Florida Regional Planning Council (SWFRPC) do not share the same jurisdictions. CHNEP is watershed delineated and includes part or all of Polk, Manatee, Hardee, DeSoto, Sarasota, Charlotte and Lee Counties. This document focuses on the CHNEP study area as shown inside the bold black lines.

Map 1: CHNEP and SWFRPC Jurisdictions

The Charlotte Harbor National Estuary Program (CHNEP) and the Southwest Florida Regional Planning Council (SWFRPC) do not share the same jurisdictions. CHNEP is watershed delineated and includes part or all of Polk, Manatee, Hardee, DeSoto, Sarasota, Charlotte and Lee Counties. This document focuses on the CHNEP study area as shown inside the bold black lines.
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. Global temperatures have risen and fallen and changed air chemistry, hydrology, geomorphology, habitats, plant and animal species, sea level, and water temperature and chemistry. With the advent of human civilization, changes in the climate have changed human economy, human health, infrastructure and land use (Thomas 1974).

The question is not whether the Charlotte Harbor region will be affected by climate change, but how much it will be affected and in what ways. Key questions include the degree to which it will continue, how rapidly change will occur, what type of climate changes will occur, and what the long-term human and ecological effects of these changes will be.

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

Through the Cenozoic, the most recent geologic era (65 million years ago up to today), temperatures have on the average been warmer and the seas higher than present day (See Figure 1). The islands of the Lake Wales Ridge characterized Florida for a longer period than today’s present configuration (See Figure 2). Through the ice ages of the Pliocene and the Pleistocene, Florida’s land extended throughout the Florida shelf.

Beginning with the ending of the last ice age (about 11,000 years ago), temperatures and sea levels have been rising and would rise in the future. This period is known as a “pluvial.”
Figure 3 shows sea surface temperatures in the Atlantic Ocean’s hurricane main development region and during the main hurricane development period from August to October. Though there is natural variability the temperature trend has been rising. The tide gauge with the longest record near the Charlotte Harbor Region is at Key West (See Figure 4). Both Atlantic sea surface temperatures and the sea level at Key West are increasing. More remarkably the general rate increases and decreases are very similar, with an interim high in the late 1940s and a more recent high in the late 2000’s.

Figure 5 illustrates the timing and severity of hurricanes that made landfall in Florida. Trends of hurricane frequency and severity are similar to Atlantic sea surface temperature. Air temperature changes and the cascading result of these changes are expected to continue in the future.

There are both natural and manmade causes of climate change. Natural causes include changes in solar intensity, eccentricity in the earth’s orbit and “wobbles,” vegetation/albedo changes, volcanic eruptions and coupled ocean/atmospheric cycles. Manmade causes include urbanization, land use changes, deforestation, aerosols and greenhouse gases (Zierden 2009).

Climate has been changing and will likely continue to change at increasing rates. Air temperature, water temperature, sea level, storms, and other phenomena are all inter-related.
Climate Change Overview

Energy from the Sun drives the Earth’s weather, climate and physical processes at the surface. The Earth absorbs energy from the Sun and also radiates energy back into space. However, much of this energy going back to space is absorbed by “greenhouse gases” in the atmosphere (see Figure 6). Because much of this energy is retained in the surface-atmosphere system, the planet is warmer than it would be if the atmosphere did not contain these gases. Without this natural “greenhouse effect” temperatures would be about 60ºF (about 33ºC) lower than they are now, and life as we know it today would not be possible (EPA 2007a).

Climate change may result from:
- natural factors, such as changes in the sun’s intensity or slow changes in the Earth’s orbit around the sun;
- natural processes within the climate system (such as changes in ocean circulation); and
- human activities that change the atmosphere’s composition (such as through burning fossil fuels) and the land surface (such as deforestation, reforestation, urbanization, desertification).

During the past century, humans have substantially added to the amount of greenhouse gases in the atmosphere by burning fossil fuels such as coal, natural gas, oil and gasoline to power cars, factories, utilities and appliances. The added gases—primarily carbon dioxide and methane—are enhancing the natural greenhouse effect and likely contributing to an increase in global average temperature and related climate changes (EPA 2007a).

The Intergovernmental Panel on Climate Change (IPCC) concluded in its 2007 report on climate change: “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and water temperatures, widespread melting of snow and ice, and rising global average sea level” (IPCC 2007a, Working Group I Summary for Policymakers, p. 5). (excerpted from National Water Program Strategy, Response to Climate Change, USEPA, EPA 800-R-08-001, September 2008)

Climate Change Drivers

Changing climate is driven by four things: air temperature, air chemistry, water temperature and water chemistry. These drivers, in turn, create many stressors on human and natural systems.

Air Temperature

Mean global atmospheric temperature has increased by more than 1 degree Fahrenheit since 1901 (IPPC 2007b). Measures in southwest Florida suggest an increase of 1.4 degrees Fahrenheit (NOAA 2009a). Eleven of the last 12 years have seen the warmest temperatures recorded (FOCC 2009).

Air Chemistry

Over the last 650,000 years, levels of atmospheric carbon dioxide (CO₂) have both increased and decreased. The rate of change in increases in carbon dioxide has been about 100 times faster in recent decades than over the past 650,000 years. Concentrations of other gases, such as methane and nitrous oxide, have also increased significantly. Concentrations of greenhouse gases, especially carbon dioxide, have increased. CO₂ emissions grew by 80 percent between 1970 and 2004. Since the Industrial Revolution, atmospheric CO₂ levels have increased by more than 30 percent, reaching concentrations higher than any observed in the last 420,000 years (Petit et
These increasing levels of CO₂ and other greenhouse gases have contributed to a rise in global temperatures of about 0.7 to 1.4 degrees Fahrenheit since 1900, with the warmest temperatures occurring in the past 20 years (Houghton et al. 2001).

**Water Temperature**

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).

Over the past 30 years, increased sea surface temperatures have led to episodic die-offs of sponges, seagrasses, and other components of coastal and marine ecosystems (FOCC 2009). Water temperatures at the sea surface rose by an average of 0.5 degrees between the 1950s and 1990s in tropical and subtropical waters (Wilkinson and Souter 2008; FOCC 2009). The year 2005 was the warmest in the wider Caribbean in the last 100 years (Wang and Enfield et al. 1998; Wilkinson and Souter 2008).

**Water Chemistry**

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. Ocean chemistry is changing at least 100 times more rapidly today than at any time during the 65,000 years prior to the industrial era (Kleypas et al. 2006).
Warm water holds less dissolved oxygen than cold water. Hypoxia, or low oxygen, occurs when the levels of oxygen dissolved in water fall with rising water temperatures to levels injurious to aquatic life. This can lead to what is called a “dead zone.” Excess nutrients can cause or exacerbate hypoxic conditions by causing certain organisms to proliferate, leading to further decreased dissolved oxygen as they die and decay. Terrestrial nutrients are introduced into the marine environment through precipitation and runoff, thus, hypoxia can occur as a natural phenomenon and also as a human-induced or exacerbated event (Turner et al. 2006). Precipitation and runoff amounts and distribution have changed over recent years and will continue to change as climate change progresses (UNEP 2006).

Climate Change Stressors

As a result of changing air temperature, air chemistry, water temperature and water chemistry, additional stressors on human and natural systems occur. These stressors include changes in rainfall, storm intensity, hydrology, and sea level rise.

Rainfall

Rainfall in Florida varies naturally and under human influence in many ways. Annual rainfall is affected by decadal-scale variability in tropical storms, such as the Atlantic Multidecadal Oscillation and the El Niño-Southern Oscillation warming phenomenon in the Pacific Ocean (Enfield et al. 2001; Jones et al. 1999; Shepherd et al. 2007). Summer rainfall varies over periods of a few decades (Jones et al. 1999). 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 (UW 2007; NOAA 2008; SECCP et al. 2005, FOCC 2009, EPA 2008). Rainfall in 28 locations throughout the Charlotte Harbor region had significant trends since the 1950s at four locations. (Janicki 2007). Three had a decreasing trend and one had an increasing trend.

Storm Frequency and Severity

In southwest Florida, most cyclonic storms originate in the Atlantic (See Figure 8). However, some originate in the southwest Gulf of Mexico. Some of the most destructive storms on record (e.g. Hurricanes Donna, Charley, and Wilma) are pushed from the Gulf of Mexico toward southwest Florida by continental fronts.

Figure 8: Paths of Hurricanes within 50 miles of the Fort Myers Mid-Point Bridge (SWFRPC 2005)
The power (severity) of Atlantic tropical cyclones, a function of wind speed, is rising rather dramatically and the increase is correlated with an increase in the late summer/early fall sea surface temperature over the North Atlantic. There is debate concerning the nature of these increases. Some studies attribute them to a natural climate fluctuation known as the Atlantic Multidecadal Oscillation (AMO), and others suggest climate change related to anthropogenic increases in radiative forcing from greenhouse-gases. Tests for causality using the global mean near-surface air temperature (GT) and the Atlantic sea surface temperature (SST) records during the Atlantic hurricane season were applied. Results show that GT is useful in predicting Atlantic SST, but not the other way around. This has provided additional evidence to support the climate change hypothesis (Elsner 2006).

While studies have shown that there is no clear, long-term trend in the number (frequency) of tropical storms (IPCC 2007a; Webster et al. 2005), there are multi-decadal cycles in storm frequency. 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).

**Humidity**

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).

**Drought**

Recent global models project that rainfall in south Florida is expected to decrease in the winter, spring and summer and increase in the fall (Sratus Consulting 2010; Wigley, 2008). The winter and spring are within the dry season and the summer and fall are within the wet season. Even if there is no decrease in total rainfall, this change in rainfall delivery will translate into more severe droughts, an extension of the dry season into the summer, and higher percentage of rain in the late wet season.

**Wildfires**

The changing climate is expected to lead to more extended and severe droughts. Though fire is an important component of habitat management in the Charlotte Harbor region, intense and unnatural wildfires have a destructive potential. Decreased air quality from particulates and other air pollutants released by the fires (NOAA 2008; EPA 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).

**Altered Hydrology**

Climate change model projections for the south Florida area include reduced average rainfall, increased high rainfall events and increased drought. These rainfall changes can result in increased high flows and decreased low flows. 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). Non-climate
human alterations to freshwater inflow into estuaries exacerbate these stresses. Such stresses include groundwater pumping (decreasing water tables), drainage projects, impervious surface which increase overland flow, decreased flow by dams, and removal of forests and wetlands which intercept and store rainfall. These alterations have changed freshwater flows which in turn have changed estuarine circulation patterns, salinity regimes, and patterns of animal use (Scavia et al. 2002). Climate change effects will be variable, and in some cases, will combine to create even more complex and/or extreme outcomes.

**Salt Water Intrusion**

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 2007b). 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).

**Sea Level Rise**

As water temperature increases sea level rises. Melting ice cap and glaciers are also adding to sea level rise. For the past few thousand years, the sea level around Florida has been rising very slowly, however, a persistent upturn in the rate of relative sea level rise may have begun recently (IPCC 2007a). 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 2007a) 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.

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 sea level rise in southwest Florida measured at St. Petersburg is 2.3 mm/year (FOCC 2009).

**Geomorphic (Landform) Changes**

Increased sea level rise and increased intensity of storms will cause increased landform changes.

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. 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).

Figure 10 displays a new inlet that was created at North Captiva Island during Hurricane Charley. The pass is called locally “Charley Pass.” The most dramatic geomorphic changes will occur during intense storms. However other erosion and accretion processes will occur as sea level rises, coastal energy gradients change, and life adapts to these changes.
Three Climate Change Scenarios

Though it is clear that climate will change, the extent and rate of change is uncertain. Many factors influence this change. Various publications offer forecasts of changes. From a planning perspective, this is analogous to forecasting population. Nobody can know future population with certainty and it is subject to a level of public debate. However population forecasts are made to provide a common base to consider future needs in human infrastructure and land development. This assessment offers climate change scenarios to inform incremental decision-making and increase future resiliency.

Three scenarios are provided:
1) **Lower**: a condition that involves a future in which significant mitigative actions are undertaken to reduce the human influence on climate change,
2) **Intermediate**: a scenario which falls within various forecasts, and
3) **Upper**: a future in which few actions are taken to address climate change and the most recent projections of more significant impacts are used, including those related to glacial ice melting.

This approach provides some measure of the outer envelopes of current estimates and with policy alternatives.

**Uncertainty**

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. Though past trends have been documented and may be projected into the future, natural variation, long-term changes in rates, potential changes in human behavior which impact climate, and unpredictable consequences of past actions which are just unfolding result in a range of possible futures.

For example, over the thousands of years since the last ice age, sea level rise has been variable. Around 5500 years ago the rate of sea level rise slowed to 23 centimeters (9 inches) every 100 years. Then around 3000 years ago, sea level rise slowed to 4 centimeters (1.5 inches) every 100 years. More recently, it has accelerated to 30-40 centimeters (12-16 inches) every 100 years. (See Figure 11). In the period from 1860-2009, rates have continued to vary (See Figure 12). Furthermore, potential future policy actions may increase or decrease greenhouse gases, deforestation, and other human influences on climate change.

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*Figure 11: Sea Level Rates of Change for South Florida (Wanless et al. 1994)*

Figure 11: Sea Level Rates of Change for South Florida (Wanless et al. 1994)

slowed to 4 centimeters (1.5 inches) every 100 years. More recently, it has accelerated to 30-40 centimeters (12-16 inches) every 100 years. (See Figure 11). In the period from 1860-2009, rates have continued to vary (See Figure 12). Furthermore, potential future policy actions may increase or decrease greenhouse gases, deforestation, and other human influences on climate change.

*Figure 12: Global Sea Level Rise 1860-2009 (IPCC 2007a)*

* blue=observed, red=modeled*
Selection of Climate Change Scenarios

Because of the uncertainty predicting climate change effects, three scenarios have been selected representing lower, intermediate, and upper predictions from the literature. Stanton and Ackerman (2007) describes the lower and upper climate change scenarios for Florida:

1) **Rapid Stabilization Case**: this case provides the lowest emissions under discussion today, plus lower outcomes of uncertain climate impacts,
2) **Business-as-Usual Case**: this case assumes steadily increasing emissions through this century, plus higher outcomes of uncertain climate impacts.

The lowest emissions under discussion today are a 50% reduction in current global emissions by 2050 and an 80% reduction in current U.S. emissions by 2050. The steadily increasing emissions are modeled on the high-end of the likely range of the IPCC’s A2 scenario. Lower outcomes of uncertain climate impacts include precipitation and hurricane intensity remaining constant. Higher outcomes include precipitation changes including less annual rain in Florida and increasing hurricane intensity.

**Time Period under Consideration**

Most estimates of future climate change offer past changes to present (most often from 1900). The most common future year used is 2100. In order to look at the factors of future climate change, we are using these most common periods. Where possible, data that existed back to the year 1900 was utilized.

Local Trends and Forecasts for Climate Drivers and Stressors

Because Stanton and Ackerman 2007 defined the outer envelope of the three climate change scenarios and because the work was set in Florida, quantitative forecasts were derived from this source first. Where data were available for the Charlotte Harbor region, the historic, current, and forecast data were adjusted accordingly. Other sources provided additional high upper forecasts. USGCRP 2009, FOCC 2009, and IPCC 2007a were also used substantially as recent and authoritative sources of information.

Table 1 summarizes the forecast for climate change drivers and stressors by climate change scenario: lower, intermediate, and upper.

**Average Air Temperature**: Air temperature is a primary driver in climate change. The Charlotte Harbor study areas possesses three weather stations with more than 100 years of daily temperature and rainfall data. These stations are in Bartow, Arcadia, and Fort Myers. Stations at Myakka State Park, Venice, and Punta Gorda were added in 1944, 1955, and 1967 respectively. None of these datasets seems to be complete, with a reading for each and every day within the period of record.
Table 1
Charlotte Harbor Region
Climate Change Scenarios by Available Drivers and Stressors

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<th>1900</th>
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<th>Scenario</th>
<th>2100</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Air Temperature (F)</strong></td>
<td>72.3</td>
<td>73.5</td>
<td>Lower</td>
<td>75.7</td>
<td>Stanton and Ackerman 2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intermed.</td>
<td>76.5</td>
<td>Analysis of local data since 1968</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>84.5</td>
<td>USGCRP 2009</td>
</tr>
<tr>
<td><strong>Days per year over 90°</strong></td>
<td>77.7</td>
<td>90.4</td>
<td>Lower</td>
<td>91.8</td>
<td>Rate applied from 1931-1949</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intermed.</td>
<td>104.6</td>
<td>Rate applied from 1901-1919</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>180</td>
<td>USGCRP 2009</td>
</tr>
<tr>
<td><strong>North Atlantic Water Temperature (^1) (F)</strong></td>
<td>80.6</td>
<td>81.7</td>
<td>Lower</td>
<td>82.8</td>
<td>IPCC 2007a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intermed.</td>
<td>82.9</td>
<td>FOCC 2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>85.3</td>
<td>IPCC 2007a</td>
</tr>
<tr>
<td><strong>Global Air CO(_2) Levels (ppm)</strong></td>
<td>298.0</td>
<td>387.0</td>
<td>Lower</td>
<td>450.0</td>
<td>USGCRP 2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intermed.</td>
<td>680.0</td>
<td>USGCRP 2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>950.0</td>
<td>USGCRP 2009</td>
</tr>
<tr>
<td><strong>Ocean pH</strong></td>
<td>8.2</td>
<td>8.1</td>
<td>Lower</td>
<td>8.0</td>
<td>Royal Society 2005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intermed.</td>
<td>7.8</td>
<td>Royal Society 2005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>7.7</td>
<td>Royal Society 2005</td>
</tr>
<tr>
<td><strong>Rainfall (inches)</strong></td>
<td>54</td>
<td>54</td>
<td>Lower</td>
<td>54</td>
<td>Stanton and Ackerman 2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intermed.</td>
<td>52</td>
<td>10-year rolling average rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>49</td>
<td>Stanton and Ackerman 2007</td>
</tr>
<tr>
<td><strong>Rainfall Delivered in Rainy Season (6/1 through 9/30)</strong></td>
<td>62%</td>
<td>68%</td>
<td>Lower</td>
<td>70%</td>
<td>10-year rolling average rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intermed.</td>
<td>74%</td>
<td>USGCRP 2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>82%</td>
<td>USGCRP 2009</td>
</tr>
<tr>
<td><strong>Sea Level Rise (inches)</strong></td>
<td>0.0</td>
<td>8.0</td>
<td>Lower</td>
<td>7.1 + 8</td>
<td>Stanton and Ackerman 2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Intermed.</td>
<td>19.8 + 8</td>
<td>Titus and Narayanan 1995</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Upper</td>
<td>45.3 + 8</td>
<td>Stanton and Ackerman 2007</td>
</tr>
</tbody>
</table>

1 Based in North Atlantic where hurricanes are generated.
2 Water Temperature is for 1950 rather than 1900.
Figure 13 provides the average temperature for the Charlotte Harbor region by averaging the Bartow, Arcadia, and Fort Myers temperature data. There is a statistically significant increasing temperature trend. These data are used for the analysis of local trends and forecasts for air temperatures.

However, a separate analysis of each station provides a richer understanding of local mechanisms behind the average numbers. Figure 14 illustrates the increasing average temperature trends in Fort Myers, which is greater than the average. Figure 15 illustrates the stable average temperature trend in Arcadia.

Air temperature for the three stations averaged 73.2 degrees annually from 1901-2008. From 1901-1906, the air temperature averaged 72.3 degrees and 73.5 degrees from 2003-2008. Statistical analysis of local temperature data since the recent cold year of 1968 suggests an average increase of 0.033 per year or 3.0 degrees by 2100, a total 76.5 degrees by 2100. Stanton and Ackerman (2007) suggests a lower scenario of 2.2 degree increase (75.7 degrees) and an upper scenario of 9.7 degrees (83.2 degrees). FOCC (2009) reports an increase from 2.5 to 10.4 degrees (76.0 to 83.9 degrees) by 2100. The upper range for USGCRP (2009) is 11 degrees (84.5).

Days per Year Over 90 Degrees: Figure 16 displays USGCRP prediction of the number of days per year with peak temperatures over 90 degrees. Note that the base period for comparison (1961-1979) does not correspond with local station data (See Figure 17).

In the Charlotte Harbor region, trends for the number of days over 90 degrees is not statistically significant. However, when considering the Fort Myers station alone, there is a statistically significant trend.

The number of days over 90 degrees from 1901 through 1919 averaged 77.7. From 1990-2008, the average was 90.4, The 19 year average from 1931 was 89.6, the lowest before 2008. The rate for the period of record was an additional 0.155 days over 90 degrees for each year. The rate from 1931 was an additional 0.055 days over 90 degrees for each year.

North Atlantic Water Temperature: Higher sea-surface water temperatures in the Northern Atlantic Ocean, where hurricanes are formed, are associated with more intense hurricanes (Emanuel 2007, USGCRP 2009). Emanuel (2007) shows the 2005 sea-surface temperature at 81.7 degrees (August
Global Atmospheric Carbon Dioxide Levels: Harding (2008) estimates that 1900 carbon
dioxide levels were at 298 parts per million (ppm). As anthropogenic carbon
dioxide emissions grew so did atmospheric carbon dioxide concentrations. NOAA (2009b) reports carbon dioxide levels at 387 ppm, up from 378 ppm in 2005 and 315 ppm in 1960. USGCRP (2009) reports with a low stabilization scenario that carbon dioxide concentrations will continue to rise to 450 ppm. USGCRP (2009) projects the highest emissions scenario at over 950 ppm.

Ocean Acidity (pH): The Royal Society (2005) reports pre-industrial ocean acidity at 8.18 and today’s at 8.07, a 0.11 unit change. They present future scenarios based on carbon dioxide concentrations. The scenarios which best match the range identified in the previous paragraph correspond to a pH of 7.9 to 7.7.

Though oceans world-wide are becoming more acid, an analysis of near-shore waters in the Charlotte Harbor region show less acidity over time (See Figure 18). Near-shore waters are heavily influenced through October in the main development region for Atlantic Hurricanes). Global average sea-surface temperature has risen degrees 1.1 Fahrenheit degrees over the past 100 years (IPCC 2007a). Sea-surface temperatures will continue to rise at least at the rate at which they have been rising for the past 100 years (IPCC 2007a), or 1.1 degrees by 2100. It is probable that water temperatures at the sea’s surface will continue to increase at the average rate of 0.54 degrees over 40 years in tropical and subtropical waters (FOCC 2009), or 1.2 degrees by 2100.
by surface water runoff. Increasing pH in nearshore waters may be the result of groundwater pumping, wetland loss and drainage.

**Rainfall:** Recent global models project that rainfall is south Florida is expected to decrease in the winter, spring and summer and increase in the fall (Status Consulting 2010; Wigley, 2008). The winter and spring are within the dry season and the summer and fall are within the wet season. Even if there is no decrease in total rainfall, this change in rainfall delivery will translate into more severe droughts, an extension of the dry season into the summer, and higher percentage of rain in the late wet season.

Rainfall measured in Bartow, Arcadia, and Fort Myers averaged nearly 54 inches per year between 1901 and 2008. Of the three stations, only Bartow had a statistically significant change in annual rainfall, a reduction of 0.056 inches annually from 1893, with a standard error of 0.028 inches. The average of the three stations also had a statistically significant change in rainfall for the 10-year rolling average, a reduction of 0.02 inches for year 10-year rolling step, with a standard error of 0.006.

Stanton and Ackerman (2007) suggest a range of 0% to 10% reduction in total rainfall in Florida by the year 2100. The 10% conforms to the 0.056 inch annual decrease identified at the Bartow station. The 0% conforms to the Arcadia and Fort Myers stations.

**Rainfall Delivery:** Total rainfall is important, but how it is delivered is equally important. Even if rainfall remains the same and it is delivered in more heavy downpours, longer dry periods result. If there are longer dry periods with less average rainfall, people and the environment suffer more from the resulting droughts.

The Bartow, Arcadia, and Fort Myers rainfall data were analyzed to review the percentage of each year’s rainfall delivered from June through September. Though no station nor the average of the stations exhibited any statistically significant change, the rolling 10-year average for all stations did. The first 10 year period starting in 1901 was 61.65% and the final 10 year average ending in 2008 was 68.46%, an 18% decrease rainfall delivered in the dry season. Regression analysis suggests a rate of 0.021% annual increase, or an additional 1.9% increase. USGCRP (2009) reports a 20% increase in rainfall delivered in heavy downpours in the last hundred years. In the USGCRP (2009) suggests an additional future increase rainfall delivered in heavy downpours from 24 to 44%
The number of days each year which had more than 1 inch of rain was assessed. Fort Myers station and the 10-year rolling average were statistically significant. However, the ranges were too narrow for a meaningful analysis.

**Sea Level Rise:** The only National Oceanic and Atmospheric Administration (NOAA) tide gauge operating in the Charlotte Harbor Region is in Fort Myers. The period of record for this station begins in 1965. The next closest tide stations with longer periods of record are St. Petersburg, Florida beginning its record in 1947 and Key West, Florida beginning its record in 1913. NOAA analysis suggests that sea level has increased at Fort Myers 4 inches (plus or minus 1 inch) over the past 43 years, the equivalent of an inch every decade. For the Key West period of record, sea level has risen the equivalent of 8 inches (plus or minus 1/2 inch) in the 95 year period. The St. Petersburg station in between the Fort Myers and Key West stations for period of record, sea level rise per year, and level of error. The trend in sea level rise appears to be accelerating.

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).

The Stanton and Ackerman (2007) describe the lower “Rapid Stabilization Case” as an increase of 7.1 inches and an upper range “Business as Usual Case” as an increase of 45.3 inches by 2100 over 2000 levels. Methods developed by Titus and Narayanan (1995) were applied to St. Petersburg tide station data to derive an intermediate case of a 19.8 inches sea level increase. Throughout the literature, sea level rise projections fall at various places within these levels.

The lower, intermediate, and upper levels were applied to digital elevation model and other topographic maps within the Charlotte Harbor Region. Map 2: Projected Charlotte Harbor Regional Sea Level Rise illustrates the areas that are likely to be vulnerable and those that are possibly vulnerable to sea level rise effects.
Map 2: Projected 2100 Charlotte Harbor Regional Sea Level Rise
Climate Change Impacts to Different Sectors

Climate change impacts are the result of climate change drivers and stressors acting on different sectors of human and natural systems. These different sectors include critical facilities, economic activities, cultural resources, human health, water resources, coastal areas, and wildlife and ecosystems.

Critical Facilities

Critical facilities in low-lying areas are most vulnerable to the impacts of climate change. Sea level rise, increased wind and storm surge effects intensity of tropical storms and hurricanes are climate effects that are most likely to impact critical facilities. Critical facilities include emergency services, communications, solid waste services, water supply and wastewater infrastructure, transportation, and energy supply.

Emergency Services

Because emergency services are sited close to the populations they serve, some of these facilities are at risk for potential impacts of climate change. Emergency services include fire and emergency medical services (EMS), health care facilities, and hurricane shelters.

Fire and Emergency Medical Services: In Florida, fire services and emergency medical services tend to be co-located. Nine Fire/EMS stations were identified within or close to the upper range for 2100 sea level rise. They include Charlotte County Fire and EMS Stations 7, 10, and 14; Captiva Fire Control District station; Upper Captiva Fire Department; Sanibel Fire Station 2; Matlacha-Pine Island Fire Station 3; and Iona-McGregor Fire Department Station 2. All stations are above the intermediate sea level rise.
As early as 1970, the City of Punta Gorda relocated its fire station to a less vulnerable location, at 1410 Tamiami Trail. In 2002, a public safety complex was constructed at the same address, housing The Fire Station #1, Fire Administration and the Police Department. Site construction included fill to increase the elevation.

**Health Care Facilities:** Vulnerable health care fatalities include regional hospitals, dialysis and surgery centers, doctors’ offices, and senior living facilities. Thirteen such facilities have been identified within the upper range for 2100 sea level rise. One additional health care facility, the Life Care Center of Punta Gorda, is within the intermediate range for 2100 sea level rise. The most significant medical district at risk is the Charlotte Regional Medical Center and four ancillary facilities. Figure 23 illustrates how close the hospital is to the mangrove fringe and the east Harborwalk pier.

Four health care facilities (doctors’ offices and surgery/dialysis centers) are associated with Health Park, in the Estero Bay Basin. Three Senior Living Facilities are near the Caloosahatchee. Finally one clinical laboratory is in Bonita Springs, near the Imperial River.

**Hurricane Shelters:** Schools are often used for hurricane sheltering. Laurel Middle School in the Dona-Roberts Bay basin and Heights Elementary School in the Caloosahatchee basin are both within the upper range for 2100 sea level rise.

**Communications**

Communications facilities include radio and television towers. Additional communications towers, such as the one depicted in figure 23, are not in the inventory of critical facilities conducted by the SWFRPC.

A cluster of radio communication towers located in Punta Gorda are within the intermediate range for 2100 sea level rise. They include WCCF and WCVU. An additional radio communication tower, WSEB, is within the upper range for 2100 sea level rise and is located on Cape Haze.

In addition to communications towers, sustained climate change instability also 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 (EPA 2008).
Solid Waste

Class 1 solid waste facilities in the Charlotte Harbor region are not at significant risk from direct climate change effects. These waste facilities could be at risk from the secondary effect of potentially large amounts of waste to be handled should increased intensity storms or surge occur. Solid waste facilities include landfills and recycling centers.

Solid Waste Facilities: Six Class 1 Landfills existing in the Charlotte Harbor region (North Polk Central Landfill, Hardee Regional Landfill, Sarasota Central Landfill Complex, Charlotte County Solidwaste Landfill-Zemel, Lee/Hendry Regional Solidwaste Disposal Facility, and Gulf Coast Landfill in Lee County). In addition, there are three waste to energy facilities (McIntosh Power Plant -Polk County, Ridge Generating Station-associated with the North Polk Central Landfill, and the Lee County Resource Recovery Facility-associated with the Gulf Coast Landfill). All these facilities are outside the upper range for 2100 sea level rise. The inactive Boca Grande Dump is within the upper range for 2100 sea level rise.

With 88% of all structures in Southwest Florida vulnerable to tropical storms hurricanes and surge events; debris management capacity (as has been observed after 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 2004-2005 hurricane seasons in southwest Florida with the need to designate temporary staging areas and no long term plan 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.

Recycling Centers: Two recycling centers are within the upper range for 2100 sea level rise: 3G’s Recycling Center and Gomez Property C&D Facility. Both are in southern Charlotte County.
Public Water Supply and Wastewater Treatment

Some public water supply facilities are potentially at risk from climate change effects. Some package plants are at risk.

**Public Water Supply Facilities:** Seventeen public water supply facilities are within the intermediate or upper range for 2100 sea level rise. Many of these are major facilities for public water supply.

The most vulnerable public water supply facility is probably the Shell Creek Reservoir, the only in-stream public supply reservoir in the Charlotte Harbor Region. The creek to the dam is tidally influenced during dry periods. The reservoir is shown in Figure 25.

Other utilities with facilities in vulnerable area is The Venice Water Department, Knights Island Utilities, Greater Pine Island Water Association and (Sanibel) Island Water Association. Smaller suppliers include Bay Lakes Estates, Caspersons Beach, Snowbirds Vistas, South Venice Yacht Club, Barnacle Phil’s, Inc, and Useppa Island Club. All are in the upper range for 2100 Sea Level Rise, except for GPIWA, Knights Island and Venice, which are in the intermediate range.

**Wastewater Treatment Facilities:** Fourteen wastewater treatment facilities are within the upper range for 2100 sea level rise. One, Burgess Island Associates Inc, is within the lower range. These facilities are smaller package treatment plants which serve small neighborhoods or single commercial facilities in the coastal area.

All public central sewer wastewater treatment plants are outside the areas at risk for potential sea level rise.
Transportation

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; (Karl et al. 2009).

Critical transportation facilities include airports, helistops, and roads of the Federal-Aid Highway system. Six critical transportation facilities are within the upper range for sea level rise in 2100. They include Boca Grande Helistop and Rotonda International in the Charlotte Harbor basin and the Captiva Helistop, North Captiva Air Inc, St. James Helistop, and Woodstock Airport in the Pine island Sound basin.

Several roads in the Charlotte Harbor region are vulnerable to sea level rise, coastal flooding and storm surge. The vulnerable most state roads include SR78 across little Pine Island and U.S. 17 in Punta Gorda. Bridge approaches and collector and local roads in low-lying areas are also at risk. Even when roads are not inundated, permanent standing water can erode and impair the road base, increasing maintenance costs and reconstruction needs.

In Florida, roads are designed with extensive stormwater management systems. These systems are normally designed for the 25-year storm event, which may change and render them less effective.

Some roads are built lower than surrounding land to begin with or surrounding land is filled to meet flood or septic tank standards, so reduced drainage capacity will increase their susceptibility to flooding during rainstorms (Titus 2002).

No major ports exist in the Charlotte Harbor region. However, ports in Florida supply the region with goods. These ports may require maintenance and reconstruction to address sea level rise impacts.

Map 5: Vulnerable Transportation Facilities

Figure 26: Widening I-75 over the Peace River
Energy Supply

EPA provides an inventory through their emissions and generation resource integrated database (WGRID) for electricity generation plants. The database does not include the new solar array installed by Florida Power and Light (FPL) in DeSoto County. This facility is the largest in Florida. Map 6: Electrical Generation Facilities shows the location of these facilities within the Charlotte Harbor region.

Currently crude oil and gas production in the Charlotte Harbor region is limited to the Lehigh Park field which produced 31,993 barrels of oil and 3,903 cubic feet of natural gas in 2007 (UFBEBR 2008 Table 15.09).

Florida’s electricity is expensive, and high energy prices can be expected well into the future, even without the added strain of climate change (Stanton and Ackerman, 2007). The electricity sector in Charlotte Harbor region includes 25 power plants. Fifteen of the plants are fueled by natural gas, two by bituminous coal, one by oil, one by wood waste and one by solid waste. The remaining five plants are operated by phosphate mining companies and are fueled by the exothermic by-product of the phosphate manufacturing process. Cogeneration produces enough to power the fertilizer manufacturing facilities. Excess electricity is used at mining sites or sold back to local power companies.

The Charlotte Harbor region is served by three investor-owned electric utilities (Florida Power and Light, Progress Energy Florida Inc, and Tampa Electric), one generating municipal electric utility (Lakeland), three non-generating municipal electric utilities (Bartow, Ft. Meade, and Wauchula), and two non-generating rural electric cooperatives (Lee County and Peace River (UFBEBR 2008 Table 15.14).

The transmission system reflects the location of power plants, with large lines extending down the center of eastern and western coastal counties. As coal plants have become less attractive politically, financially, and environmentally, the state has increased its reliance on natural gas plants, causing concern about the lack of diversity in Florida’s energy portfolio (Platts 2007).

Florida’s energy infrastructure is particularly vulnerable to sea level rise and storm impacts (Karl et al. 2009). The most vulnerable of these is the Florida Power and Light Fort Myers plant. Vulnerability was reduced dramatically when the plant converted from oil to natural gas in the 1990s. The plant had been fueled from a oil tanks located on Boca Grande via (the Belcher Oil Company) barge. The storage tanks were decommissioned before Hurricane Charley passed over the area in 2004. Most of the petroleum products consumed in Florida are delivered by barge to three ports, two on the east coast and one on the west coast. The interdependencies of natural gas production and distribution, transportation fuel distribution and delivery, and electrical generation and distribution were found to be major issues in Florida’s recovery from recent major hurricanes. (Bull et al. 2007).
Economic Activities

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

Economic sectors to be evaluated separately include agriculture, forestry, tourism, land development, the ocean economy, and mining. Table 2 enumerates the personal non-farm earnings by sector. The top non-farm industries include construction, health care, retail sales, professional services, manufacturing, administrative services, finance/insurance, and manufacturing.

Residents and visitors alike benefit economically from the natural resources of the Charlotte Harbor region. The multibillion dollar agriculture, championship fishing and tourism industries, for example, are directly related to the quality of the natural environment. Natural resources also provide jobs and industry earnings as well as other public and private benefits such as recharging groundwater aquifer water supplies and providing fish and wildlife habitat. Climate change impacts can significantly change the health and vitality these economic activities.

<table>
<thead>
<tr>
<th>Economic Sector</th>
<th>Charlotte</th>
<th>DeSoto</th>
<th>Hardee</th>
<th>Lee</th>
<th>Polk</th>
<th>Sarasota (half)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
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<td>Construction</td>
<td>$322,302</td>
<td>$22,422</td>
<td>$15,123</td>
<td>$2,220,622</td>
<td>$826,120</td>
<td>$532,543</td>
<td>$3,939,132</td>
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<tr>
<td>Health Care</td>
<td>$378,686</td>
<td>$40,929</td>
<td>$1,053,923</td>
<td>$1,130,823</td>
<td>$634,374</td>
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<td>$3,238,735</td>
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<td>Retail</td>
<td>$265,541</td>
<td>$58,421</td>
<td>$21,514</td>
<td>$1,346,714</td>
<td>$831,599</td>
<td>$414,563</td>
<td>$2,938,352</td>
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<td>Professional Serv.</td>
<td>$141,082</td>
<td>$7,009</td>
<td>$5,896</td>
<td>$802,764</td>
<td>$731,281</td>
<td>$414,563</td>
<td>$2,086,580</td>
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<tr>
<td>Manufacturing</td>
<td>$43,613</td>
<td>$20,551</td>
<td>$9,076</td>
<td>$416,922</td>
<td>$1,265,976</td>
<td></td>
<td>$2,051,809</td>
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<tr>
<td>Admin. Serv.</td>
<td>$65,710</td>
<td>$8,039</td>
<td>$14,781</td>
<td>$625,868</td>
<td>$779,487</td>
<td>$363,284</td>
<td>$1,780,688</td>
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<td>Finance/Insurance</td>
<td>$102,171</td>
<td>$9,303</td>
<td>$11,784</td>
<td>$523,429</td>
<td>$588,391</td>
<td>$363,284</td>
<td>$1,598,362</td>
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<td>Wholesale</td>
<td>$41,740</td>
<td>$9,808</td>
<td>$13,580</td>
<td>$487,201</td>
<td>$591,733</td>
<td>$155,019</td>
<td>$1,299,081</td>
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<tr>
<td>Other Serv.</td>
<td>$103,995</td>
<td>$13,999</td>
<td>$11,588</td>
<td>$520,576</td>
<td>$353,796</td>
<td>$185,902</td>
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<td>Accommodations</td>
<td>$75,180</td>
<td>$7,285</td>
<td>(D)</td>
<td>$527,834</td>
<td>$235,381</td>
<td>$185,902</td>
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<td>Transportation</td>
<td>$23,219</td>
<td>(D)</td>
<td>(D)</td>
<td>$241,253</td>
<td>$626,415</td>
<td>$43,777</td>
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<td>Real Estate</td>
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<td>$2,095</td>
<td>$535,878</td>
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<td>$526,695</td>
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<td>$125,222</td>
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<td>Management Serv.</td>
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<td>$1,066</td>
<td>$207,459</td>
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<td>(D)</td>
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<td>(D)</td>
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<td>$31,784</td>
<td>$225,588</td>
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<td>(D)</td>
<td>(D)</td>
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<td>(D)</td>
<td>(D)</td>
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<td>(D)</td>
<td>(D)</td>
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<td>$3,930,515</td>
<td>$25,701,410</td>
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</table>

(D) Data withheld to avoid disclosure of information about individual firms.

(Source: UFBEBR 2008, Table 5.34)
**Agriculture**

Agriculture would be affected by changes in rainfall and temperature viability. With more rain delivered in the fall, stresses on field drainage systems would be increased. Investments would need to be made to retain water for the dry season which is expected to be even drier (Stratus Consulting 2010). High- and low-temperature stresses on crops would be increased. Both high- and low-temperature stresses require more water and fertilization. (United States Global Change Research Program. 2010)

Agriculture is an economic anchor of Florida, second only to tourism in the Charlotte Harbor region, but first in the Peace River basin. Within the Charlotte Harbor region, agriculture occupies 819,072 acres or 31% of the region’s land area of 2,918,331 acres. Important crops include citrus, tomatoes, bell peppers, cucumbers, squash, watermelons, greenhouse and nursery plants and sod. Livestock include significant cow/calf operations, along with beef, egg, dairy, and rabbit production. Climate variability may lead to selection of different crops, better suited to the changing conditions.

Climate instability affects agricultural production and water use. While Florida’s mild climate allows produce to be grown year-round, short duration freezes can cause havoc. Freezes in the 1980s in northern Florida accelerated the establishment of citrus groves in southwest Florida, notably in Lee and Hendry Counties. Water is used to protect sensitive winter crops such as strawberries and citrus. Agricultural pumping during a string of freezes in 2010 led to a 60 foot drop of aquifer levels around the Peace River basin. Aquifer level drops contributed to the formation of sinkholes which, in turn, caused road closures in Lake Wales and other locations.

Overall, the greatest water demand in Florida is for agriculture (Marella 2008). Total freshwater use for agriculture has trended upward in the past several decades, reaching an average of 2 billion gallons per day in 1970 compared to almost 4 billion in 2000 (Marella 2004). Furthermore, these averages mask large seasonal variations; farmers need water most at the driest times of the year, when surface water supplies are likely to be most limited. Irrigation required more than seven times as much water in April as in July in the year 2000 (Marella 2004). With less rainfall delivered during the winter and spring months, agricultural freshwater demand is expected to increase. Perhaps more acreage will be given over to freshwater storage to capture increased autumn rains.

Over-pumping of the Floridan aquifer has already caused large decreases of groundwater pressure and also increases the potential for saltwater intrusion. Mineralized groundwater used for irrigation...
purposes may escape agricultural areas by runoff or seepage and add to stream flows, changing the natural water chemistry of Myakka and Peace River tributaries. Fertilizers and pesticides, which may find their way into surface and groundwater, are being addressed through recently adopted agricultural best management practices.

**Forestry**

Prolonged droughts, higher maximum summer temperatures, and higher evapotranspiration rates may stress plant communities and cause shifts in the spatial extent of sensitive species, changes in community structure along hydrologic gradients, and changes in diversity and ecosystem function. Projected effects of climate change in the southeastern forests are: (1) accelerated wildfire frequency resulting from longer periods without rainfall, (2) reduced soil moisture available for plant transpiration, (3) increased infestation of southern forest stands by pine bark beetles, and (4) changed ecosystem community dynamics. (Kish 2008).

Forestry is not a large component of the Charlotte Harbor region, occupying 5785 acres or less than 1% of the Charlotte Harbor region land area. However, more attention may be given to forest retention and restoration in southwest Florida because of potential financial incentives related to sequestering carbon to meet greenhouse gas targets.

The most common forestry species in the Charlotte Harbor region include cypress and slash pine. However, there may be opportunities related to specialty woods such as mahogany.

Climate change will affect the distribution of forest tree species (Box et al. 1999, Crumpacker et al. 2001). Many species will experience increased productivity from higher levels of atmospheric carbon dioxide, up to an optimum level. For some species, temperatures will increase beyond their tolerance for survival. Higher temperatures will increase water stress from more evapotranspiration (water loss through leaves) and decreased soil moisture (NRDC and Florida Climate Alliance 2001). Sea level rise will also threaten coastal and low-lying forests.
Tourism

Tourists and residents are drawn to southwest Florida because of many natural amenities. Tourists demand clean beaches or they will seek other destinations with their vacation dollars.

Climate change will likely have a variety of impact on the tourism industry. Increasing erosion of beaches, harmful algal blooms, variations in extremes of temperature and other climate change effects may create needs to protect the vital tourism industry.

As sea levels have increased, so has the frequency of beach renourishment. In addition the life expectancy of these projects has been reduced.

Red tide can cause serious respiratory and skin problems. Blue-green algae blooms are also toxic. These imbalances come into the system with high flows and nutrients. Extreme weather events such as the 2004 and 2005 hurricane seasons created high nutrient-laden water flows. In southwest Florida, the tourism industry has suffered from several types of algal blooms. Red tide, blue-green algae, and brown drift algae has at various times destroyed tourism seasons. So much so, that the Lee County Tourist Development Council has invested more than $200,000 to research red tide and red drift algae. In addition, many tourist businesses have joined forces to lobby to develop better water and nutrient management (www.leewaterfacts.org).

The tourism of southwest Florida focus on outdoor activities including beaches, kayaking/canoeing, hiking in natural areas, and the like. As temperatures become more extreme, these activities become less desirable.

Land Development and Building

The same qualities that render the Charlotte Harbor region desirable for tourists are the same qualities that make it desirable to move to permanently. In fact, many residents saw the area first as tourists. In addition to the vulnerabilities found in tourism, water availability, increased intensity of storms, increased and vulnerability of low lying development may affect the future health of the construction industry.

Much of the land platted for residential development were created on the coast from dredged low-lying areas. Many of these areas are vulnerable to the impacts of sea level rise. Additional land that had been slated for development within the most vulnerable zones associated with Estero Bay and Charlotte Harbor was acquired and managed for environmental purposes, improving the overall resiliency of area.
Over-fishing has already led to declining fish populations in Florida, and climate change will exacerbate the problem by destroying crucial habitats (FWC 2005b; Schubert et al. 2006). In particular, climate change will likely have devastating effects on the estuarine wetland ecosystems and coral reefs upon which many fish species depend.

As sea levels rise, estuarine wetlands will be inundated and vegetated areas will be converted to open water (Levina et al. 2007). If sea levels rise gradually and coastal development does not prevent it, the wetlands and the species they support could migrate landward (Brooks et al. 2006). But rapid sea level rise combined with structures built to protect human development, such as seawalls, prevent landward migration, causing estuarine habitats to be lost altogether. Sea level rise in the upper range for 2100 is more than enough to turn most estuarine wetlands into open water (Stanton and Ackerman 2007).

More intense hurricanes also threaten to damage estuarine habitats. During Hurricane Andrew in 1992, large quantities of sediment from inland sources and coastal erosion were deposited in marshes, smothering vegetation (Scavia et al. 2002). The high winds of hurricanes also pose a direct threat to mangrove forests, knocking down taller trees and damaging others (Doyle et al. 2003). Mangrove wetlands are critical to the life stages of some species and is important aspect of the food web.

Because shellfish feed by filtering estuary water, they assimilate and concentrate materials carried in the water. In clean water free from bacteria, red tide and other pollutants, the shellfish can be safely eaten year round. In areas of the estuaries affected seasonally by red tide or nearby urban areas, shellfish may not be safe to consume. Therefore, shellfish are monitored regularly to protect public health. Currently, about one-third of Pine Island Sound is approved for shellfish harvesting year round. Many areas in Lemon Bay, Gasparilla Sound and the Myakka River are conditionally approved for seasonal harvest when bacteria and red tide levels are at safe levels. Pine Island Sound and Estero Bay are closed to shellfish harvesting throughout the year due to measured or probable bacterial contamination.

The importance of healthy waters for safe shellfisheries has taken on a new significance in Charlotte Harbor. A 1995 state constitutional amendment precluded the use of typical nets used in commercial fishing. Many of the commercial fishermen in the Charlotte Harbor region took advantage of aquaculture training programs. Areas of the submerged estuary bottomlands are leased to individuals by the state for shellfish aquaculture. Areas where such leases have been issued include Gasparilla Sound and Pine Island Sound. Marine shellfish aquaculture in Charlotte Harbor is primarily hardshell clam. Clams require proper salinity, oxygen and nutrients to grow at a reasonable rate, as well as good water quality to be safe to eat.

Figure 30: Charlotte Harbor Mangroves Damaged from Hurricane Charley
Mining

Mining is an important part of the Charlotte Harbor region’s economy and comes with environmental impacts that contribute to the vulnerability of regional natural resources. A total of 167,400 acres were designated as extractive land uses in 2005 within the Charlotte Harbor region. The largest of these areas were for phosphate mining. Other areas are mined for fill, sand, gravel and crushed stone.

The phosphate industry is a significant factor in resource management within the Charlotte Harbor region. The “Bone Valley” phosphate deposit, of more than 500,000 acres, lies principally within the Peace River watershed and is shown on Map 9 in light purple. This deposit is a large resource, used for agricultural fertilizer production. Mineable reserves within the Bone Valley deposit are projected to last until at least 2050. The deposit provides approximately 75 percent of the phosphate required by U.S. farmers and about 25 percent of the world supply.

The presence of the bone valley is responsible for high phosphorous levels in the Peace River basin. It is currently expected that rainfall is south Florida is expected to decrease in the winter, spring and summer and increase in the fall (Stratus Consulting 2010; Wigley, 2008). The increase in rainfall during the fall may stress the ability of clay settling areas and other water containment systems to retain adequate amounts of water. This will likely translate into more difficulties for phosphate mining concerns to meet water quality standards.

Beginning in 1975 with the advent of stricter phosphate mining regulations in the state of Florida and improved methods, groundwater consumption during the mining process has dramatically decreased. Between 1985 and 2000, it is estimated that mining processes use nearly 60% less, or 125 million gallons per day (SWFWMD 2003). During the same period agriculture and public water supply use of groundwater increase by nearly 20% or 52 million gallons per day. This improvement in phosphate mining techniques will improve the resiliency of phosphate mining to the impacts of climate change. However, with less rainfall during the dry season and higher public supply demands, the phosphate industry will be competing for a more limited water resource during these periods.
Cultural Resources

The National Register of Historic Places names historic districts, archeological districts and buildings to its registry. The State of Florida Historic Preservation Office maintains a database of historic structures.

Historic Structures

Over 10,000 historic structures are in the Charlotte Harbor region. Of these, just over 200 are potentially eligible for the National Registry of Historic Places. For Sarasota, Charlotte, and Lee Counties, these structures are clustered in some of the areas most vulnerable to storms and sea level rise. Note in Map 10 how these structures are clustered in areas that are accessible by water and vulnerable to the effects of sea level rise and severe storms.

Historic Districts

In the Charlotte Harbor region, 36 districts have been named to the National Register of Historic Places. Of these, the archeological districts of Big Mound Key (Charlotte), Galt Island and Pineland (Lee) are the most vulnerable to sea level rise.

Lighthouses

Of 22 lighthouses listed for the State of Florida, three are located in the Charlotte Harbor region. They include the Boca Grande Rear Range Lighthouse (built 1881), Sanibel (San Ybel) Lighthouse (built 1884) and the Boca Grande Lighthouse (built 1890). The lighthouses were all well built and are maintained by the state. They are also elevated so that inundation would not be an immediate problem. However, geomorphic changes of the underlying barrier islands may affect the foundations of the structures over time.

Other Community Resources

The SWFRPC inventoried community resources as part of its critical facilities information for hurricane preparedness planning. These facilities include attractions/stadiums, faith-based facilities, libraries, local and state government facilities and relief agencies.

In addition to lighthouses, three community resources are within possible sea level rise levels. They include The Bryan B. Branch Library in Lee County and the Punta Gorda Library in Charlotte County. In addition, the Florida Fish and Wildlife Conservation Commission Law Enforcement office.

Map 9: Historic Structures and Lighthouses
Human Health

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). Similar effects from climate change on Charlotte Harbor region may be anticipated.

Human health effects of climate change may include increased:

- Direct stress from higher temperatures;
- Freshwater shortages;
- Disease-carrying insects and mammals;
- Water and food-borne illnesses;
- Water pollution and toxins;
- Air Pollution; and
- Other indirect effects.

Direct Stresses from Higher Temperatures

Higher temperatures poses potential health threats of several kinds: direct health stresses, increased prevalence of disease, and potentially increased smog formation.

Increased heat stress could result in increased human mortality. The Charlotte Harbor region has an increasing 19-year rolling average of temperatures over 90 degrees, which may increase the number of local heat-related deaths and the incidence of heat-related illnesses, particularly among its high proportion of older residents and visitors (Twilley et al. 2001). Projected changes in the Charlotte harbor region average temperature is estimated between 2.2 and 11°F (Stanton and Ackerman 2007; USGCRP 2009). In addition the number of days over 90°F is expected to increase from 90 per year to 91 to 180 days per year.

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.

Freshwater Shortages

Changes in rainfall pattern and sea level rise could 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 increased evaporation rates and saltwater intrusion caused by a combination of sea level rise, land subsidence, and periodic low river flows (Twilley et al. 2001). Increased evaporation could also increase concentrations of pollutants to exceed drinking water thresholds. The City of Punta Gorda is already investigating alternative methods to meet these standards.
Disease-carrying Insects and Mammals

Changing climate conditions may expand the habitat and infectivity of disease-carrying insects and mammals; increasing the potential for transmission of diseases such as dengue fever and malaria. Although dengue fever is currently uncommon in the United States, conditions already exist in the Charlotte Harbor region that makes it vulnerable to the disease. Warmer temperatures resulting from climate change could increase this risk (EPA 1997).

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; EPA 2008).

Hotter temperatures, extreme rainfall and increased runoff can increase populations of disease carrying insects and boost the potential for transmission of some tropical diseases. 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, ticks, fleas, rodents, ticks, and other animals. Dengue fever, malaria, west Nile virus, yellow fever, encephalitis, and equine encephalitis transmitted by mosquitoes. Lyme disease, Rocky Mountain spotted fever, ehrlichiosis, and typhus fever is tick-borne. Rabies, hantavirus and tularemia are spread by mammals. Chagas (Trypanosoma cruzi), spread by other insects, has been cited as a potential problem by the CDC, but statistics for this disease are not maintained by the state. Table 4 details the instances of these diseases in the Charlotte Harbor region.

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 and Florida Climate Alliance 2001).

Lafferty (2009) has asserted that early reviews about climate change exaggerated claims that diseases will...

<table>
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<tr>
<th>County</th>
<th>Charlotte</th>
<th>DeSoto</th>
<th>Hardee</th>
<th>Lee</th>
<th>Polk</th>
<th>Sarasota (half)</th>
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Table 3: Tropical Disease Occurrence in Charlotte Harbor Region
increase in the future (Randolph 2009). Commentaries from ecologists with 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. 2002; Ostfeld 2009; Pascual and Bouma 2009; Randolph 2009).

Climate change is likely to affect insects and animals that spread diseases, much 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 2009)

The Charlotte Harbor region depends on periodic low temperatures associated with cold fronts to knock back mosquito, flea, and tick populations. As the number of cooler days decreases, these pests can become a year-round phenomenon.

**Water and Food-borne Illnesses**

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 seasonal rainfall projected for the Charlotte Harbor region 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 and Florida Climate Alliance 2001).

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).

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 (EPA 1997).

**Water Pollution and Toxins**

Increase rainfall during the summer would increase wet season stormwater discharges which 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).

Threats to ecosystems rich in biodiversity, such as 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).
Increased Air Pollution

While the Charlotte Harbor region is in compliance with current air quality standards, increased temperatures could make remaining in compliance more difficult. 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 et al. 2005).

Increased temperatures along with the associated increased use of fossil fuels could increase a range of air pollutants.

**Ground-level Ozone:** 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). In addition, ambient ozone reduces agricultural crop yields and impairs ecosystem health (EPA 1997).

Ground-level ozone, 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. Increased rainfall and stronger winds could actually decrease smog formation. Climate change could increase concentrations of ground-level ozone. Specific weather conditions, strong sunlight, and stable air masses, tend to increase urban ozone levels.

**Particulates:** Airborne particulate matter have well-documented human health effects that may be exacerbated with the increases in their concentrations that will likely occur with longer dry seasons. 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 2009b).

**Pollutants associated with Fossil Fuels:** 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. 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 and Florida Climate Alliance 2001).

**Pollens and Molds:** 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 2009c).
Water Resources

Climate change will impact many aspects of water resources (Stratus Consulting 2010). The competing needs of water supply, adequate instream flows and drainage will be taxed with increased rainfall in the fall and decreased rainfall in the winter and spring. Already, drainage of the landscape to accommodate wet season rainfall has resulted in limited groundwater and surface water supplies during the dry season. Decreased dry season rainfall will exacerbate these limitations.

The region has been experiencing recent record-breaking droughts (SFWMD 2009a). Even so, Florida is generally a wet state and southwest Florida some of the wettest of the wet (Bradley 1972). The area averages 54 inches of rainfall per year, a level matched only by a few other states in the Southeast, and by Hawaii. Huge aquifers can be found under all regions of the state, and many areas have abundant surface water as well. The majority of south Florida was a vast wetland less than 100 years ago. Current agricultural and residential development is dependent on the massive drainage efforts of the twentieth century. Florida has succeeded all too well in draining its former “excess” of water, adding to recent shortages, as well as a long and expensive process of environmental restoration of the Everglades and other wetland ecosystems.

Precipitation is not evenly distributed throughout the year, but is heavily concentrated in the rainy season, June through October. In that hot, wet period, most of the rainfall, as much as 39 of the 54 inches, evaporates before it can be used. Demand for water, on the other hand, is highest during the dry months of the winter and spring, driven by the seasonal peak in tourism and by the irrigated winter and spring agriculture.

In Florida, water resources are managed through several mechanisms. The Charlotte Harbor region includes portions of two water management districts: the Southwest Florida Water Management District (SWFWMD) and the South Florida Water Management District (SFWMD). The five water management districts in Florida are the agencies primarily responsible for managing water for:

- Water Supply;
- Flood Protection;
- Water Quality; and
- Natural Systems.

Water Management Districts are required to adopt and update Water Supply Plans and to establish Minimum Flows and Levels (MFLs). In addition, SWFWMD has designated a Southern Water Use Caution Area (SWUCA) and SFWMD is preparing the Southwest Florida Feasibility Study (SWFFS).

Water Supply Plans

In Florida, water management districts are required to develop and update water supply plans to forecast water demands by sector and to identify needed new water supplies. New water supply alternatives within the existing water supply plans include the following alternative sources:

- Captured Surfacewater/Stormwater during high flows;
- Reclaimed Water;
- Seawater Desalinization;
- Brackish Groundwater Desalinization;
- Fresh Groundwater;
- Non-agricultural Water Conservation;
- Agricultural Water Conservation; and
- Aquifer Storage and Recovery. (SFWMD 2006 and SWFWMD 2006).

In-stream reservoirs are no longer permitted. In addition, more emphasis is now being placed by SWFWMD in developing water resources which can improve the environment rather than harm it.

Each method of providing new water supplies to a growing population and growing industries has costs, benefits, advantages and disadvantages. Traditionally, expensive capital improvements such as reservoir construction and water treatment plans have had funding source availability over water conservation efforts. However, efforts are being developed statewide to reverse this funding emphasis.

Existing water supply plans fail in addressing changing trends of demand (assuming only existing per capita demand levels) and alternative climate futures. With higher percentage of rainfall delivery in the wet season, water storage becomes critical.
Minimum Flows and Levels

Both SWFWMD and SFWMD established Minimum Flows and Levels (MFLs) within the Charlotte Harbor region. MFLs have been (or shortly will be) adopted for:

- Dona Bay/Shakett Creek below Cow Pen Slough;
- Myakka River (Upper);
- Peace River (Upper); and
- Peace River (Middle);
- Peace River (Lower and Shell Creek);
- Lake Hancock plus 13 other lakes in Polk County;
- Floridan Aquifer (SWUCA);
- Caloosahatchee River; and
- The Lower West Coast Aquifer System (SWFWMD 2009a and SFWMD 2009b).

The MFLs have been set with analysis of past water flows, use of environmental indicators such as seagrass and oysters, and existing sea levels within estuarine systems. CHNEP has formally requested that in future reevaluations of MFLs, water management districts consider potential climate changes.

Both water management districts have developed projects to meet MFLs. One example is the Lake Hancock Level Modification project. It is projected to meet about 50% of minimum flow requirements and reduce nitrogen levels by 27% (see Figure 31). Both the SWUCA recovery strategy and the SWFFS provide strategies and propose projects which would help to meet MFLs and other environmental water needs.

Southern Water Use Caution Area

The entire southern portion of the SWFWMD, including the Charlotte Harbor region, encompassing the Southern Groundwater Basin, was declared the Southern Water Use Caution Area (SWUCA) in 1992. The SWUCA encompasses approximately 5,100 square miles, including all or part of eight counties. In response to growing demands from public supply, agriculture, mining, power generation and recreational uses, groundwater withdrawals steadily increased for nearly a century before peaking in the mid-1970s. These withdrawals resulted in declines in aquifer levels throughout the basin, which in some areas exceeded 50 feet. Although groundwater withdrawals have since stabilized as a result of management efforts, depressed aquifer levels continue to cause saltwater intrusion, and contribute to reduced flows, including zero flow, in the upper Peace River, and lowered lake levels of some of the more “leaky” lakes in the upland areas of Polk and Highlands counties.

The proposed 1994 SWUCA rule had three main objectives. SWUCA II was adopted in 2006 and revised the goals to: (1) Restore minimum levels to priority lakes in the Lake Wales Ridge; (2) Restore minimum flows to the upper Peace River; (3) Reduce the rate of saltwater intrusion in coastal Hillsborough, Manatee and Sarasota counties; (4) Ensure sufficient water supplies for all existing and projected reasonable-beneficial uses; and (5) Protect investments of existing water use permittees (SWFWMD 2009b).

The goal from 1994 was to “substantially halt saltwater intrusion” but was modified in 2006 to “reduce the rate of saltwater intrusion” to address the current realities of the problem. As sea levels continue to rise, saltwater intrusion will accelerate. With a higher percentage of rainfall delivery in the rainy season, more water will leave the system as surfacewater runoff than percolate into the ground, replenishing aquifers, rendering recovery of the Floridan Aquifer more difficult.
Southwest Florida Feasibility Study

Congress approved funding for the Southwest Florida Feasibility Study (SWFFS) under the Water Resources Development Act (WRDA) in 2000. The SWFFS is related to Everglades Restoration. Both are a collaboration of SFWMD and the U.S. Corps of Engineers, under the Florida Department of Environmental Protection and with the participation of a wide variety of stakeholders.

The purpose of the SWFFS is to restore water quantity, water quality, and habitat for environmental purposes. The process included developing a natural systems hydrologic model so that the impact of project alternatives could be assessed. Figure 32 demonstrates that hydrologic flows are more natural with implementation of Tier 1 and 2 projects. Implementation of the SWFFS would project water resources by re-hydrating the landscape.

CHNEP and SWFRPC prepared an assessment of the SWFFS related to climate change for the 2008 Greater Everglades Ecosystem Restoration conference. Ninety percent of project area is above 120 inches and would not be affected by sea level rise. The remaining projects, even if inundated, would reduce non-climate stresses on the system, protecting water resources.

Overall, the SWFFS improves climate change resiliency by:
• Providing latitudinal and elevational gradients for animal and plant movement;
• Protecting heterogeneity and refugia;
• Accommodating gene flow and connectivity;
• Increasing protective water quality targets;
• Removing invasive species; and
• Restoring freshwater flow regimes.


Figure 32: Comparison of Flows into Estero Bay
(green= natural system flows; blue=resulting flows)

Source: Richard Punnett, ACOE
Coastal Resources

Coastal resources are particularly vulnerable to climate changes. These resources are subject to all the climate change challenges identified through this report plus additional vulnerability to erosion and inundation.

Erosion

According to the Florida Department of Environmental Protection (FDEP), beach erosion threatens the very resource that residents and visitors enjoy. In the Charlotte Harbor region, there are over 40 miles that have been identified for beach erosion. The June 2005 list included of 40 miles total, 34.1 miles of critically eroded beach, 0.5 miles of critically eroded inlet shoreline, 5.5 miles of non-critically eroded beach, and 0.5 miles of non-critically eroded inlet shoreline statewide (FDEP 2006). “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.

Sea level rise and erosion will change coastlines in many ways (EPA 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. Continued sea level rise will exacerbate erosion (Sallenger et al. 2009), reducing the elevation of barrier islands (Sallenger et al. 2009) and affecting coastal transportation infrastructure. Increased overwash and breaching of coastal roads will occur (Sallenger et al. 2006). Low barrier islands will vanish, exposing marshes and estuaries to open-coast; high fetch conditions (Sallenger et al. 2009). The faster the increase in sea level the greater the increase in erosion. Much of the erosion will occur during storm events while the shoreline will return to a different equilibrium condition following the event, typically more inland.

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; NOAA 2008; EPA 2008; SCCP et al. 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.
Inundation

Coastal inundation occurs from three sources: rainfall flooding, tidal flooding, and storm surge. Climate change effects could exacerbate each of these conditions.

Rainfall and Tidal Flooding:

More rainfall is expected to be delivered in the autumn, at the end of the rainy season. Therefore, more rainfall flooding is expected as a result of climate change. Flooding occurs when climate, geology, and hydrology combine to create conditions where water flows outside of its usual course. Floods can be slow or fast rising but generally develop over a period of days. Floods can come in the form of “flash floods,” which usually result from intense storms dropping large amounts of rain within a brief period.

Flood waters can be extremely dangerous. The force of six inches of swiftly moving water can knock people off their feet. The 100-year floodplain has been mapped by the Federal Emergency Management Agency in the 1990s. Data for Lee and Charlotte Counties were updated in the 2000s.

Significant areas on the coast are within the 500 year floodplain. In addition, the coastal areas are subject 100-year flooding with velocity hazard (wave action).

Rainfall flooding is expected to increase because more rain is expected to be delivered at the end of the wet season. In addition, increased frequency of floods are expected to result from rising sea temperatures and from higher base water level stage at coast and in groundwater.

The City of Punta Gorda experiences flooding in streets during high tides (see Figure 33). Flap gates are being installed in late 2009 to address this nuisance.

Figure 33: Flooding at W. Marion Ave. and Berry Road
Source: Mitchell Austin, City of Punta Gorda
Storm Surge:

Climate change is likely to worsen hurricanes, but precise effects are uncertain. 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; NOAA 2008; EPA 2008). Damage will multiply as the effects from more intense hurricanes are added to more severe storm surges and higher sea levels.

From over 20 years ago, SWFWMD lead the state in hurricane preparedness planning. A keystone product of this work is the storm surge map series. The series has helped to guide land use decisions, infrastructure investments and conservation land acquisition. Storm surge estimates were develop in terms of predicted surge levels the Sea, Lake and Overland Surges from Hurricanes (SLOSH) Model is used throughout the Gulf by emergency managers.

The 1990 Charlotte Harbor SLOSH Model has been used for the last 20 years. Its highest surge level is up the Peace River at 31.7 feet. Table 5: Storm Surge Elevations in the Charlotte Harbor region, demonstrates the variation in surge levels depending on landfall location and local geomorphology. It is expected that increased intensity hurricanes and sea level rise will influence storm surge levels and locations.

In the aftermath of Hurricane Charley in 2004, observed and SLOSH model computed storm surge were compared (URS Group, Inc. 2004). Comparison of the observed storm surge hydrographs at Estero Bay, Ft. Myers and Franklin Locks to the SLOSH model calculated storm surge hydrographs showed reasonable results, including the greatest impact of Charley’s storm surge on Estero Island.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sarasota</th>
<th>Charlotte</th>
<th>Lee</th>
<th>Lower SLR</th>
<th>Mod. SLR</th>
<th>Upper SLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS</td>
<td>N/S</td>
<td>3.1’ to 5.7’</td>
<td>4.1’ to 5.6’</td>
<td>+ 0.6’</td>
<td>+ 1.7’</td>
<td>+ 3.8’</td>
</tr>
<tr>
<td>1</td>
<td>5.1’ to 6.3’</td>
<td>4.3’ to 6.6’</td>
<td>4.4’ to 7.4’</td>
<td>+ 0.6’</td>
<td>+ 1.7’</td>
<td>+ 3.8’</td>
</tr>
<tr>
<td>2</td>
<td>8.9’ to 10.1’</td>
<td>8.3’ to 12.3’</td>
<td>7.9’ to 12.4’</td>
<td>+ 0.6’</td>
<td>+ 1.7’</td>
<td>+ 3.8’</td>
</tr>
<tr>
<td>3</td>
<td>11.7’ to 13.2’</td>
<td>11.3’ to 20.0’</td>
<td>11.2’ to 19.5’</td>
<td>+ 0.6’</td>
<td>+ 1.7’</td>
<td>+ 3.8’</td>
</tr>
<tr>
<td>4+</td>
<td>17.5’ to 27.5’</td>
<td>17.2’ to 31.7’</td>
<td>16.5’ to 28.7’</td>
<td>+ 0.6’</td>
<td>+ 1.7’</td>
<td>+ 3.8’</td>
</tr>
</tbody>
</table>

Table 4: Storm Surge Elevations in the Charlotte Harbor Region
Wildlife and Ecosystems

Climate change is predicted to be one of the greatest drivers of ecological change in the coming century. Air temperature, water temperature, air chemistry, water chemistry, rainfall, storms, wildfire, hydrology, sea level, and geomorphology all influence ecosystem structures and wildlife. Therefore, changes in climate can have a profound influence on these systems. 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.

Ecological Zones

Ecological zones, particularly in Florida, are often structured by elevational and latitudinal gradients. As average and extreme temperatures rise, economical zones will tend to expand northward. As sea levels increase, ecological zones will tend to move up-gradient (See Figure 34).

Many factors will confound these natural shifts in ecological zones. Soils have a great bearing on the presence of certain ecological zones. Soil types cannot move quickly if at all. Man-made barriers can halt the movement of ecological zones.

If wetlands plant communities are unable to keep vertical pace with sea level rise they will likely be unable to keep pace with lateral migration upslope (Cahoon et al. 1999) 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 shift from nontidal wetlands directly to open subtidal waters (Titus, Pers. Comm. 2009). This would be mediated by fetch and wave action as well as by the emergent vegetation that is present, since both red mangrove and saltmarsh cordgrass can colonize low energy intertidal zones.

Some ecosystem types are more resilient to climate changes and will have an advantage over others. Mangroves are more adaptable to these changes and are currently expanding at the expense of salt marshes but are not moving for retreating seagrass and unvegetated tidal flat communities (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 up-slope migration is prevented by upland defenses such as seawalls (Estevez 1988; Schleupner 2008).

Geomorphologic changes will influence water table locations and, with them, soil moisture and drainage which are important to habitat structure. For instance, natural pine forests can tolerate lower soil moisture than oak-pine forests (Twilley et al. 2001). In addition upland communities and freshwater wetlands would likely be reduced.

Lower-diversity wetlands will replace high-diversity wetlands in the tidal freshwater reaches of coastal rivers (Van Arman et al. 2005). Major spatial shifts in wetland communities, including invasions of exotic species, will occur (Dahdouh-Guebas et al. 2005). More lowland coastal forests will be lost during the next one to three centuries as tidal wetlands expand across low-lying coastal areas (Castaneda and Putz 2007). Most tidal wetlands in areas with low freshwater and sediment supplies will “drown” where sea level rise outpaces their ability to accrete vertically (Nyman et al. 1993). More than half of the salt marsh, shoals, and mudflats critical to birds and fishes foraging in Florida estuaries could be lost during the 21st century (Glick and Clough 2006). Recreational and commercial fish species that depend on shallow water or intertidal and subtidal plant communities will be at risk (Glick and Clough 2006). The loss of tidal wetlands will result in dangerous losses of the coastal systems that buffer storm impacts (Badola and Hussain 2005).
Figure 34: Conceptual Diagrams of Habitat Migration between 2000 and 2100 in the Charlotte Harbor Region
Habitats

Estuarine Habitat Model: The Sea Level Affecting Marshes Model (SLAMM) was developed with EPA funding in the mid 1980s (Park et al. 1986). 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.

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

The model used the A1B (15” mean and 27.5” maximum sea level rise) 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. The mean scenario is between the lower (7.1”) and intermediate ranges (19.8”) identified earlier in this report.

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%. Hardwood swamps have similar results.

The habitat model Existing tidal flats, including seagrasses, are predicted to be 97-99% eliminated. Mangroves are predicted to thrive under these scenarios increasing by 75-119% provided the sea level rise is gradual. Estuarine open water may increase 46-48%, Appendix 2 details area and percentage changes under this scenario.
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. Since 1950, landward migration has been documented (See Map 14). In addition, seagrass transect sites showed significant increasing trend in water depths from 1999 to 2008 of approximately 1 1/2 inches per decade (Ott 2009). This increased seagrass depth is not expected to continue. 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 to appropriate depths. Though SLAMM assumes nearly total loss of seagrass. 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; EPA 2008).

Mangroves: Sea level change is an important long-term influence on all mangroves (Gilman et al. 2008). Though mangroves are adaptable to climate changes, if sediment surface elevations do not keep pace with sea level rise, significant mangrove losses can occur. In addition, killing storms can eliminate red mangrove forests with loss of sediment as rootlets die.

Salt Marshes: Depending on the rate and extent of local sea level change, mangrove and salt marsh systems will respond differently (Titus and Richman 2005, 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.

Coastal Wetlands: Although Charlotte Harbor region tide ranges are relatively small, tidal effects extend far inland because much coastal land is low in relative elevation. Because sea level change has been relatively

Map 13: Seagrass Migration
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. Estuarine circulation, salinity, and faunal use patterns are already changing with changes in climate and sea level (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 tidal wetlands.
Wildlife

Habitat changes will certainly affect the wildlife that depends on those individual habitat. Additional wildlife impacts are as follows.

**Marine Fauna:** 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).

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 (EPA 2008; Rubinoff et al. 2008; Holman 2008; NOAA 2008).

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 (CSO 2007; Holman 2008; FOCC 2009; EPA 2008).

**Anadromous fish:** Changes to phenology of anadromous fishes and other estuarine fishes will follow changes in fresh flows, tide levels, and timing of river flows (Peterson et al. 2007; EPA 2008). The cycle of spawning, eggs, early larval stages, nursery escape to vegetated wetlands, juvenile movement into seagrass beds, and adult entry to deeper waters or specialized habitats can be disrupted by the patterns of distribution and volumes of freshwater flows into the estuary.

The smalltooth sawfish is a listed anadromous fish. The Small-tooth Sawfish critical habitat area was recently identified by NOAA and the U.S Army Corps of Engineers. Any parcels in this area ‘may require special management considerations or protection due to human and natural impacts to the features, including development, marine construction, and storms.’

**Birds:** 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; EPA 2008).

Increased temperatures will assist in the expansion of the summer range of the magnificent frigate bird in the Charlotte Harbor region. The frigate bird is a food stealer and predator on young chicks. With increased presence there can be an expected increase in food stealing from colonial nesting birds attempting to feed young, resulting in malnutrition or starvation for chicks, and increased direct predation on chicks.

**Insects:** 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; EPA 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.

**Non-native Invasive Species:** The spread of invasive species may involve a gradual pushing out of native species of plants and animals (Holman 2008; FOCC 2009; EPA 2008). By giving introduced species an earlier start, and increasing the magnitude of their growth and recruitment compared with natives, global warming may facilitate a shift to dominance by non-native species, accelerating the homogenization of global animal and plant life (Stachowicz et al. 2002).
This section addresses significant climate change vulnerabilities to the Charlotte Harbor region’s people and environment. It also outlines challenges and opportunities to minimize social, economic, and environmental costs of anticipated effects.

**Summary of Significant Vulnerabilities**

The most significant vulnerabilities facing the Charlotte Harbor region are changes related to drought, flood, hurricane severity, land area, habitats, biological cycles, and uncertainty in environmental models.

**Drought**

A long term decrease in rainfall coupled with a higher percentage of rain delivery in the rainy season (June through September) translates into a greater frequency of severe droughts. Droughts may be caused by increased atmospheric temperatures and rising sea temperatures. For the Charlotte Harbor region, precious cold fronts yield the greatest amount of rain in the dry season. When cold fronts stall before reaching the Charlotte Harbor region, less rain is delivered.

Extended or severe droughts result in a number of problems for man and the environment:
- Agricultural yields are negatively impacted, especially for winter vegetables and other winter crops;
- Public water supplies are strained during the period of greatest demand for water (dry season);
- Minimum Flow and Level (MFL) regulations become more difficult to meet;
- Aquifers receive less water even if total rainfall remains the same. Rainy season saturated soil reduce infiltration;
- Saltwater intrusion increases further reducing aquifer freshwater storage; and
- Drought exacerbates the salinity increases associated with sea level rise and result in decreased oligohaline and mesohaline (lower salinity) estuarine areas.

**Flood**

The other side of greater percentage of rain delivered in the wet season is greater stormwater runoff. When soils are already saturated, water does not have the opportunity to infiltrate into the ground and is carried by waterways into the estuary. Increased wet season flow, increases the duration and extent of hypoxia in the estuary and of harmful algal blooms. Increase in water temperature is an exacerbating factor with both hypoxia and harmful algal blooms.

**Hurricane Severity**

Hurricane severity is one of the vulnerabilities associated with “climate instability.” A 5 to 10% increase in hurricane wind speed due to rising North Atlantic sea surface temperatures is expected. Hurricane Charley made landfall as a category 4 hurricane in the Charlotte Harbor region. With the high wind speeds of Hurricane Charley, trees in upland and wetland forests were lost. Destruction of structures and vehicles resulted in chemicals and building materials in waterways and wetlands. Tributaries and Charlotte Harbor itself became anoxic causing movement of fish. Upstream containment areas released unacceptable levels of pollutants.

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*Figure 37: Portions of the Peace River disappeared with each of the extreme droughts of this decade*
Source: Richard Gant, SWFWMD
Land Area

Land area loss is expected through sea level rise. Since the most vulnerable land has been acquired through significant public investment to acquire conservation land, most of the first land area lost to sea level rise will be that of conservation land. Loss of land area is an example of “Geomorphic Changes.” Land area was lost (probably permanently) at “Charley Pass,” a new break in north Captive Island. This represented a loss of conservation land acquired by the state. Fortunately, because it was state conservation land, private property responses did not occur. One measure of incremental land area loss is through coastal erosion rates. However, the most dramatic losses will probably be the result of storms such as Hurricane Charley’s creation of Charley Pass.

Habitats

Habitats of most concern related to climate change include seagrasses, salt marshes, mangroves, freshwater wetlands, coastal strand, and sandbar/mudflat.

Seagrasses: Seagrasses are living resources which are a measure of estuarine productivity and water quality. As such, CHNEP has developed seagrass targets for habitat and water quality protection and restoration. The SLAMM model suggests a 97-99% loss of seagrasses by 2100. Data between 1950 to 1999 demonstrate a landward migration of seagrasses. Data between 1999 and 2008 suggest increasing depth of seagrass beds.

Salt Marshes: SLAMM suggests a 89-98% loss of salt marshes by 2100. Past filling and drainage practices have left salt marshes in the Charlotte Harbor region more vulnerable to the effects of climate change. Setting proper elevations is an important component of hydrological restoration of salt marsh. Consideration of climate change impacts for acquisition of upland buffers and restoration of existing salt marsh will be critical to maintaining healthy salt marshes.

Mangroves: SLAMM suggests a 75 to 119% increase in mangrove extent. Mangroves have the ability to accrete sediment to maintain its position. In addition, as adjacent wetlands are inundated, mangroves can expand into these areas too. If, as tide gauges suggests, sea level rise rates continue to increase, Existing mangrove positions may be overwashed and replaced by seagrass, sand bar, and mud flat habitats.

Coastal Strands: Coastal Strands are the upland type must vulnerable to erosion and sea level rise. Changes to the coastal energy gradient can also impact the coastal strand location and extent.

Sandbars/Mudflats: Tidal flats including sand bars and mud flats are unvegetated submerged and intertidal systems. These are important habitats in their own right. SLAMM includes tidal flats with seagrasses. If mangroves maintain their position, much tidal flat could be lost.

Biological Cycles

Phenology is the study of periodic plant and animal cycle events and how these are influenced by seasonal and interannual variations in climate. Fish, amphibian, bird and insect populations are dependent on timing of food resource availability. With changes in climate, mismatching of the resources and time that the animals require these resources may occur.

Environmental Models

CHNEP and its partners utilize various environmental models to help make decisions regarding infrastructure investments, land use, conservation, restoration and regulations. Most of these models are validated using existing and past conditions. Given the uncertainties regarding climate change (See Table 1), these models need to be revisited with a range of changes due to possible climate changes. These alternative scenarios would reduce risk, improve resiliency, and avoid costly mistakes.
Challenges and Opportunities

This report has presented many challenges related to our changing climate. The following outlines various opportunities related to significant vulnerabilities outlined above.

Drought: Continued water supply development to meet all demands cannot continue. Water conservation will be critical. Existing per capita reductions in water use are already providing some relief to the public water supply over past predictions of water use. Investments toward water conservation need to have an improved weighting as compared to infrastructure development.

Flood: Excess stormwater is in many ways the result of the past century’s very effective drainage programs. Many areas were over-drained and vastly reduce the amount of water that may be stored in the ground and within wetlands. Where adjacent flooding of developed areas will not be exacerbated, the State of Florida, water management districts, and local governments are plugging old drainage courses to allow the rehydration of the landscape.

Hurricane Severity: Hurricane Charley provided many lessons in the Charlotte Harbor region. Improved building standards, improved hurricane advisories, expansion of hurricane preparedness concerns, using rebuilding to improve communities, using stem-wall construction instead of mound-filling, incorporating water treatment opportunities during reconstruction, and testing methods of forest restoration are all opportunities that are being realized.

Land Area: Loss of land area to sea level rise is a problem for both conservation lands and urban lands on the cost. FEMA requirements have already protected most urban development from near-term sea level rise. These requirements will need to be adjusted to accommodate the typical 75-year life of structures in the Charlotte harbor region. Continued acquisition of land at risk will be important to allow future migration of habitats.

Habitats: Efforts are made to protect and restore seagrasses, salt marshes, mangrove forests, and other systems. As restoration activities occur, it will be important to set elevations so that the restored systems have the opportunities to migrate.

Biological Cycles: Pheneological events of the Charlotte Harbor region have not been measured to a great extent. In order to develop strategies to reduce mismatching for native species, these data will be vital. USGS proposes a citizen monitoring network for pheneological events (CHNEP 2009).

Environmental Models: CHNEP has the opportunity to review most environmental models developed for its region. Appropriate scenarios outlined in Table 1 will be offered to partners to test various futures.

Our Further Efforts

This report is one component of CHNEP’s overall strategy to implement its CCMP priority action SG-Q related to climate change. The following additional resources have been or will be developed.

Comprehensive Climate Change Vulnerability Assessment: SWFRPC completed a comprehensive climate change vulnerability assessment. Though this report was based in this assessment, additional data, analysis, and maps were added here. More information, particularly for the areas of southwest Florida outside of the Charlotte Harbor region can be found in the base assessment. The report can be found at: www.chnep.org/projects/climate/CRE.htm.

Punta Gorda Climate Change Adaptation Plan: Through the EPA's Climate Ready Estuaries (CRE) program, SWFRPC, CHNEP, and the City of Punta Gorda identified significant vulnerabilities for the city and outlined several adaptation options. The report can be found at: www.chnep.org/projects/climate/CRE.htm.

Climate Change Vulnerability Assessment and Adaptation Opportunities for Salt Marsh Types in Southwest Florida: SWFRPC and CHNEP will map the physical extent of the five types of salt marsh and will identify significant potential effects on these salt marsh ecosystems from anticipated climate change.

Environmental Climate Change Indicators: EPA is providing funding to develop 3-5 indicators of climate change in the Charlotte Harbor region.

Model Language: EPA, SWFRPC, CHNEP and local partners will develop model local government comprehensive plan and ordinance language to improve the resiliency of local communities to the effects of climate change.


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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCMP</td>
<td>Comprehensive Conservation and Management Plan</td>
</tr>
<tr>
<td>CHNEP</td>
<td>Charlotte Harbor National Estuary Program</td>
</tr>
<tr>
<td>EPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>SFWMD</td>
<td>South Florida Water Management District</td>
</tr>
<tr>
<td>SLAMM</td>
<td>Sea Level Affecting Marshes Model</td>
</tr>
<tr>
<td>SWFRPC</td>
<td>Southwest Florida Regional Planning Council</td>
</tr>
<tr>
<td>SWFWMD</td>
<td>Southwest Florida Water Management District</td>
</tr>
</tbody>
</table>
 Appendix 1
Climate Change Grouped Vulnerabilities

**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. Sea level rise reduces 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. 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

The Charlotte Harbor National Estuary Program (CHNEP) prioritized the grouped priorities according to perceived ability of implement its Comprehensive Conservation and Management Plan (CCMP). The prioritization is roughly:
   1. Altered Hydrology
   2. Climate Instability
   3. Water Temperature and Chemistry
   4. Habitat and Species Changes
   5. Sea Level Rise
   6. Air Temperature and Chemistry
   7. Geomorphic Changes
   8. Land Use Changes
   9. Human Health
   10. Infrastructure
   11. Human Economy

CHNEP acknowledges that this prioritization will be different for its partners, based on the goals and particular vulnerabilities of each partner..
## Appendix 2

### SLAMM 4.1 Predictions of Habitat Fates under Scenario A1B for Charlotte Harbor

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