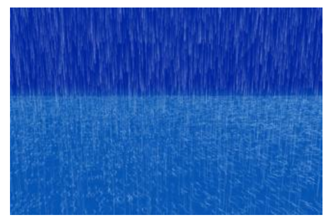
Florida Water Management and Adaptation in the Face of Climate Change

A White Paper on Climate Change and Florida's Water Resources

November 2011





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PURPOSE OF DOCUMENT

The state of Florida will be faced in the coming years with significant challenges and opportunities for managing water in a highly dynamic and changing climate. The impacts of climate change on water resources management will have consequences for the economic sustainability and growth of the state. A strong awareness of climate change impact issues and potential adaptation strategies that could be implemented by the state will increase its resilience over the long-term to uncertain climatic conditions and sea level rise. To that end, a series of white papers have been prepared by State University System (SUS) of Florida Universities to coalesce our understanding of realized and predicted climate change impacts with a focus on various topics. The report presented herein addresses water resources and adaptation issues across the state. The primary objectives of this report are: (1) to identify Florida's water resources and water-related infrastructure that are vulnerable to climate change; (2) show demographics in the state that are vulnerable to climate change impacts with a focus on water resources and sea level rise; and (3) highlight some of the alternative technologies currently being used to solve water resource supply issues in the state that are likely to expand and be challenged under various scenarios of climate change.

Florida is highly vulnerable to climate change as a result of its expansive shoreline, low elevation and highly permeable aquifers, and the location of high population centers and economic investments close to the coastline. Further, the state receives a high frequency of tropical storm landings that are accompanied by tidal surges that compound the risks of sea level rise. Because the state is highly vulnerable compared to other regions globally, Florida's academic, governmental and non-governmental institutions are developing adaptation strategies and conducting research on climate change. In this white paper, we highlight climate change issues relevant to water management, but also recognize the financial challenges to implement adaptation measures to address climate change solutions. Implementing adaptation measures will require an unprecedented level of resource leveraging and coordination among academic, governmental, non-governmental, and private sector entities.

EXECUTIVE SUMMARY

Introduction

Traditional planning by water managers and utilities assumes that hydrologic conditions remain relatively stationary. Under this assumption, historical hydrologic and water use patterns are adequate to design, regulate and manage water supplies, storm water runoff, and wastewater conveyance and treatment systems. As climate change progresses, however, hydrologic systems will be altered due to changes in the water cycle and rising sea levels. These fundamental changes to the water system interject uncertainty about how climate change will impact Florida's hydrologic systems and present significant difficulties for water managers attempting to develop strategies to meet long-term water supply, stormwater and wastewater treatment needs for the state. The uncertainty about how climate change will impact Florida's water resources and its infrastructure creates a challenge for most sectors of Florida's economy. Uncertainty is exacerbated by the strong human imprint on water resources through consumption of fresh water, disposal of wastewater, alterations in land cover, and control of surface water flows. Thus, in addition to climate change, shifts in the economy, demographics, consumer preferences, and attitudes towards the environment add to the uncertainty about future water demand and infrastructure needs.

What will Florida's climate be like in the future?
Because there are so many complex factors that control climate, and scientists do not fully understand their interactions, there is uncertainty about what climate will be like in the future.
However, there is overwhelming scientific evidence that climate is changing at an unprecedented rate.

Florida is expected to experience warmer temperatures, more prolonged droughts, higher precipitation events and more intense storms. All these factors influence water management.

Florida's Water Use

There remain significant uncertainties about the volume of water needed to sustain the state's surface water and groundwater aquifers now and in the future. Florida's surface waters, including major wetland ecosystems, are a significant source of recharge for the aquifers that provide most of the fresh water for residential, industrial, and agricultural uses. Florida's total water withdrawals were approximately 18 billion gallons per day in 2005, 37% from fresh groundwater and surface water sources and 63% from saline water sources. In 2005, the gross per capita water use in Florida was 158 gallons per day. Florida ranks sixth in the nation for groundwater use, using more groundwater than any other state east of the Mississippi. However, it is predicted that by the year 2025, Florida's population will increase by 57% and water consumption 30%. Many areas of the state are currently struggling to find alternative sources of water as supplies of fresh water from relatively inexpensively treated groundwater sources are dwindling because of high usage and inadequate recharge. In fact, each of the water management districts has designated Water Resource Caution Areas that have, or are expected to have, critical water supply problems within 20 years. One of these caution areas is central Florida, which is entirely dependent on groundwater. In this area, it is estimated that demand will exceed the availability of groundwater by 2014 and groundwater flows to wetlands and springs have already been significantly diminished. Demographic changes over time will put further pressure on the central part of the state requiring new water resources and public water supply infrastructure in this caution area.

Where does the water we use at my house come from?

Most likely from the ground. More than 90% of Florida's public water supplies come from aquifers (sand and rock layers that store water).

Climate Change and Water Supply

Long-term water management planning will continue to be severely challenged by the uncertainty of future demands, limited water supplies, and a changing climate. Florida's precipitation patterns are uncertain because they are dependent on large-scale global weather systems as well as being controlled by regional and local weather patterns. Climate variability, which is predicted to become more extreme, has major influences on weather in Florida. Climate oscillations control long periods of extreme drought and higher than normal precipitation through the dry and wet seasons. The responses of these global, regional and local weather patterns to climate change will dictate the amount of water recharge available to replenish Florida's aquifers and surface water sources. Higher temperatures in the state will also increase the loss of freshwater surface sources to the atmosphere (evapotranspiration) and those losses will be enhanced under prolonged droughts. Thus, there is a need to better understand how climate change will affect Florida's water supply now and in the future.

Does Florida have enough water?

Although Florida receives abundant rainfall, there are several factors that limit the availability of fresh water supplies. These include, population growth, overuse of groundwater, and the frequency of prolonged periods with little rain (droughts). The other issue is water storage-it is not possible to store large amounts of water on a flat surface like Florida, so for flood protection it is released to the ocean when it rains.

Sea level rise will reduce the land areas where fresh water can be stored and contaminate coastal aquifers and other freshwater reservoirs (wetlands).

More alternative water supplies will need to be found to keep up with demand and loss of current sources-these can be expensive and require additional energy.

Complicating water supply issues under a changing climate is sea level rise. Rising sea level increases the salinity of surface water and groundwater due to inundation of low-lying coastal land and saltwater intrusion into coastal aquifers. The impact of sea level rise on saltwater intrusion is probably small at present compared to the impacts from pumping and land drainage. However, the impact from sea level rise is likely to become much more significant in the near future, particularly under a rapid sea level rise scenario. Some coastal cities in southeast Florida are already having salinization problems in their public supply wells. In these areas, canals are currently being used to move inland waters to the coast in order to sustain groundwater elevations in coastal aquifers to limit salt water intrusion. As these coastal aquifers are critical to water supplies it is important to understand where the saltwater intrusion front is and how fast it is moving in response to sea level rise and aquifer withdrawals.

As relatively low-cost aquifer sources become depleted, or contaminated with chlorides, water utilities must continue to provide uninterrupted, high-quality water to their customers, and many must also plan for rapidly growing populations. Even in the absence of climate change, Florida's existing fresh groundwater and surface water sources may not be able to meet projected future demand through 2025. The state of Florida, together with the water management districts, has been actively pursuing alternative water supplies, such as reclaimed water and desalination, in order to ensure adequate fresh water supplies for the future. Stormwater capture, artificial recharge, and aquifer storage and recovery represent other potential water sources. Although water conservation does not represent an alternative water source, it is a key component of the state's strategy for meeting future water demand and is being considered side-by-side with the more expensive engineered alternative supply options.

Climate Change and Flooding

In Florida where topographic relief is relatively low, gravity-driven movement of water is challenging. Yet, much of Florida's stormwater is managed through gravity-driven canals. South Florida in particular relies heavily on a gravity-driven canal system in which water managers prevent flooding by discharging stormwater to tide. In low elevation areas of Florida where the flood control infrastructure was established several decades ago, water managers are already challenged by the sea level rise over the past 50 years. Although sea level changes are variable over geological time scales, and sometimes change abruptly on human time scales, sea level over the last 100 years (7.78 inches) has increased at a modest rate of 0.079 inches/yr. If sea level rise rates accelerate significantly, as predicted, and even if

What about Flood Protection?

Climate change with more frequent and intense storms, and sea level rise will limit the functionality of flood protection infrastructure that was built 50 years ago under more "stable" weather and sea levels.

Rising sea level will also limit short-term water storage during high rainfall because groundwater will rise with sea levels.

the slower rates of rise continue, the coastal water infrastructure will be compromised in very low-lying areas of the state in the near future. The problem with sea level rise is that it decreases the water elevation gradient along the canal system, and in so doing reduces the capacity for gravity-driven drainage through the canal network. In addition to these drainage issues from sea level rise, flooding events may occur more frequently due to potential increases in extreme precipitation events. Some of these events are likely to exceed the capacity of the current flood control system in some areas. Furthermore, as sea level rises, groundwater elevations will increase, reducing the storage capacity of the unsaturated soil zone which can temporarily hold a proportion of stormwater runoff. Thus, increases in precipitation intensity and rising sea level will make coastal zones more prone to flooding.

Climate Adaptation and Energy

It is estimated that about 80% of all energy consumed in the United States is used to pump, transport, treat and heat water. In most Florida communities, the water and wastewater plants are the largest power consumers on the grid. Because the state's water supplies are currently not adequate to meet future demand, the need for energy intensive advanced treatment of alternative water supplies will increase utility power demands. Climate change is expected to further increase the energy requirements for water and wastewater utilities in Florida. Alternative water supplies, such as desalination and advanced treatment of wastewater for reuse, are more energy intensive than traditional water treatment. Also, more pumping of water to provide flood protection will be required with sea level rise and greater storm intensities. Power plants will also need more water for cooling as intake water temperatures rise. Thus, water management adaptation to climate change will add to the energy requirements on top of the energy needs that will be needed for cooling as temperatures rise and the warm season expands.

The Human Element of Climate Adaptation

As climate change results in greater weather extremes and shifting weather patterns, utilities and water managers may be forced to make rapid changes in water conservation policies, such as water restrictions. Additionally, interruptions in water supply are conceivable due either to water shortages during extreme droughts or infrastructure damage during extreme storm events. With 57% of Floridians reporting that they worry only a little or not at all about global warming, it is likely that many Floridians may not take water policies related to climate change seriously. Furthermore, in the current period of slow economic growth, it could prove very difficult to gain public support for funding initiatives to upgrade or develop new water supply and flood protection infrastructure. Because the success of climate change adaptation strategies hinges in part on public perceptions and responses, adaptation strategies should explicitly include education measures to inform the public about the need for policy and infrastructure changes.

Florida's coastal population growth will also make the undertaking of climate change adaptation increasingly challenging as more and more people reside, seek job opportunities and retire in coastal vulnerable areas. Over the past thirty years, Florida exhibited the fastest rate of growth in the nation together with Texas, North Carolina, Georgia and California. The 35 coastal counties bore the brunt of the most recent population increase as nearly 1.9 million new residents settled on Florida coasts in the past ten years alone. In 2010, the population of all coastal counties in Florida was approximately 14 million people or 75 percent of the state's total population of approximately 19 million. The inland counties are home to ~5 million and in the past 10 years the rate of growth was faster (24%) than coastal Florida (16%). The majority of the population lives along the coast where the state's water infrastructure is concentrated, but this area is vulnerable to coastal hazards and salinization of aquifers. However, inland migration would create additional challenges, as water resources and infrastructure are limited in central Florida. Changing population demographics are important to climate adaptation because Florida has a high ethnic and culturally diverse

How do People fit in?

Most people in Florida live in coastal cities vulnerable to climate change and sea level rise.

Elderly, diverse and low-income populations need more assistance to respond to hazards which climate change is predicted to cause.

People are likely to move to central Florida under extreme climate change scenarios; water supply infrastructure would need to be established, as this area does not rely heavily on public water supplies.

Education and awareness of the public to the unique vulnerabilities of Florida to climate change will be needed to implement successful adaptation measures to make the state resilient for future generations.

population where communicating risks associated with climate change requires cultural competence and understanding of diverse groups' perspectives, needs, languages, beliefs and norms. Further, Florida has the highest percentage of people aged 65 years and over with 3.2 million people greater than or 65 years old. Elderly populations can have limited mobility and they are susceptible to extreme high temperatures. Another vulnerable population is those from lower-income backgrounds because of their inability to relocate to areas less prone to flooding in the long-term or quickly evacuate during a natural disaster.

Summary and Conclusions

The direct effects of climate change on water resources include increased threats on the sustainability of water supplies, flooding, salt water intrusion in coastal areas and threats to water quality. Most of the state currently relies on groundwater. However, it is clear that groundwater resources are inadequate now to meet future water demand in many parts of the state, and climate change adds to the vulnerability of groundwater supplies and uncertainty of supply and demand. Therefore, developing alternative water supplies is a priority. While a few municipalities and counties are planning to develop new surface water sources, the difficulties of storing water in regions with little topographic relief, porous geology, and shallow water tables, and their environmental impacts limit the viability of developing significant surface water sources. Because of these limitations on traditional surface and groundwater sources, alternative sources such as desalination and reuse will be significant components of Florida's future water supplies. Conservation measures will also become increasingly important in the state's effort to maintain sustainable water supplies.

The current economic reality and other financial challenges in meeting the water needs of Florida, and protecting its infrastructure, in the face of climate change will require an unprecedented level of resource leveraging and coordination among academic, governmental, non-governmental, and private sector entities. There are multiple institutions and organizations that are currently working on sustainable water resource issues and the socio-economic implications of water security, and are capable and prepared to work together to increase the resilience of the state of Florida to the present and future challenges of planning and adapting to climate change.

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ABBREVIATIONS

AMO	Atlantic multi-decadal oscillations
AO	Arctic oscillation
AWWA	American Water Works Association
Bgal/d	Billion gallons per day
CDC	Center for Disease Control
DEP	Department of Environmental Protection
ENSO	El Niño southern oscillation
FAS	Floridian aquifer system
FAU	Florida Atlantic University
FCMP	Florida Coastal Management Program
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FEMA	Federal Emergency Management Agency
IAS	Intermediate aquifer system
IPCC	Intergovernmental Panel on Climate Change
Mgal/d	Million gallons per day
NOAA	National Oceanographic and Atmospheric Administration
NOEP	National Ocean Economics Program
NRC	National Research Council
PDO	Pacific Decadal Oscillation
PWS	Public Water System
SAS	Surficial aquifer system
SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SST	Sea surface temperature
TBRPC	Tampa Bay Regional Planning Council
UF	University of Florida
UF-IFAS	University of Florida Institute of Food and Agricultural Sciences
U.S.	United States
USCCSP	United States Climate Change Science Program
USEPA	United States Environmental Protection Agency
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
USGS DEM	United States Geological Survey Digital Elevation Model

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1.0 GLOBAL WATER CYCLE AND FLORIDA

Global climate change is modifying the global water cycle by shifting the residence times of water in various reservoirs (oceans, ice sheets, glaciers, atmospheric vapor, etc.). It was once considered that water stored in ice sheets and glaciers on earth had a very long residence time, operating on geological time scales, and only became part of the active water cycle over thousands to millions of years. However, recent evidence is showing the potential for climate change to rapidly shorten the residence times of water in ice sheets and glacial ice pools, potentially producing abrupt changes in weather patterns (IPCC, 2007; USCCSP, 2008). These shifts in the water cycle will have profound effects on low-lying coastal areas with an acceleration of the current relatively slow rates of sea level rise (Wanless, 2008). While the melting of ice sheets may be slow, initial melting and indirect effects, such as the lower reflective capacity of an ice-free Arctic and thawing of the permafrost, may set into motion critical feedback systems that will accelerate deglaciation processes and cause more rapid sea level rise. While a large part of current sea level rise is due to ocean warming and thermal expansion, contributions from ice melt and glaciers will be important contributors to future sea level rise (IPCC, 2007; Appendix A).

The transition of ice to water in the global water cycle, as well as the increased moisture capacity of warmer air, puts greater moisture into the atmosphere. Greater moisture content in the lower atmosphere is predicted to increase the frequency and intensity of heavy precipitation events and lead to more flooding in some regions of the world (IPCC, 2007). At the same time, increased temperature and more moisture will increase the probability of stronger tropical storms. While more intense, high-precipitation events are predicted for much of the southeastern US, some areas, including the subtropics in which Florida resides, are predicted to experience more frequent and intense droughts (Bates et. al., 2008). Thus, the state of Florida is likely to be affected by both intense rainfall events and more frequent droughts, leading to the need to consider water management in a highly variable water cycle (Milly et al., 2008; Appendix B). To further add to these challenges, census data predicts future population growth, which means greater demand for water.

Although these are challenges on the horizon, Florida has been on the cutting edge of water management in variable and extreme water availability conditions over the last few decades (Trimble et al., 2006). For example, the South Florida Water Management District has been applying climate and weather forecasting data to make daily decisions on the movement of water for water supply, flood protection and environmental concerns in a system of numerous canals and pumps that support 6 million people (Obeysekera et al., 2011). Further, there exists an excellent relationship between academic and governmental institutions in Florida, and these collaborations are providing the best cutting-edge data, models and other techniques to manage water in the state. Even with a high level of sophistication in water management, it is anticipated that the state of Florida will need an even more comprehensive understanding of the hydrological cycle and the factors that affect water management under climate change. In particular, there is a need to understand how intra- and multi-decadal global climatic oscillations and local processes, such as the sea breeze and local convective water recycling (Appendix B), will respond to climate change and affect Florida water resources. A more complete understanding of these weather drivers and their influence on tropical storm activity, along with rising sea surface temperatures and sea level rise (Appendix A), will be critical for developing water management strategies to protect Florida's population and economy in the face of climate change well into the future.

2.0 WATER MANAGEMENT UNDER CLIMATE CHANGE

It is generally accepted that the water management sector will be significantly influenced by climate change (Jacobson and Tropp, 2010; Craig, 2009). Traditionally, water managers and utilities have assumed that hydrologic conditions remain relatively stationary (Milly et al., 2008; Obeysekera, 2009; Teegavarapu, 2010); therefore, they have relied on historical hydrologic and water use data to regulate and manage water supplies, stormwater runoff, and wastewater conveyance and treatment systems (National Drinking Water Advisory Council, 2010). As climate change progresses, hydrologic systems will be significantly altered due to changing patterns of precipitation and evapotranspiration and rising sea levels. These fundamental changes to the water system interject uncertainty about how climate change will impact Florida's hydrologic systems and present significant difficulties for water managers attempting to develop strategies to meet long-term water supply, stormwater, and wastewater treatment needs for the state. Due to population density, natural resources, and infrastructure across the state each region will have unique challenges with respect to climate change and water resources adaptation strategies. Transportation infrastructure, commercial and agricultural enterprises, and natural resources all strongly depend on both the natural and constructed components of the state's hydrologic systems. Consequently, the uncertainty about how climate change will impact Florida's water resources and water/wastewater infrastructure creates a challenge for most sectors of Florida's economy. Uncertainty is exacerbated by the strong human imprint on water resources through consumption of fresh water, disposal of wastewater, alterations in land cover, and control of surface water flows (Gordon et al., 2005 and Rost et al., 2008). Thus, in addition to climate change, shifts in the economy, demographics, consumer preferences, and attitudes towards the environment add to the uncertainty about future water demand and infrastructure needs (Jacobson and Tropp, 2010). Although challenging, it is imperative to have a long-term view of the potential impacts and adaptation strategies, as hydrological infrastructural changes will take decades to implement.

In the following sections, we synthesize existing data and information about Florida's water resources and water management in order to identify water supplies and infrastructure that are vulnerable to climate change and where appropriate, highlight adaptation strategies and critical research and monitoring needs.

3.0 FLORIDA'S CURRENT WATER USE PATTERNS

There remain significant uncertainties about the volume of water needed to sustain the state's surface water and groundwater aquifers now and in the future. Florida's surface waters, including major wetland ecosystems, are a significant source of recharge for the aquifers that provide most of the fresh water for residential, industrial, and agricultural uses; however, as sea levels rise, these will likely become threatened due to the encroachment of seawater. Already, large withdrawals of groundwater for public supply in southeast Florida are causing salt water intrusion into freshwater aquifers. Long-term water management planning will continue to be severely challenged by the uncertainty of future demands, the sustainability of water supplies, a changing climate, sea level rise and potentially major shifts in demographics to areas with modest potential to meet the necessary water demands (Section 10.0).

The most recent estimates of Florida's water use are based on data from the joint USGS and FDEP Florida Water-Use Program from 2005 (Marella, 2009). This program surveys water withdrawals across Florida every five years to provide rough estimates of human water demand; however, the next state-wide water use inventory is not expected to be available until 2014. Using the available data, Florida total water withdrawals were approximately 18 billion gallons per day (Bgal/day) in 2005 (Fig. 3.1; Marella, 2009). Based on these data, the withdrawals from groundwater and surface water sources accounted for 37% of the total, while saline water withdrawals accounted for the other 63%. Nearly all of the saline water withdrawals were used for cooling power plants (Marella, 2009). For several decades the largest withdrawals of fresh water in Florida were for agricultural irrigation. However, in recent years a number of factors such as declining irrigated acres, improved water conservation techniques, and long-term watering restrictions led to a decrease in withdrawals for agricultural irrigation. At the same time, population growth led to a steady increase in public water supply withdrawals. Public water supply withdrawals are expected to eclipse those for agriculture within the next few years (Fig. 3.2; FDEP, 2010a).

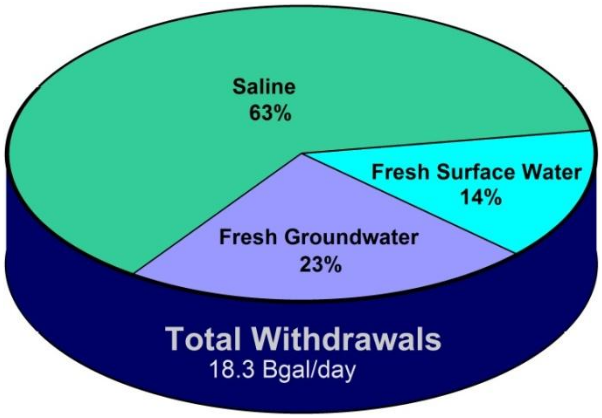

Figure 3.1. Total 2005 state-wide fresh and saline water withdrawals in billions of gallons per day (Bgal/day) (Marella, 2009).

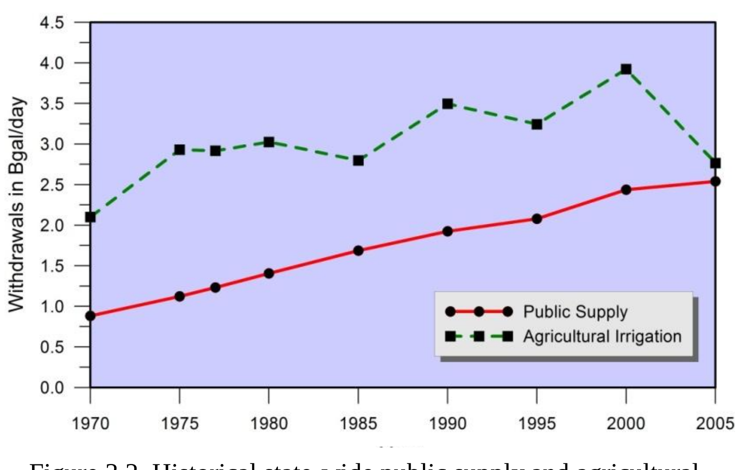

Figure 3.2. Historical state-wide public supply and agricultural irrigation withdrawals. Data from USGS Florida Water Science Center, website accessed 9/25/2011.

In 2005, the gross per capita water use in Florida was 158 gal/d, slightly less than the national average of 172 gal/d. In terms of groundwater withdrawals, Florida ranks sixth in the nation and uses more groundwater than any other state east of the Mississippi. Not surprisingly, water withdrawals are concentrated in areas with the highest population density, with 50% of the state's freshwater withdrawals coming from the region operated by the South Florida Water Management District (Fig. 3.3). Since 1980, there has been a decline in per capita water use that has been primarily attributed to water conservation efforts (Marella, 2009). It is predicted that by the year 2025, Florida's population will increase by 57%. However, water consumption is expected to increase by approximately 30% during this same time period (FDEP, 2010a). Thus, population growth is expected to put significant pressure on Florida's water resources while per capita water use is declining. Therefore, future water supply planning is an imperative both with and without the impact of climate change.

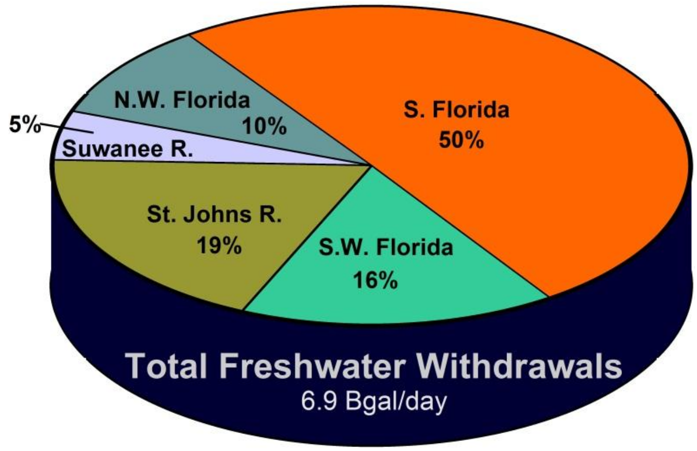

Figure 3.3. State-wide 2005 freshwater withdrawals and proportion of freshwater withdrawals by water management district. Data are from the most recent USGS-FDEP water use compilation (Marella, 2009).

4.0 FLORIDA'S CURRENT WATER SUPPLIES

Florida has three primary sources of water including groundwater, a few surface water bodies, and the ocean. In 2005, almost 90% of Florida's population (16.2 million people) obtained their drinking water from groundwater aquifers, including the surficial aquifer system (SAS), the intermediate aquifer system (IAS), and the Floridan aquifer system (FAS) (Copeland et al., 2009, Marella, 2009) (Fig. 4.1).

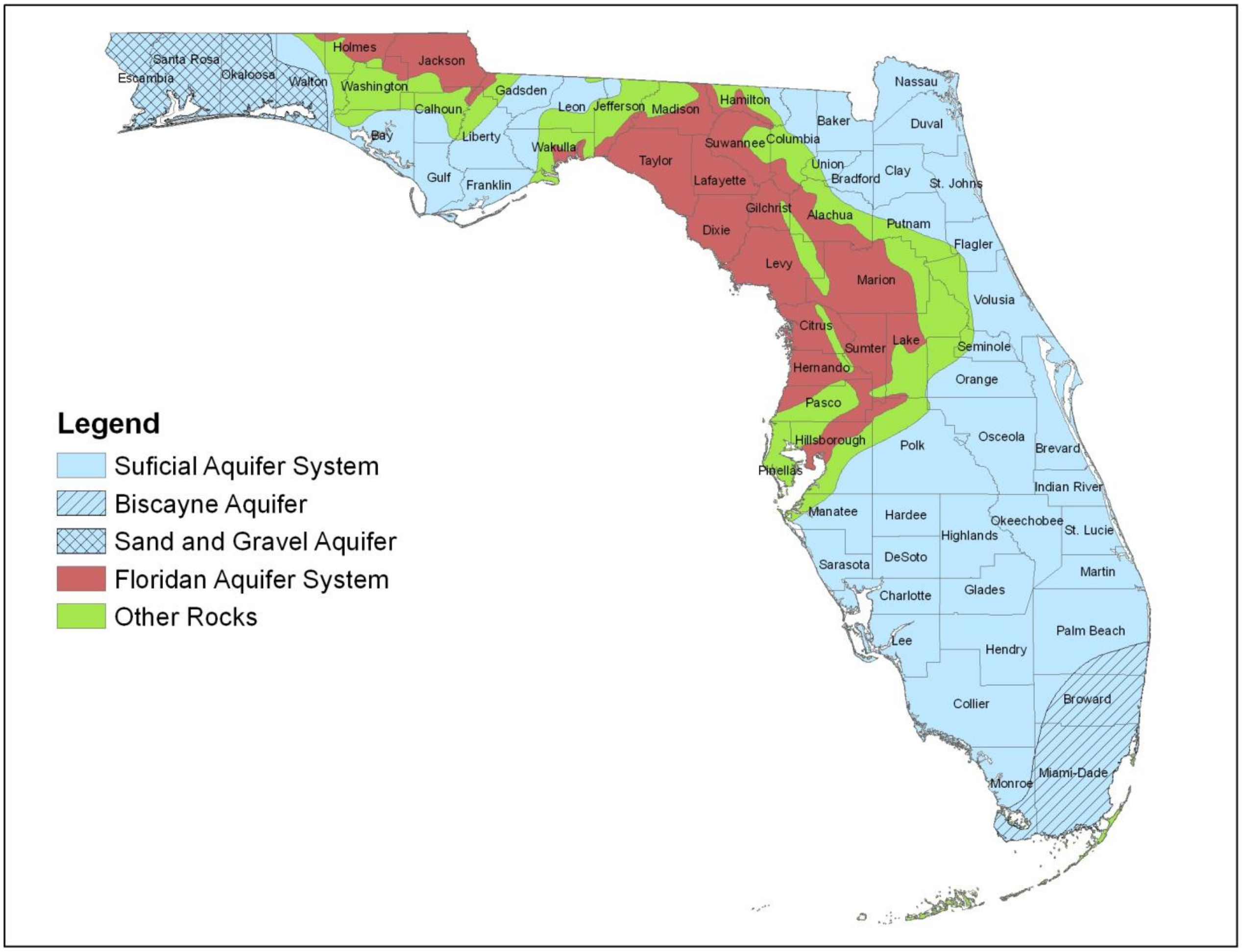

Figure 4.1. Map showing principle aquifers as they occur at the land surface. The intermediate aquifer system (IAS) is beneath the other aquifers and thus does not appear on the map. The Floridan Aquifer System (FAS) is also beneath other aquifers except where shown the map. Modified from USGS data file aquip_oct03.shp.

4.1 Aquifer systems and groundwater sources

The surficial aquifer system (SAS) includes the Biscayne aquifer and the sand and gravel aquifer (Fig. 4.1). The sand and gravel aquifer is limited to the westernmost panhandle of Florida, while the Biscayne aquifer underlies approximately 4,000 square miles of southeastern Florida (Miller, 1990). In most other areas of the state, the sediments of the SAS are thin and discontinuous. Thus, the SAS in these areas is typically only used for domestic wells, and most of the fresh water withdrawals come from other aquifer systems (Copeland et al., 2009). In 2005, 19.5% (829 Mgal/d) and 12.5% (532 Mgal/d) of the state's groundwater withdrawals came from the Biscayne and sand and gravel aquifers, respectively (Marella, 2009). The sand and gravel aquifer yields moderate volumes of water and is the primary source of drinking water for

Santa Rosa and Escambia counties (Miller, 1990). The Biscayne aquifer (Fig. 4.1) is the principal source of potable water for all of Miami-Dade and Broward Counties and the southeastern part of Palm Beach County (Fig. 4.2).

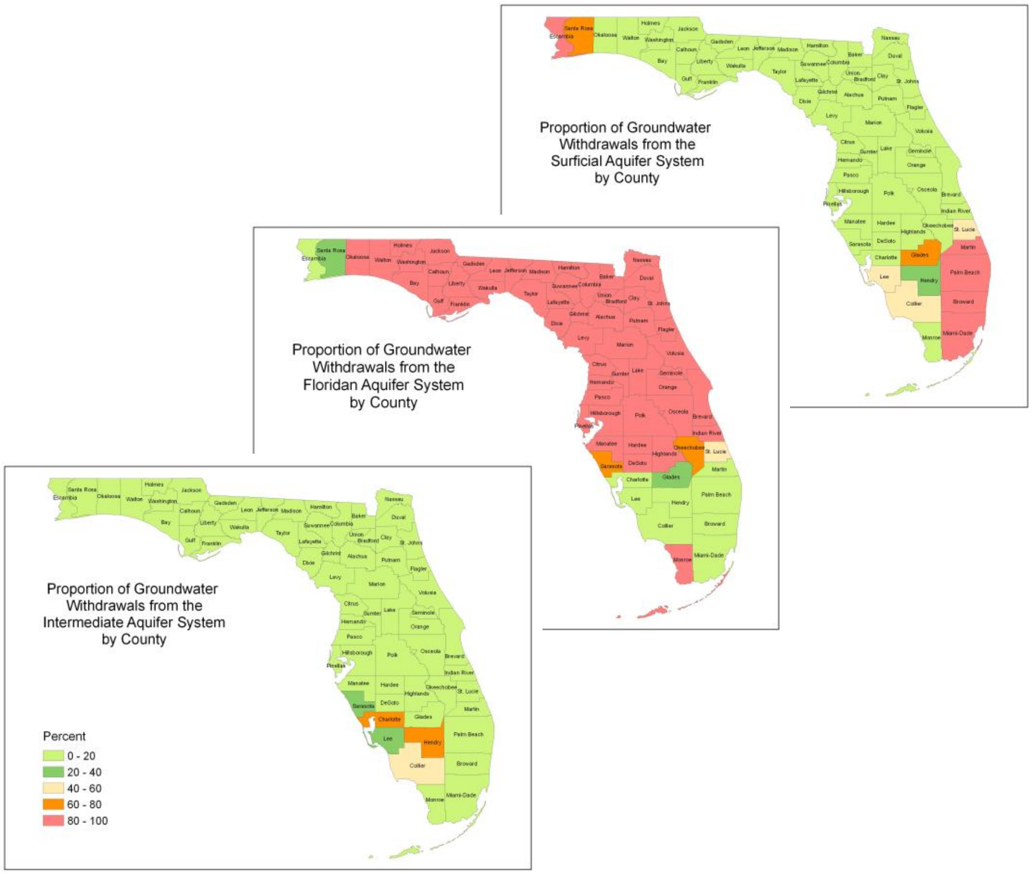

Figure 4.2. Proportion of groundwater withdrawals from principle aquifers by county, 2000. Data from Copeland et al. (2009).

Although the sediments that comprise the IAS are present over much of the state, in many areas those sediments are not permeable enough to yield water to supply wells. Because the IAS is not extensively used, its characteristics are not well known. At present, the only significant use of the IAS for water supply is in southwestern Florida (Fig. 4.2) (Copeland et al., 2009).

The FAS underlies a large region of the southeastern United States and supplies water to several large cities. It is present beneath all of Florida and is the most widely used source of groundwater in the state (Fig. 4.2). In 2005, nearly 60% (2,527 Mgal/d) of the state's groundwater withdrawals came from the Floridan aquifer (Marella, 2009). South of Lake Okeechobee, water in the FAS is brackish, and therefore it has not historically been used for water supply purposes in south Florida (Copeland et al., 2009); however, some of this saltwater is withdrawn for cooling purposes and some converted to freshwater through desalinization. Desalinization of the water from the Floridan is one of the water supplies to the Florida Keys, which have no other source of freshwater except that which is imported from their Florida City plant via pipeline (Miller, 1990).

4.2 Surface water sources

Approximately 38% of Florida's freshwater supplies come from surface water sources including, rivers, lakes, and canal systems. The majority of fresh surface water withdrawals (56%) are used for agricultural irrigation and power generation accounts for another 20%. Not surprisingly, fresh surface water withdrawals are greatest in the counties with significant agricultural land use including Glades, Hendry, Collier, Lee and Palm Beach. Only about 10% of Florida's residents obtain their drinking water from surface water sources. The Hillsborough River in Hillsborough County, Deer Point Lake in Bay County, and Clear Lake in Palm Beach County are among the most significant surface water sources of public supply water in the State (Marella, 2009).

4.3 Alternative water sources

Although most of Florida has historically obtained fresh water from the state's aquifers, reliance on a single source of water diminishes these sources and decreases the resilience of the state's water supplies. Many areas of the state are currently struggling to find alternative sources of water as supplies of fresh water from relatively inexpensively treated groundwater sources are dwindling with high usage. In fact, each of the water management districts has designated Water Resource Caution Areas that have, or are expected to have, critical water supply problems within 20 years (FDEP, 2011). One of these caution areas is central Florida, which is entirely dependent on groundwater. In this area, it is estimated that demand will exceed the availability of groundwater by 2014 and groundwater flows to wetlands and springs have already been significantly diminished (FDEP, 2010a). The state is already addressing water supply issues through increasing and diversifying the state's water supply sources. To this end, the state legislature recently funded the Water Protection and Sustainability Program (FDEP, 2010b). Of the funded projects, 63% were reclaimed-water projects and 22% were brackish water desalinization projects. Reclaimed and desalinized water are likely the future for Florida. Even today, Florida currently uses more reclaimed water than any other state (663 Mgal/d or 43% of wastewater) and leads the country in desalination with more than twice the desalination capacity of California, a state with the second highest capacity in the country (FDEP, 2010b; NRC, 2008). Currently, brackish groundwater and surface water are the largest sources for desalination facilities in Florida, and relatively few facilities use ocean water (FDEP, 2010b). FDEP estimates that by 2025, Florida will need to increase the amount of water available for consumptive use in the state by about 2 Bgal/d. The water management districts estimate that they will only be able to supply about 38% of this additional needed supply through their currently planned alternative water supply projects (FDEP, 2010a).

This review of existing information about Florida's current water supplies and water use trends demonstrates that the state already has challenges meeting the water supply needs of its citizens. It is anticipated that climate change will further elevate the importance of developing alternative sources of water and water conservation programs.

5.0 CLIMATE CHANGE IMPACTS ON FLORIDA'S WATER RESOURCES

5.1 INTRODUCTION

Building on the preceding overview of Florida's water resources, the following section discusses some of the most significant climate change impacts on water resources. Climate change will significantly influence water demand and supply throughout the state, and sea level rise will also impact freshwater sources and stormwater management in coastal regions. It is predicted that a changing climate in Florida will cause more frequent and potentially more severe droughts in response to global climate changes (Appendix B). Also, rising temperatures will increase evapotranspiration rates that could simultaneously reduce supplies and enhance demands on water resources. Traditionally, water management has been based on predictable principles because precipitation patterns, albeit variable, have been predictable within known historical boundaries. Further, while growing, the state's population centers have been relatively stationary. Under stable climate conditions, historical water demand has been a robust tool for predicting future demand. However, the ability to manage water with climate change requires new thinking and a new approach where known location and amounts of water demands may be more uncertain. Although with climate change water will have to be managed with greater uncertainty than present, current understanding and modeling tools enable anticipation of changing supply and demands, as well as identification some of the major future problems and evaluation of various adaptation strategies.

5.2 CLIMATE CHANGE AND WATER DEMAND

Demand for water is highly dependent on temperature and precipitation (Karl et al., 2009; USGCRP, 2001). Florida has distinct seasonal precipitation patternsthat influence water use requirements. For example, fresh water withdrawals are largely related to supplemental needs of the agricultural sector during the dry season (Marella, 2009). Florida's historical water use data demonstrate that past droughts have caused significant fluctuations in water demand for agricultural irrigation (Fig. 5.1; Marella, 2004; Verdi et al., 2006; Marella, 2009). Therefore, if climate change causes precipitation in Florida to decline or increases the frequencies of droughts, water demand for agricultural, recreational, and lawn irrigation will increase. This will lead to more competition amongst sectors (e.g., energy, agriculture, public) for limited water resources. Compounding this problem is the likely demographic shift from large coastal populations vulnerable to flooding (Section 10.0) from sea level rise inland to central Florida where water supplies are more limited.

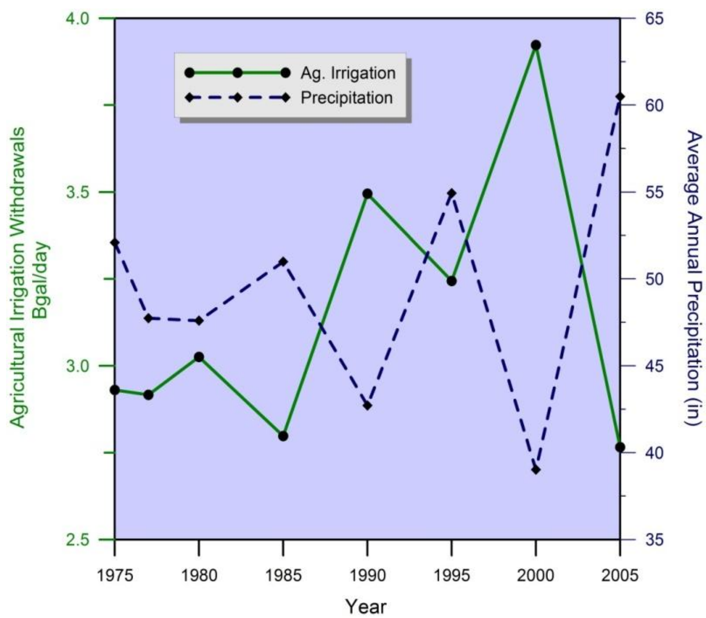

Figure 5.1. Agricultural irrigation withdrawals (USGS Florida Water Science Center) and average annual precipitation from 16 stations across the state (Southeast Regional Climate Center).

5.3 Climate change and water supply

SALTWATER INTRUSION

Rising sea level increases the salinity of both surface water and groundwater due to inundation of low lying coastal areas and saltwater intrusion into coastal aquifers. Although groundwater pumping is currently the primary cause of saltwater intrusion along the coasts, sea level rise and declining water tables also lead to significant saltwater intrusion. The impact of sea level rise on saltwater intrusion is probably small at present compared to the impacts from pumping and land drainage. However, the impact from sea level rise is likely to become much more significant in the near future, particularly under a rapid sea level rise change scenario (Appendix A).

Cities located along Florida's coasts are experiencing more frequent water shortages as public water supply wells are becoming contaminated with chlorides. In the case of south Florida, saltwater is moving inland toward the Biscayne aquifer. This aquifer is the primary source of water for Miami-Dade and Broward Counties and most of Palm Beach County (Fig. 4.2). The freshwater Everglades currently provides a significant amount of recharge for the Biscayne aquifer. As rising sea level submerges low-lying portions of the Everglades, parts of the aquifer may become saline. On the other hand, during droughts, some cities currently obtain a portion of their water from upper freshwater sections of rivers. If sea level rise pushes higher salinity water upstream, the existing water intakes might draw on this higher salinity water during dry periods. The same canal system used for flood control is also relied upon for mitigation of saltwater intrusion. Properly placed control structures prevent the inland migration of seawater in canals. There is fresh water on the inland side of the structures; whereas, waters on the ocean side are tidal and brackish. As sea level rise progresses, the capacity of these canals to move freshwater to coastal areas and the effectiveness of the control structures will be diminished affecting both freshwater supply and flood protection.

Some coastal cities in southeast Florida are already having salinization problems in their drinking water. For example, Hallandale Beach has already abandoned six of its eight drinking water wells because of saltwater intrusion. Groundwater with elevated chlorides is now reaching Miami International Airport and wellfields near cities such as, Dania Beach, Lantana, Lake Worth, and Fort Lauderdale. Other wells in south Miami-Dade, including those that serve

Florida City, the Florida Keys, and Homestead are at risk because they are close to the saltwater intrusion line (Heimlich et al., 2009).

The severity of saltwater intrusion is largely related to the expected rate of sea level rise over the next 100 years. Three rates of sea level rise, resulting in 3.5 to 34.7 inches (9 to 88 cm) total rise by the year 2100, are presented in Table 5.1. As a case study, a numerical model, representative of the hydrogeologic conditions in Broward County, was developed to evaluate the movement of the 250 mg/L chloride concentration line (isochlor) under each of these sea level rise scenarios presented in Langevin and Dausman (2005; Table 5.1). This line is important as 250 mg/L chloride is the maximum chloride concentration recommended by the National Drinking Water Regulations of the Environmental Protection Agency. The Biscayne aquifer that is east of the modeled 250 mg/L isochlor (Fig. 5.2) is predicted to be significantly impacted by saltwater intrusion by the year 2100.

Table 5.1. Modeled migration of the salt water front by the year 2100 with varying rates of sea level rise (from Langevin and Dausman, 2005).

Rate Classification	**Sea level rise rate in mm/yr (in)**	**Total Sea Level rise in cm (in)**	**250 mg/L chloride isochlor moved inland in m (feet)**
Slow rises	0.9 (0.035)	9 (3.54)	40 (131.2)
Moderate rises	4.8 (0.19)	48 (18.9)	740 (2427.8)
Fast rises	8.8 (0.35)	88 (34.65)	1800 (5905.5)

Broward County supply wells that are likely to be impacted by saltwater intrusion with a sea level rise between three and four feet were identified by combining the results in Table 5.1 with modeled inundation of low lying areas and capture zones for supply wells. In order to simplify the model, groundwater flow was assumed to be horizontal, and the complex vertical interactions between the tidal canal network and the aquifer were neglected. Because of these simplifying assumptions, this model provides only a rough estimate of the magnitude of saltwater intrusion. However, more robust models have not yet been developed. The results indicate that with a sea level rise between three and four feet, up to 50 supply wells in Broward County could be affected by salt water intrusion (Fig. 5.3). Collectively, these wells provide water to about 250,000 people. While this analysis was conducted for only one county, this type of modeling and analysis is critical in order to ascertain the impacts of sea level rise on southeast Florida's water supply wells.

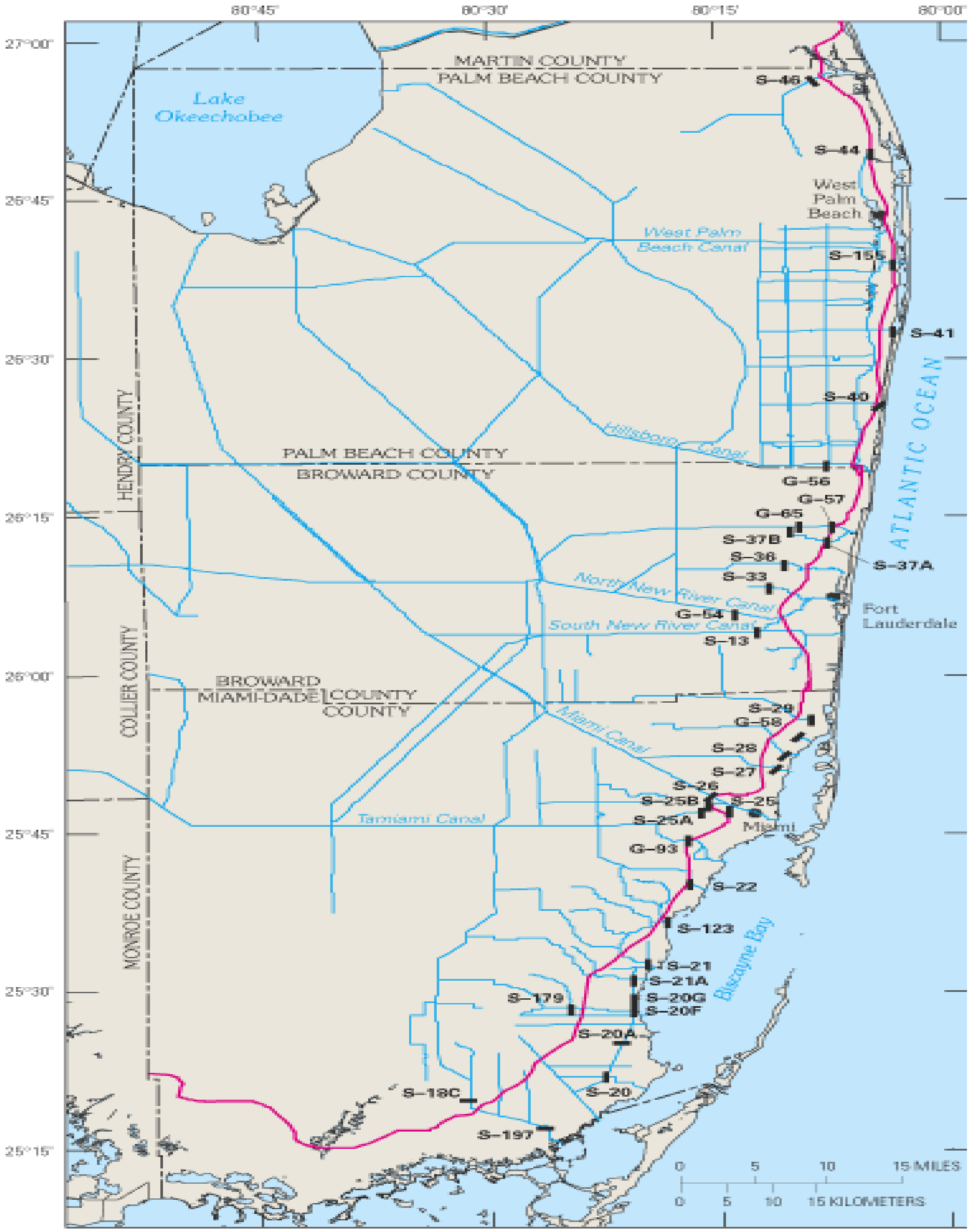

Figure 5.2. Approximate position of the saltwater interface given by the 250 mg/L isochlor for Broward County (Renken, 2005).

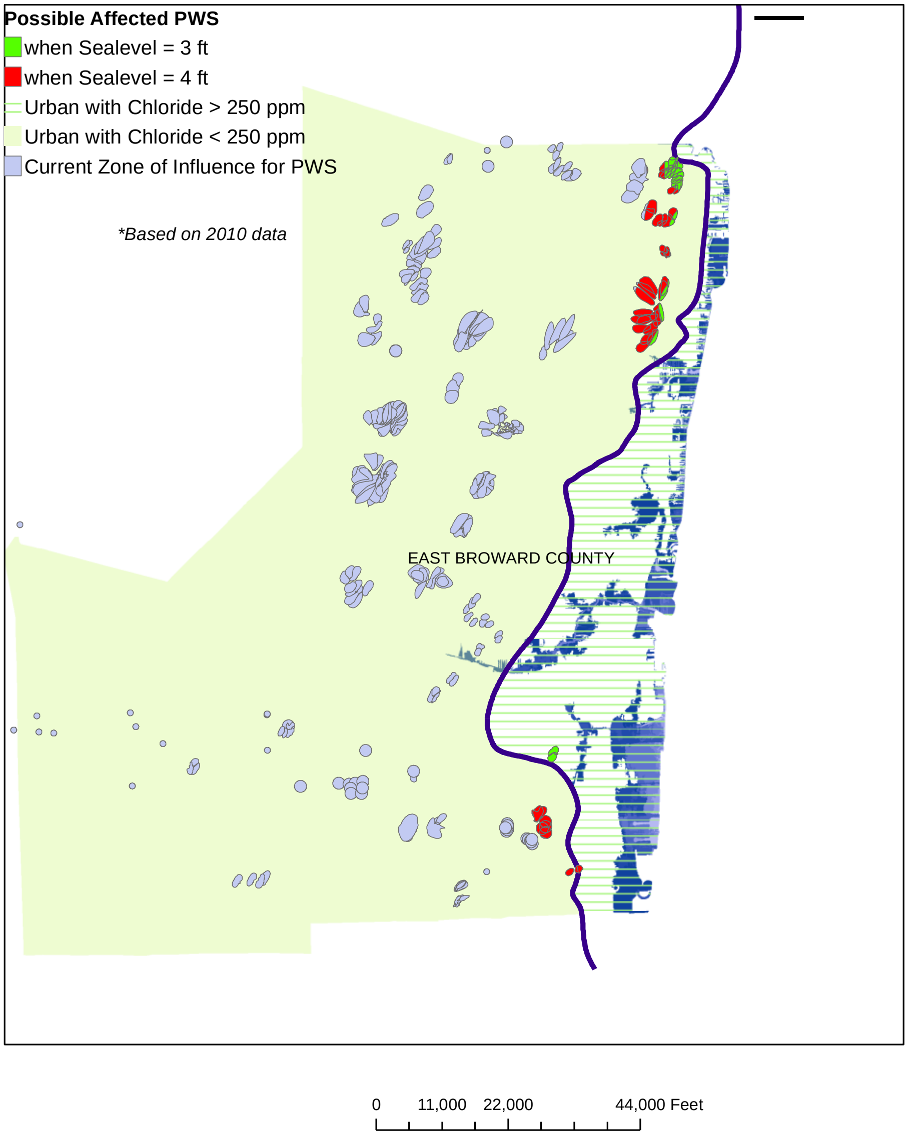

Figure 5.3. The saltwater intrusion line from Broward in 2009 with the capture zones for public supply wells. (Capture Zone data source: Source Water Assessment and Protection Program website, Florida DEP).

5.4 ALTERNATIVE WATER SUPPLIES

As low-cost aquifer sources are depleted or contaminated with chlorides, water utilities must continue to provide uninterrupted, high-quality water to their customers, and many must also plan for rapidly growing populations (Section 10.0). During the past decade there have been regulatory and water policy requirements to develop non-traditional sources of water supplies. Even in the absence of climate change, Florida's existing fresh groundwater and surface water sources will not be able to meet projected future demand through 2025 (FDEP, 2010b). The state of Florida, together with the water management districts, has been actively pursuing alternative water supplies, such as reclaimed water and desalination in order to ensure adequate fresh water supplies for the future. Stormwater capture, artificial recharge, and aquifer storage and recovery represent other potential water sources. Although water conservation does not represent an alternative water source, it is a key component of the state's strategy for meeting future water demand and is being considered side-by-side with more expensive engineered alternative supply options (FDEP, 2010b).

RECLAIMED WATER

Treating and reusing wastewater is an effective way to minimize disposal of wastewater and decrease the use of treated potable water. Over the past two decades, reclaimed water use has grown rapidly in Florida. The state's reuse capacity has expanded from 362 Mgal/d in 1986 to 1,562 Mgal/d in 2010 (Fig. 5.4). Reclaimed water use is a major component of the state's overall sustainable water supply strategy with an estimated $1.3 billion in construction planned for new reclaimed water projects (FDEP, 2011). Most reclaimed water in Florida is used for irrigating residential areas, golf courses, parks, athletic fields, and agricultural feed crops that are not used for human consumption (Martinez and Clark, 2009).

Potable water supply systems draw from sources that are constantly available and are designed to supply water 24 hours a day year round. However, the source for reclaimed water is only available as it is delivered to the treatment plant, typically in pulses after periods of high water use. Therefore, reclaimed water is not always available in the system to meet demand. Conversely, there are times when supply exceeds demand, and treatment plants must

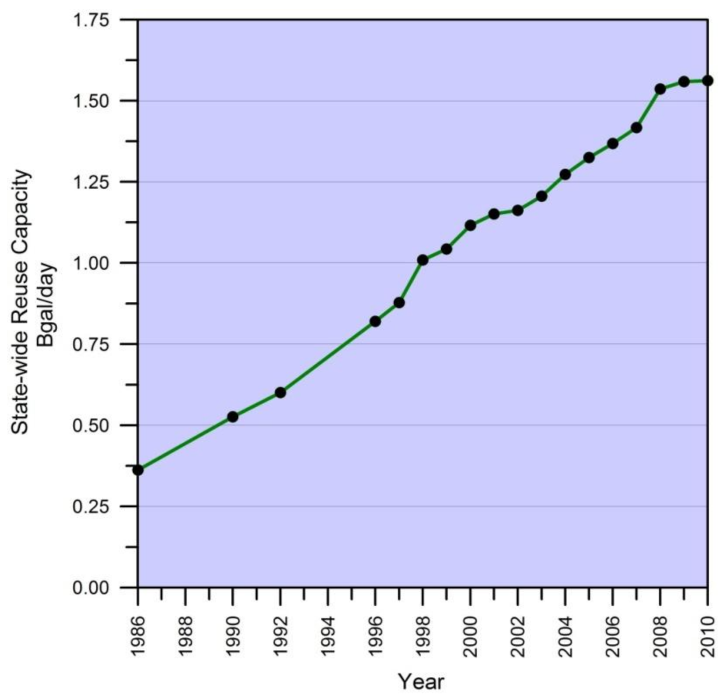

Figure 5.4. Historical trends in state-wide reuse capacity. Data from FDEP, 2011.

either store water to meet future demand or discharge it by other means (Sisler, 2004).

Because reclaimed water is primarily used for irrigation, sea level rise and the associated rise in groundwater levels, will likely decrease demand for reclaimed water in low lying coastal areas that will be inundated or subjected to frequent flooding. In more inland areas, increases in temperature and changes in precipitation patterns will change both demand for irrigation water and the timing and magnitude of wastewater arriving at reclaimed water plants. Therefore, climate change might make it even more challenging for reclaimed water facilities to balance supply and demand. Planning for future reclaimed water projects should consider these impacts of climate change.

DESALINATION

Ocean water and brackish groundwater are capable of supplying a significant portion of Florida's freshwater needs using desalination technology even during prolonged droughts. Florida's existing desalination infrastructure is concentrated in the densely populated regions near the coast (Fig. 5.5). In these areas, saltwater has begun to intrude into aquifers so alternative sources must be found. In this case, it is more cost effective to desalinate brackish groundwater than to transport fresh water from inland sources. As the cost of traditional water supplies increases, and the cost of desalination technology decreases, Florida is expected to continue to increase its desalination capacity (FDEP, 2010b).

Although desalination is, and will continue to be, a significant source of Florida's public water supply, it has drawbacks like any technology. The desalination process is more energy intensive, and thus generates more greenhouse gas emissions than traditional water treatment technologies. Also, the desalination process produces a residual of concentrated salts that must be disposed of in a manner that minimizes environmental damage and is feasible with all site-specific logistic issues and regulations.

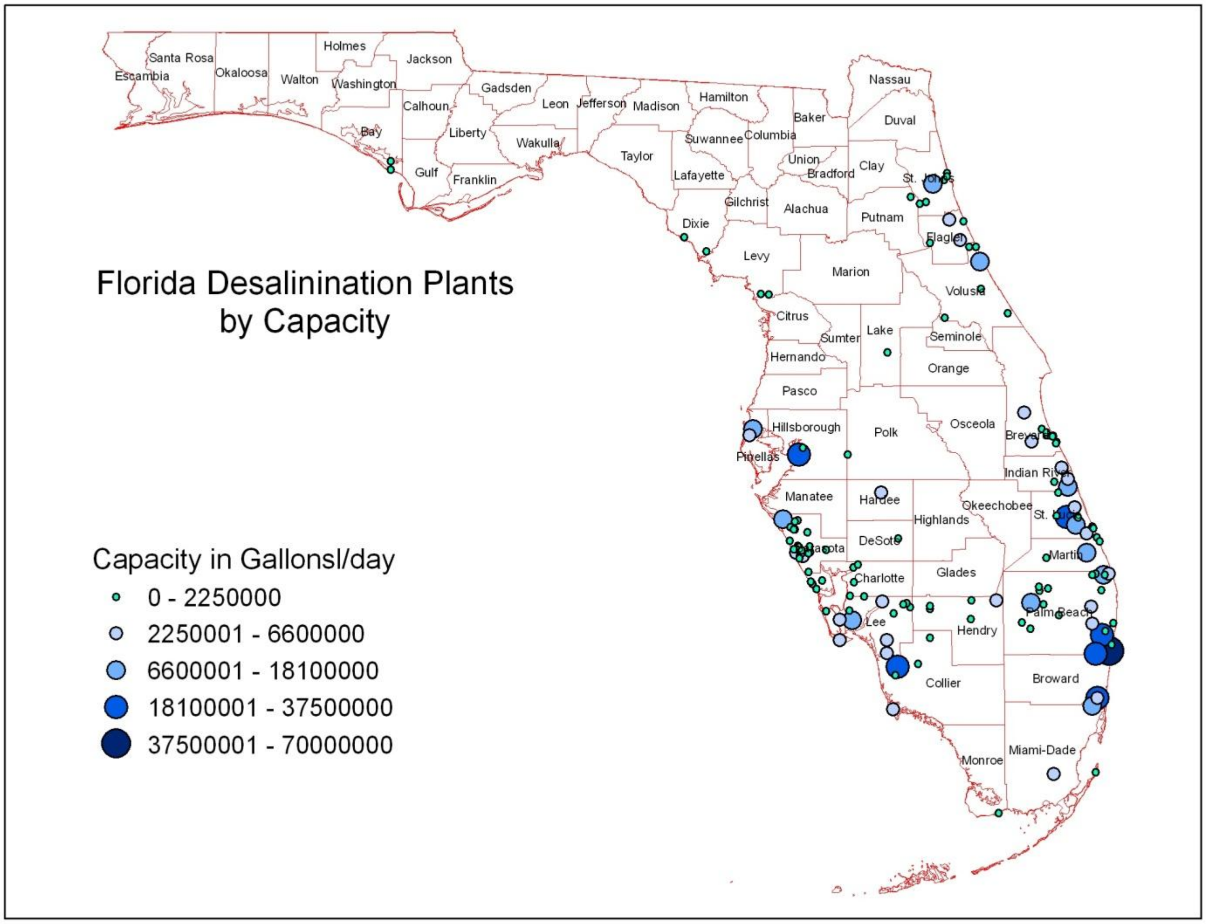

Figure 5.5. Location of desalination plants in Florida and their capacity in gallons per day (gal/d) as of 2008. Data: (FDEP, 2010b).

As sea level rises and ocean water infiltrates into coastal aquifers, the salinity of the brackish groundwater, which is currently the source for most of Florida's desalination facilities, will increase. The salinity of feedwater for facilities drawing seawater from estuaries is also likely to increase with sea level rise. As an example, the existing seawater desalination plant in Tampa draws its feedwater from Tampa Bay, which has lower salinities (5 – 32 parts per thousand [ppt]) than open ocean water (35 ppt) (FDEP, 2010b). Both the capital and annual operational costs of seawater desalination are significantly greater for higher salinity feedwater. Generally, desalinating ocean water costs 50% more than desalinating brackish water (NRC, 2008). Increased feedwater salinity will also lead to more concentrated residual wastes. The salinity of the residual from ocean water desalination can be 2.5 times that of seawater (NRC, 2008). Thus, the increases in salinity due to sea level rise will result in significantly more concentrated desalination residuals that have greater potential to change the salinity of receiving waters and are more expensive to manage.

The changes in groundwater and surface water levels and flows that result from climate change could potentially influence the way desalination plants manage residual disposal. The primary methods of managing desalination residual in Florida are deep well injection, land application, discharge to sanitary sewers, and discharge to surface water (Fig. 5.6) (FDEP, 2010b). The increased flooding that is expected to occur with climate change could make land application infeasible in low lying areas. Sea level rise diminishes the capacity of the existing gravity-driven sewage systems; therefore, discharges to sanitary sewers might also become impractical in some areas. These two concentrate management methods, which are the most vulnerable to sea level rise, currently account for more than 40% of desalination concentrate discharges in the state (Fig. 5.6).

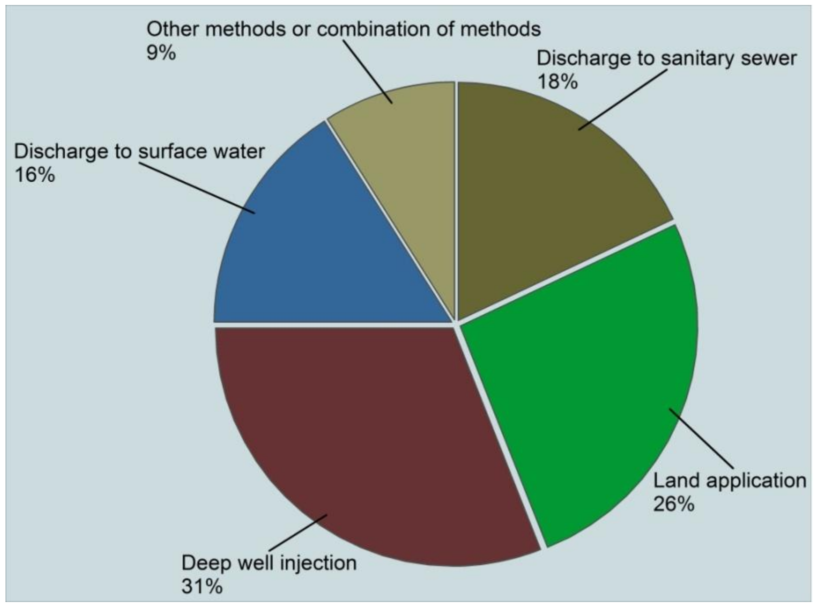

Figure 5.6. Desalination concentrate management methods in Florida and the percent of permitted discharges by category (modified from FDEP, 2010b).

OTHER ALTERNATIVE WATER SUPPLIES

Because 55% of Florida's annual precipitation falls during the four months of the rainy season (Fernald and Purdum, 1998), storing water from the rainy season in surface reservoirs is an attractive option (Borisova et al., 2010). Indeed, some of Florida's future water supplies will likely come from surface water sources, such as the St. John's River (SJRWMD, 2009), or newly constructed reservoirs. However, worldwide, the viability of storing water in surface reservoirs is being questioned due to a variety of factors including, ecological damage, loss of land area and high cost. Therefore, storing water underground during wet periods and extracting it for use during times of drought and/or high demand is growing in popularity (NRC, 2008), and such aquifer storage and recovery strategies are a component of Florida's water supply plans. Stormwater impoundments are another potential alternative water supply that is used primarily for agricultural irrigation (Shukla and Jaber, 2010).

In the future, new surface water projects, aquifer storage and recovery, and stormwater capture will be significant water sources in some local areas in Florida. However, collectively these strategies are anticipated to provide less than 20% of the total planned alternative water supplies in the state (FDEP, 2010a). The state's capacity for surface water storage and stormwater capture is limited because large portions of the state are relatively flat, have very permeable geology, and a shallow water table, all of which disfavor surface water storage. As sea level rises, groundwater levels near the coast will also rise, further decreasing the thickness of the unsaturated ground available for surface water storage. Additionally, higher temperatures and the anticipated decrease in precipitation over the Florida peninsula will likely lead to high evaporative losses from surface water reservoirs. The climate change impacts on aquifer storage and recovery projects will likely be minimal. However, aquifer storage and recovery projects in Florida are facing other challenges, including significant water quality concerns primarily caused by the injected water reacting with aquifer rocks.

6.0 SEA LEVEL RISE AND FLOOD CONTROL

In Florida where topographic relief is relatively low (Fig. 6.1) gravity-driven movement of water is challenging. Yet, because moving water by other means is expensive and poses new engineering challenges, much of Florida's stormwater is managed through gravity-driven canals. South Florida relies very heavily on a gravity-driven canal system that water managers use to prevent flooding by discharging stormwater to tide. In low elevation areas of Florida where the flood control infrastructure was established several decades ago, water managers are already challenged by the sea level rise over the past 50 years. These challenges are becoming more acute and will in the near and far future become increasingly more problematic depending on sea

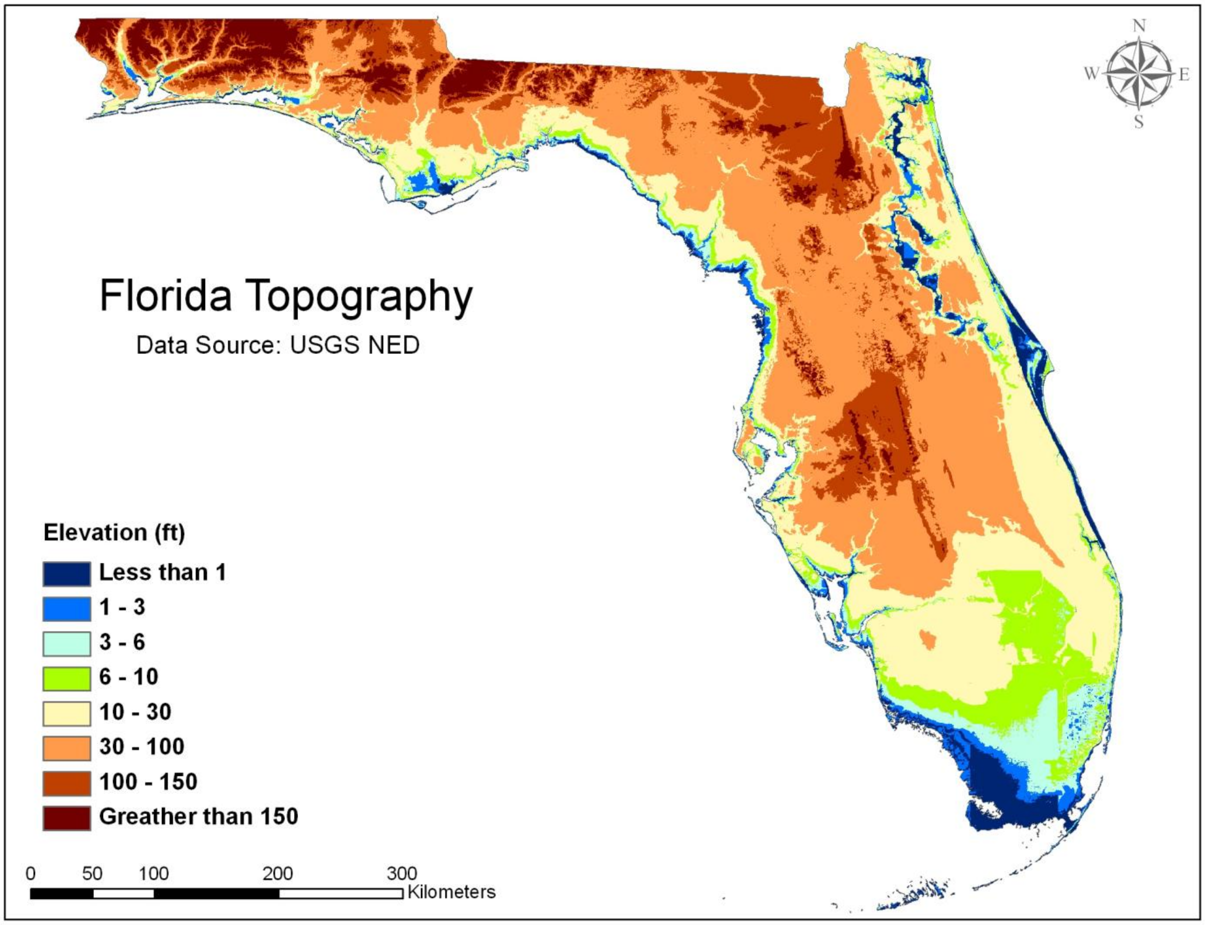

Figure 6.1. Florida's topography illustrating the low-lying areas all along the coastline; the lowest elevations are in the southern part of the state (USGS National Elevation Data Set; 1 arc-second ~30 m resolution).

level rise. Sea level rise has been occurring over the last 100 years (7.78 inches) at a modest rate of 0.079 inches/yr (~2 mm/yr). If sea level rise rates accelerate, as predicted (Appendix A), and even if the slower rates continue, the water management infrastructure will continue to be progressively compromised. Thus, it is important to evaluate the specific issues that will be the most important to address with climate change and begin making water management more resilient (Heimlich et al., 2009).

Inundation of low-lying areas due to sea level rise is a major concern. Additionally, sea level rise will decrease the water elevation gradient along the canal system that will reduce the capacity for gravity-driven drainage through the canal network. This will diminish the capacity of the canal system to move water toward the coast. In addition to these drainage issues from sea level rise and climate change, it is also predicted that flooding events will increase due to increased precipitation events (Appendix A). These events are likely to exceed the capacity of the current flood control system in some areas. Furthermore, groundwater elevations will increase with sea levels, reducing the storage capacity of the unsaturated soil zone (Fig. 6.2). Thus, increased precipitation intensity and rising sea level will make coastal zones more prone to flooding through both direct increases in ocean levels at high tide and a reduction in storage capacity for stormwater (Fig. 6.2).

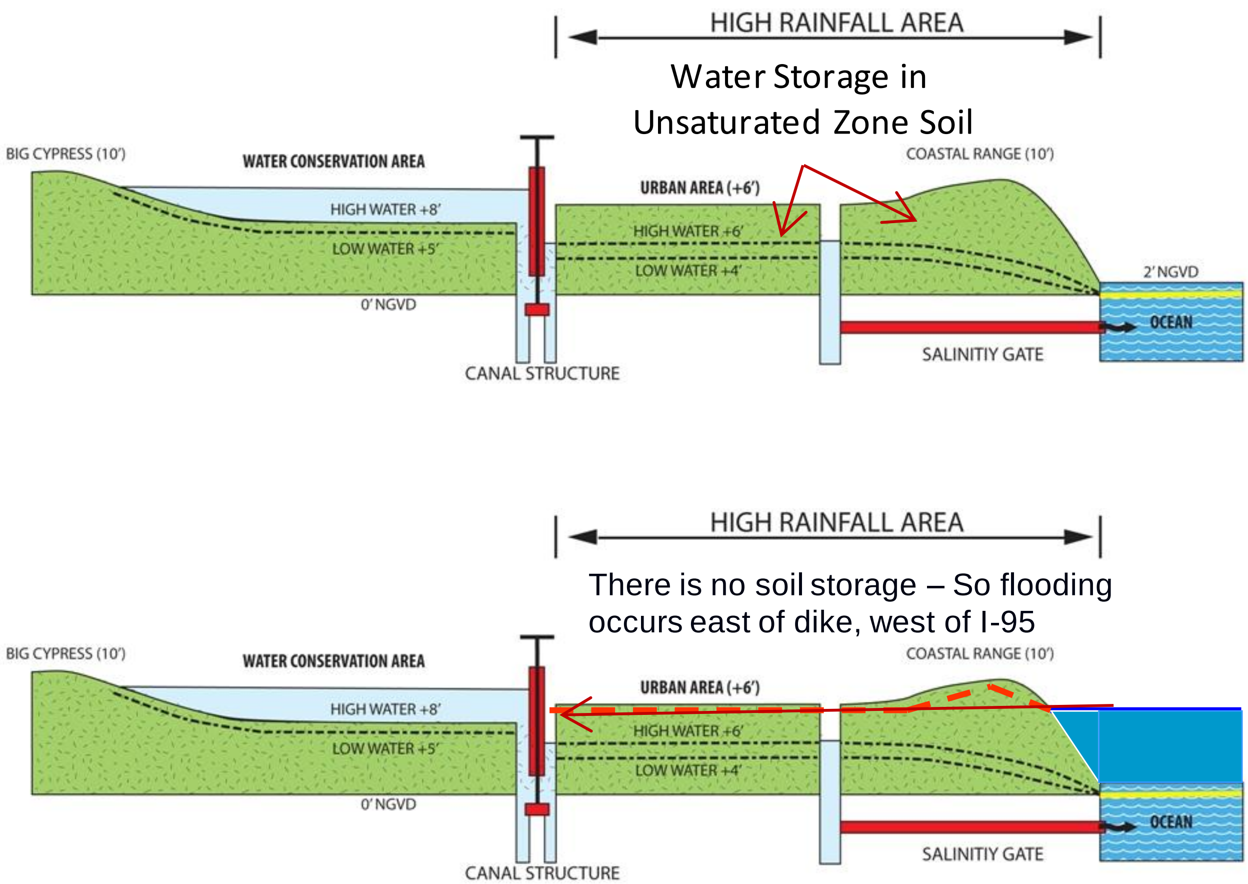

Figure 6.2. Illustration depicting the water storage capacity of the soil with low sea levels (upper panel) in comparison to high sea levels where this seawater rise raises the groundwater levels to the point where the unsaturated soil zone can no long serve as water storage during high rainfall events (Heimlich et al., 2009).

7.0 CLIMATE CHANGE AND WATER QUALITY

In addition to desalination concentrate and storage-recovery effects on water quality, sea level rise will result in an encroachment of seawater into low-lying coastal areas through surface or groundwater and create major water quality problems in some areas. For example, with only a ½ foot of sea level rise, the South Dade sewage and wastewater treatment facility and south Dade landfills would be threatened as they are sited at very low elevation (Fig. 7.1a,b). The flooding scenarios worsen when examined using a 1 and 3 foot rise (Fig. 7.1c,d). In fact, at 3 feet the

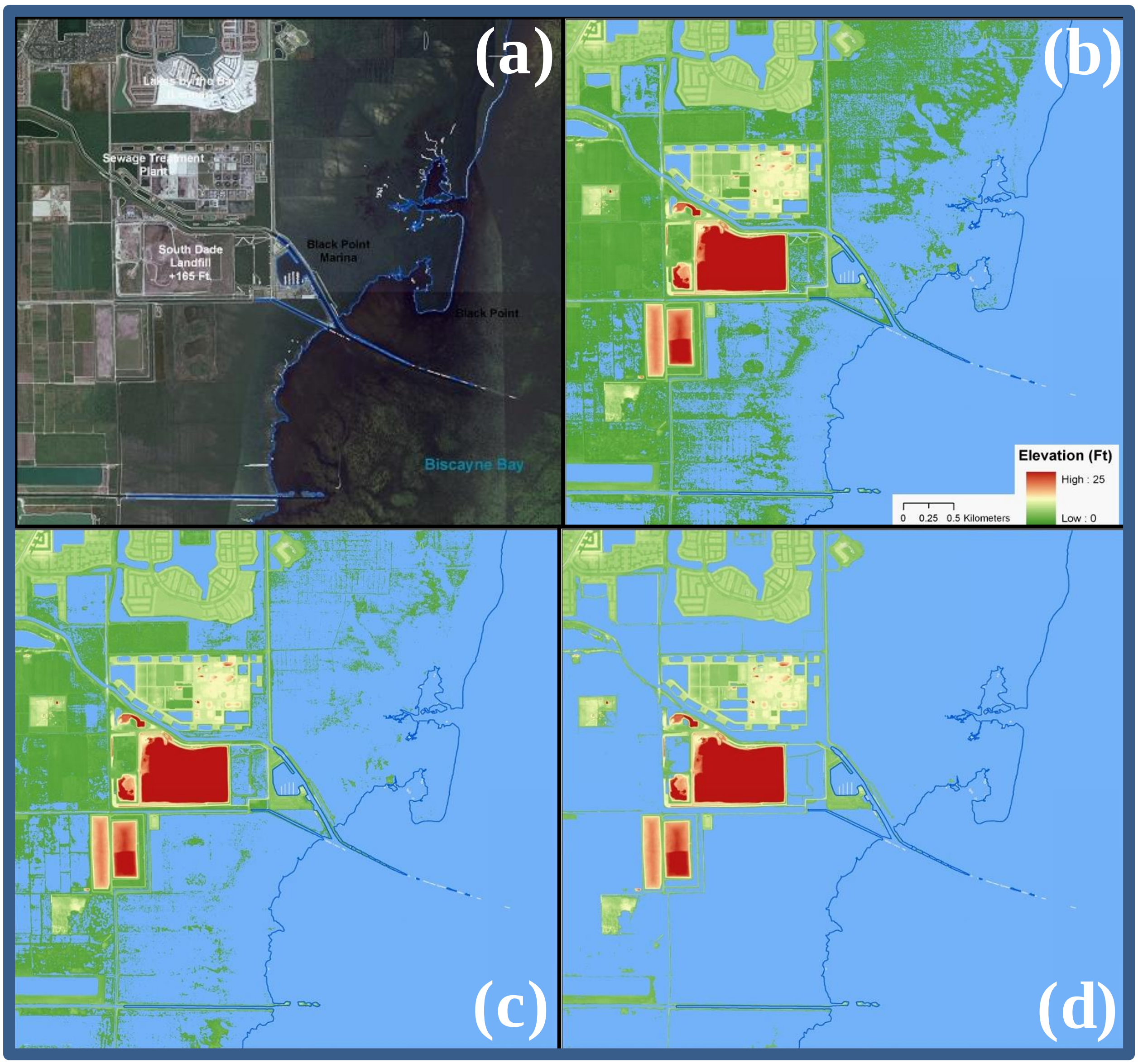

Figure 7.1. Vulnerable infrastructure with implications for creating large water quality problems with sea level rise. An aerial photo of the South Dade Landfills and Sewage Treatment Plant near Black Point on the west side of Biscayne Bay (Florida Dept. of Transportation). Topography was determined using LiDAR-derived maps which are adjusted to the local tidal prism and show mean higher high water inundation at future levels of 0.5, 1, and 3 foot.

landfills become islands (Fig. 7.1d). Inundation of waste disposal sites such as this will release contaminants to both surface and groundwater. The wastewater treatment facility includes injection wells used to pump partially treated water to the boulder zone of the Floridan Aquifer hundreds of feet below the land surface; inundation will likely compromise these wells and create significant challenges for wastewater disposal. In order to understand the vulnerability of water resources infrastructure in low-lying regions of Florida at a scale relevant to adaptation and for planning purposes, highly accurate elevation maps, such as these created with lasar technology and hydrodynamic models (Fig. 7.1), are clearly needed.

Water quality impacts of climate change will require utilities to use more advanced treatment to deal with increased pollutant loads and higher salinities in source water near the coasts. Increased flooding and groundwater levels, more intense storms, and shifts in water temperature will change the behavior of contaminants. Therefore, it is likely that the type and distribution of contaminants in source waters will change. Utilities will need to adjust to changing source water quality and treat for an evolving suite of contaminants. Utilities also need to prepare for pulses of contaminants as a result of extreme precipitation events (Appendix A). Regulatory agencies will need an adaptive approach as guidelines might become obsolete as a result of climate change induced impacts on water quality.

8.0 ENERGY COSTS OF WATER MANAGEMENT

Restructured water management systems in the future should be designed to minimize new energy requirements. This is critical as water utilities have a high energy footprint. In fact, the U.S. Environmental Protection Agency estimated that about 80% of all energy consumed in the United States is used to pump, transport, treat and heat water (Grumbles, 2007). In most Florida communities, the water and wastewater plants are the largest power consumers on the grid. Most of this energy is used to pump raw water, distribute treated potable water, and convey wastewater to treatment plants (Bloetscher and Simons, 2008). Because the state’s water supplies are currently not adequate to meet future demand, the need for energy intensive advanced treatment of alternative water supplies will increase utility power demands. Climate change is expected to further increase the energy requirements for water and wastewater utilities in Florida. Alternative water supplies, such as desalination and advanced treatment of wastewater for reuse, are more energy intensive than traditional water treatment. Also, more pumping of water to provide flood protection will be required with greater storm intensities and lack of water storage as groundwater rises.

A specific example can be found in the relationship between energy for desalinization and salinity of source water. The energy usage for reverse osmosis desalination of brackish water is approximately 0.5 to 3 kwh m^{-3}, whereas for seawater, the typical energy use is about 3-7 kwh m^{-3} (NRC, 2008). Therefore, sea level rise will increase the energy required to desalinate groundwater near the coast and estuarine water. The relationships between sea level rise, salinity, energy use, greenhouse gas emissions, and climate change will create a positive feedback system (Fig. 8.1). These feedbacks underscore the importance of considering interactions in future water management planning.

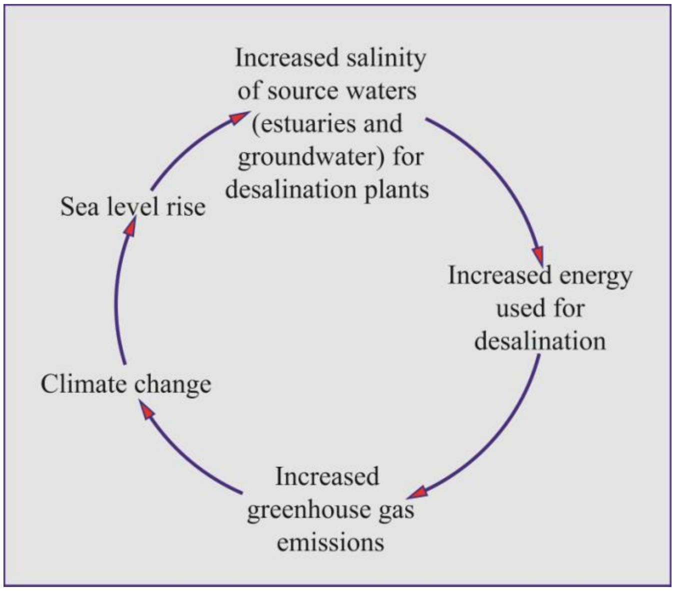

Figure 8.1. A positive feedback system between alternative water sources, energy usage and generation of greenhouse gas emissions.

Further, power demands for greater air conditioning will be needed due to increased temperatures, and power plants themselves will require more cooling water in a hotter climate (Karl et al., 2009; National Assessment Synthesis Team, 2010). TetraTech (2010) estimated that increased power generation alone will increase cooling water withdrawals by approximately 8 and 13% by 2030 and 2050, respectively. However, these needs might be met by greater use of seawater where possible. Another problem is that to meet new power demands the state will need to add power generating facilities and/or enhance its power grid capability, particularly high voltage lines, if they plan to import energy supplies. At present, the power grid infrastructure across the state will not be adequate for movement of large amounts of new power.

9.0 WATER POLICIES AND REGULATIONS

9.1 POLICIES IN A CHANGING CLIMATE

Just as predictions of future water demand have traditionally been based on historical climate and water use trends, water resources policies and regulations are grounded in pre-existing hydrologic, climatic, and ecological stable conditions (National Drinking Water Advisory Council, 2010). Some policies that might require revisions include consumptive use permitting, source water protection programs, and water quality standards. As natural systems adjust to climate change, assumptions about precipitation, runoff, groundwater levels, storm frequency, etc. will likely no longer be valid, even though they are at the core of Florida's water policies and regulations. Thus, climate change has the potential to make current rules that are tied to stream flows, water levels, water temperature, or water quality, not completely amenable to new conditions. Water policies and regulations will need to be assessed along with the physical infrastructure for water management in the future.

9.2 PUBLIC PERCEPTIONS AND SUPPORT

The interactions between climate change, sustainability of water resources, water management policies, and the public are complex and the feedbacks between these elements are not well characterized and are rarely considered in analyses (NRC, 2010). However, public support will be essential to the success of climate change water supply adaptation strategies. The importance of the public's role in the sustainability of Florida's water resources is exemplified by the fact that public water supply will soon represent the greatest demand for water in the state. Water conservation by reducing residential and commercial water use is a significant component of the state's water supply strategy. For this effort, and to develop new water resources, residents will be asked to fund the development of alternative water supply infrastructure through taxes, levies, and/or increased water rates.

Water shortages and climate change are forcing managers to shift from traditional strategies of managing supply to meet demand to managing demand itself (NRC, 2010). As climate change results in greater weather extremes and shifting weather patterns, utilities and water managers may be forced to make rapid changes in water conservation policies, such as water restrictions and water pricing structure. Taste, odor, and color of public water supplies are likely to change as the quality of source water changes and utilities switch to different water sources and/or shift to different treatment technologies (AWWA, 2007). Additionally, interruptions in water supply are conceivable due to water shortages during extreme droughts or infrastructure damage during extreme storm events. Rapid policy changes, especially when combined with changing aesthetics of public water supplies and potential interruptions in service, have the potential to erode public confidence in policy makers. With 57% of Floridians reporting that they worry only a little or not at all about global warming (Leiserowitz and Broad, 2008), it is likely that many Floridians will not take water policies related to climate change seriously. Furthermore, it could prove very difficult to gain public support for funding initiatives to upgrade or develop new water supply infrastructure in the current period of slow economic growth. Because the success of climate change adaptation strategies hinges in part on public perceptions and response, adaptation strategies should explicitly include education measures to inform the public about the need for policy and infrastructure changes.

10.0 CLIMATE CHANGE AND FLORIDA'S POPULATION

Florida's coastal population growth will make the undertaking of climate change adaptation increasingly challenging as more and more people reside, seek job opportunities and retire in areas potentially vulnerable to an increased risk of inundation, shore erosion, saltwater intrusion into freshwater aquifers, intense tropical cyclones and related storm surge damage. This section identifies vulnerable populations relative to climate change projections for Florida and related water management issues. Using census data from 1980 through 2010, present population distributions and past population trends across the state are examined[1].

[1] The Florida Coastal Management Program (FCMP) established with the Florida Coastal Management Act of 1978 (Chapter 380, F.S., Part II, Coastal Planning and Management) considers the entire state of Florida as being part of the coastal zone due to its extended coastline, low-lying topography, shallow depths to coastal aquifers and numerous rivers and canals reaching the coastal zone. In fact, no area in Florida is more than 75 miles away from the coastline which "makes it difficult to establish a boundary that would exclude inland areas" (FDEP, 2011: 7). According to Section 380.23(3)(c) (F.S.), the thirty five counties adjacent to the coastline and their adjoining territorial waters are considered "coastal" for purposes of planning and resource protection (FDEP, 2011).

10.1 FLORIDA POPULATION GROWTH TRENDS

Over the past thirty years, Florida exhibited the fastest rate of growth in the nation (Crossett et al., 2004). Since 1980, its total population has increased by more than nine million people, representing a 92.9 percent change over a 30-year period. This unprecedented population growth is primarily due to migration of people who are retiring or seeking job opportunities (Crossett et al., 2004; Franklin, 2003). According to the U.S. Census Bureau recently released data, Florida remains among the fastest growing coastal states together with Texas, North Carolina, Georgia and California. In the past 10 years, the population percent change in all four states, except California, exceeded two times the national average of 9.7 percent (U.S. Bureau of the Census, 2010 County QuickFacts). The 35 coastal counties bore the brunt of the most recent population increase as nearly 1.9 million new residents settled on Florida coasts in the past ten years alone (Table 10.1) making these areas more vulnerable to coastal hazards with climate change. In addition, 84 percent of the state's population currently lives in urbanized areas compared to only 54% in 1960, which are primarily coastal cities making coastal counties vulnerable to coastal hazards (Fig. 10.1).

Table 10.1. Overview of population change in Florida by region and by decade, 1980 to 2010

	Year	Florida	Coastal	Inland	Atlantic	Gulf
Population	2010	18,801,310	14,194,603	4,882,194	8,461,141	5,733,462
	2000	15,982,824	12,286,141	3,936,135	7,449,032	4,837,109
	1990	12,938,071	10,066,343	3,064,221	6,074,688	3,991,655
	1980	9,746,961	7,664,138	2,231,478	4,692,638	2,971,500
Percent change	2000 to 2010	17.6	15.5	24.0	13.6	18.5
	1990 to 2000	23.5	22.1	28.5	22.6	21.2
	1980 to 1990	32.7	31.3	37.3	29.5	34.3
Absolute change	2000 to 2010	2,818,486	1,908,462	946,059	1,012,109	896,353
	1990 to 2000	3,044,753	2,219,798	871,914	1,374,344	845,454
	1980 to 1990	3,191,110	2,402,205	832,743	1,382,050	1,020,155

Data Source: U.S. Bureau of the Census: 1980, 1990, 2000 and 2010 censuses

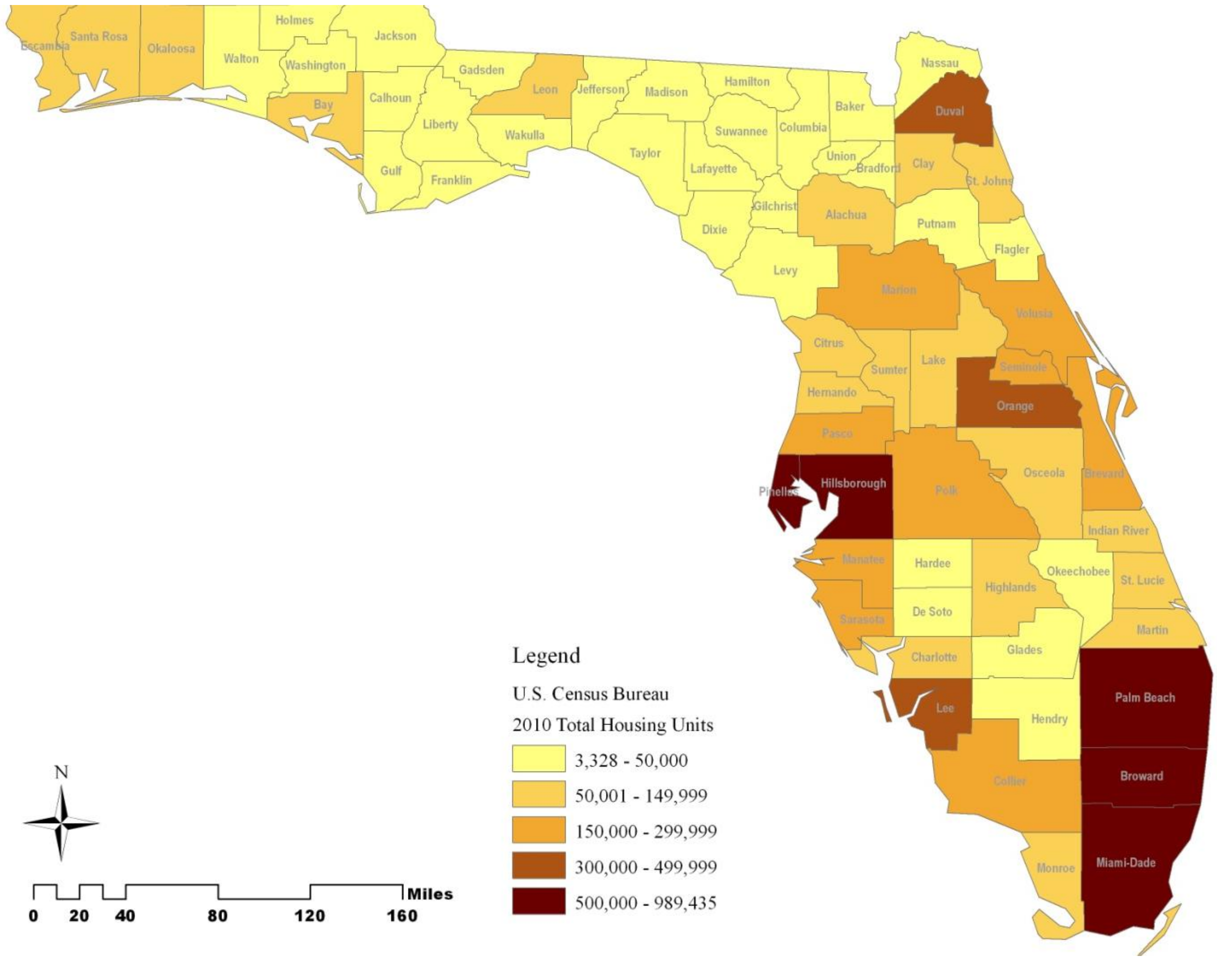

Figure 10.1. Total number of housing units in 2010 (*Data Source*: The U.S. Bureau of the Census, 2010 Census)

According to the data provided by the 2010 Census, the current population of all coastal counties in Florida is 14,194,603 people or 75 percent of the state's total population of 18,801,310. The inland counties are home to 4.8 million Florida residents. In the past 10 years, the population of inland Florida has increased by 0.95 million. The rate of growth, however, was much faster (24%) compared to that in coastal Florida (15.5%). Over the past 10 years, the Atlantic coast of Florida, consisting of 13 counties, added a population of slightly over one million. The population of the Gulf Coast (consisting of 22 counties) increased by 896,353 new residents. The overall rate of growth of all Gulf Coast counties in Florida is higher than the observed growth rate on the state's Atlantic Coast. Both coasts of Florida face climate change risks because of their low-lying topography and water supply and flooding issues (see previous sections).

10.2 FLORIDA: VULNERABLE POPULATIONS TO CLIMATE CHANGE

DIVERSE POPULATION AND CHALLENGES

According to the U.S. Census Bureau 2009 American Community Survey, nearly 3.5 million people currently residing in Florida are foreign-born. In the 2010 Census, Florida has maintained its status as one of the most ethnically and culturally diverse states in the nation, together with New York, California and Texas. Future population projections indicate that Florida's racially and ethnically heterogeneous population is expected to increase in diversity. Diversity and multicultural environment provide a notable competitive advantage for the state's business in the 21st century globalizing economy as the state's economy continued to grow despite the recession (Enterprise Florida, 2011); however, in such an environment, communicating risks associated with climate change requires cultural competence and understanding of diverse groups' perspectives, needs, languages, beliefs and norms. These populations and their special needs will have to be part of any climate change education program to prevent these people from becoming vulnerable populations, particularly in the big coastal cities.

POPULATION AGE AND VULNERABILITY

In addition to communication issues, climate adaptation planning will have to consider the challenges posed by an aging population because of their unique requirements during extreme events and evacuation. According to the 2010 Census, the median age in the state of Florida is 40.7 years, higher than most states except West Virginia, Maine, Vermont and New Hampshire (Howden and Mayer, 2011). Although Florida is no longer at the top of the highest ranking states in terms of median age, it still remains the state with the highest percentage of people aged 65 years and over (17.3%), followed by Iowa (14.9%) and Vermont (14.6%). Overall, 3.2 million people in Florida are 65 years old and over and the State has a higher percentage of all age cohorts above the age of 55. Further, the 2010 Census shows Florida coastal counties have a higher percentage of people 65 years old and over (18.0 %) compared to inland counties (15.2%). A comparison of the Atlantic and Gulf coasts suggests higher percentage of people aged 65 and over living on the Gulf Coast (20.1%) compared to the Atlantic Coast (16.6%).

In addition to elderly limits on mobility, they are also very susceptible, along with young people and those with outdoor occupations, to extreme high temperatures (Hanna et al., 2011). According to the Centers for Disease Control and Prevention (CDC), heat waves in the United States cause more deaths (700) annually than the combined effect of all other weather-related natural disasters such as tornadoes, hurricanes, floods and earthquakes (CDC, 2011). Climate change is expected to exacerbate the frequency and severity of extreme heat waves. According to the IPCC (2007), there will be more hot days and more days with higher record temperatures. Due to population aging and a higher number of outdoor workers employed in agriculture, fisheries, military and tourism, heat waves may pose a considerable health risk for Florida in the coming decades threatening not only the well-being of its residents but also the productivity of several key sectors. CDC projects almost seven-fold increase in excess heat-related deaths in the U.S. by the year 2050 (CDC, 2011).

POPULATION INCOME AND VULNERABILITY

The third vulnerable population is those with low incomes because of their inability to relocate to areas less prone to flooding in the long-term or quickly evacuate during a natural disaster. According to the U.S Census Bureau 2009 American Community Survey, the median household income ($44,755) and the per capita income ($26,503) in the state of Florida are on average lower than that observed nationwide ($50,221 and $27,043, respectively) (U.S. Census Bureau, County QuickFacts 2010). One positive finding is that these populations are typically not located along the coast in Florida. Coastal Florida counties have a higher median household income ($45,565) than the inland counties where the median income is only $36,664. Among the shore-adjacent counties, the Atlantic coast has on average higher median household income than the Gulf coast. Similar trends are observed with the per capita income. In 2009, the South Central Region composed of rural inland counties had the lowest median and per capita income, followed by the North Central Region and the Northwest Region. The highest median household income is observed in Northeast Florida where in 2009 four counties (Clay, Nassau, St. Johns and Flagler) are reported to have surpassed the level observed nationwide. Data obtained from the U.S. Census Bureau 2009 American Community Survey suggest that many Florida counties have a percentage of people living below the poverty line higher than the state average of 15 percent and the national average of 14.3 percent. The poverty rates are particularly high in the

North Central Region where Hamilton County has a poverty rate of 28.5% (the highest for the state), followed by Union (26.4%), Madison (26.2%) and Gadsden (26.0%). In 2009, high poverty rates were also observed in the rural South Central Florida where Hardee County has a poverty rate of 28.4 %, followed by DeSoto (25.6%). Among the shore-adjacent counties, the highest poverty rates were found in Taylor, Dixie, Levy, Jefferson, Franklin, Gulf, Escambia and Miami-Dade. The Gulf Coast has on average higher poverty rates than the Atlantic coast. The lowest poverty rates were observed in the coastal counties of the Northeast. Among the well-to-do counties, Sarasota holds the lead statewide with the lowest poverty rate of 8.7% and the highest median household income (over $62,000). Both the Southwest Coast and the Treasure Coast have poverty rates below the state and national average.

10.3 VULNERABLE POPULATIONS TO SEA LEVEL RISE

Approximately 30 percent of the state's population currently lives in southeast Florida which is most vulnerable to sea level rise due to its uniquely flat, low-lying landscape, and salt water intrusion threats to its freshwater aquifer systems (Section 6.0). Based on the AR-4 projection of sea level rise of approximately 1-3 ft by 2100 (IPCC, 2007), cities, towns and named populated places in Florida were identified with areas below ~ 1.5 ft (0.5 m) (Fig. 10.2) and 3-foot (1 m) (Fig. 10.2) elevation. The city and town areas that are vulnerable were quantified within their jurisdictions and identified to be highly vulnerable in the future with sea level rise. It was estimated that sea level rise could affect nearly 93 cities, towns and named places under the 1.5 ft scenario (Fig. 10.3). However, under the 3-foot scenario these estimates triple to where approximately 358 urban settlements are threatened.

With its extensively developed coast and rapidly increasing population Tampa Bay region is also uniquely vulnerable to sea level rise. According to the 2006 Tampa Bay Regional Planning Council Report, entitled "*Sea Level Rise in the Tampa Bay Region*", more than 71,000 ha, or 64% of the region's shorelines fall under the category "protection almost certain" under various sea level rise scenarios. The category applies to areas designated primarily as industrial, commercial and residential land uses which comprise 96.5 percent of Pinellas County and large portions of coastal Hillsborough, Manatee and Pasco counties. The largest amount of land in this category or 32,000 ha belong to Pinellas County, followed by Hillsborough (19,300 ha), Manatee (14,500 ha), and Pasco (5000 ha) (TBRPC, 2006). Approximately 68 % of the land uses under

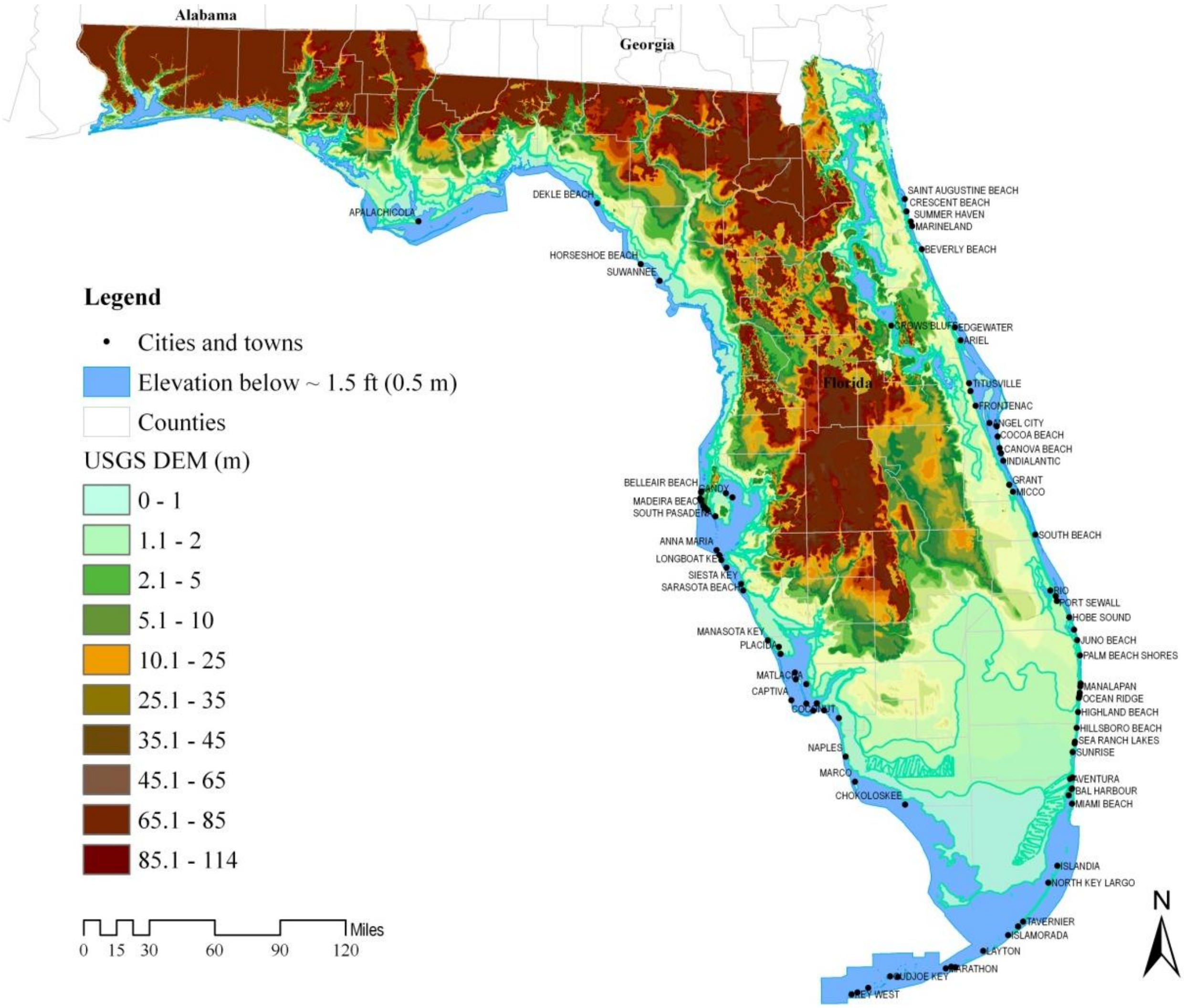

Figure 10.2. Coastal flatlands and areas below ~ 1.5 ft (0.5 m) elevation within city and town jurisdictions (*Data Sources*: USGS DEM, National Atlas of the United States, Geographic Names Information System).

the category "protection almost certain" are residential (TBRPC, 2006).

State population projections indicate an expected change in total population size by almost a hundred percent over the next 50 years. It is anticipated that Florida's population will increase to 28 million by 2030 (Enterprise Florida, 2011) and approximately 34 million people by 2060 (FDOT, 2011). The projected population change is expected to be accompanied by related changes in land use planning, housing and construction. Past trends indicate that a significant portion of these new developments will still be located in the most vulnerable coastal areas, particularly along the southwest and southeast coast. According to the 2010 Census,

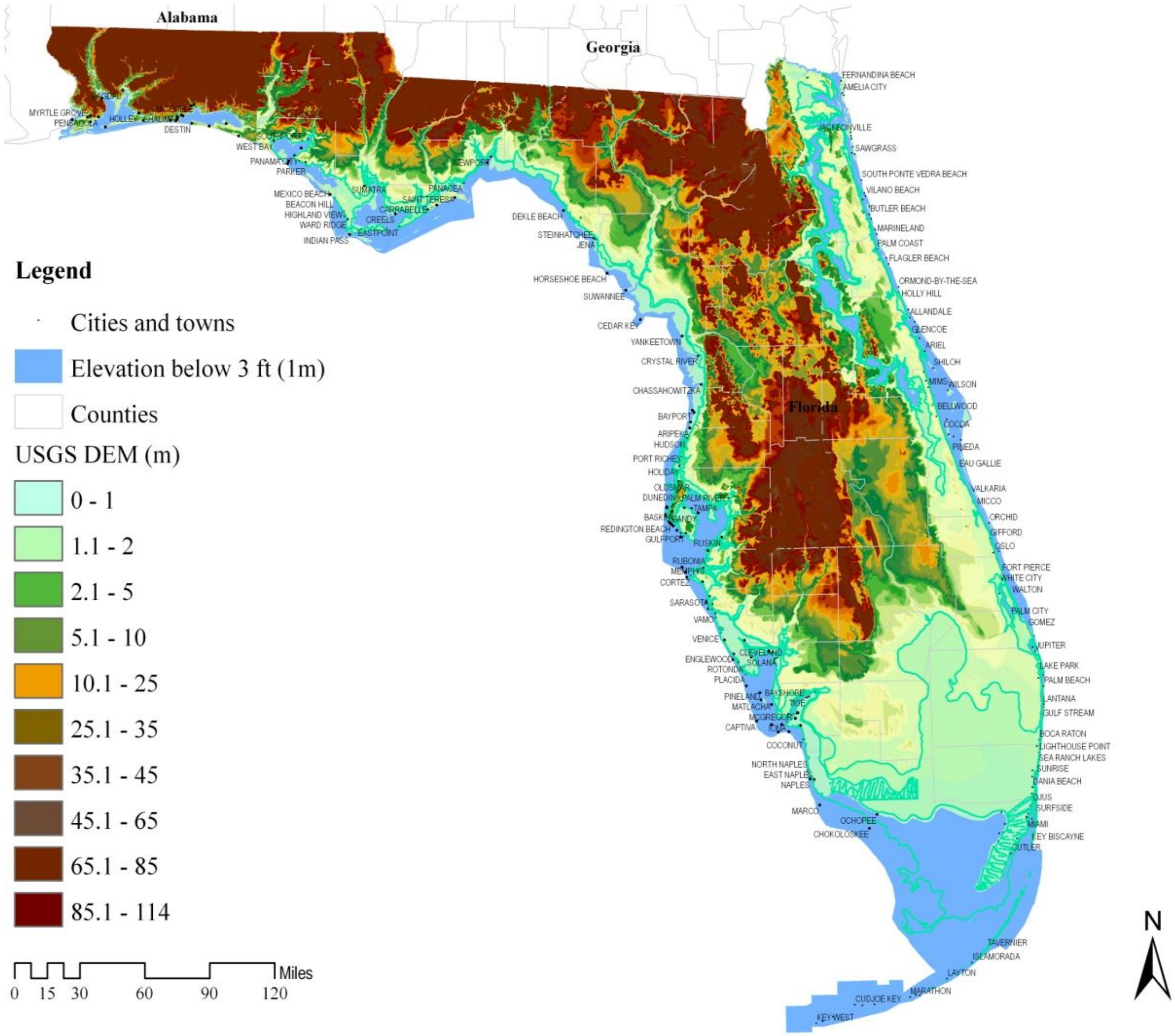

Figure 10.3. Coastal flatlands and areas below ~ 3-foot (1 m) elevation within city and town jurisdictions (*Data Sources*: USGS DEM, National Atlas of the United States, Geographic Names Information System).

Miami-Dade, Broward, Palm Beach, Pinellas and Hillsborough counties have the largest number of housing units. Large portions of these residential uses are located along the coast or in low-lying areas vulnerable to flooding, storm surge damage and inundation from sea level rise. Despite these concerns, development pressure in these vulnerable areas continues as evidenced by the large number of new building permits issued in 2009.

If sea level rise rates increase in the next few decades, or other coastal impacts occur, such as a major storm surge from a large tropical storm, coastal populations would likely begin to migrate toward the interior of the state. Under this scenario, the current faster rate of population increase in central (24%) in comparison to coastal Florida (15.5%) would be even greater putting pressure on water resources in central Florida. Such a scenario would also result in rapid population growth in parts of the state where there is presently very little public water supply infrastructure. There is very little public water supply infrastructure in central Florida illustrated by the fact that most of the counties in this region are primarily served by private wells with a smaller percentage of the population on public water supply sources (Fig. 10.4).

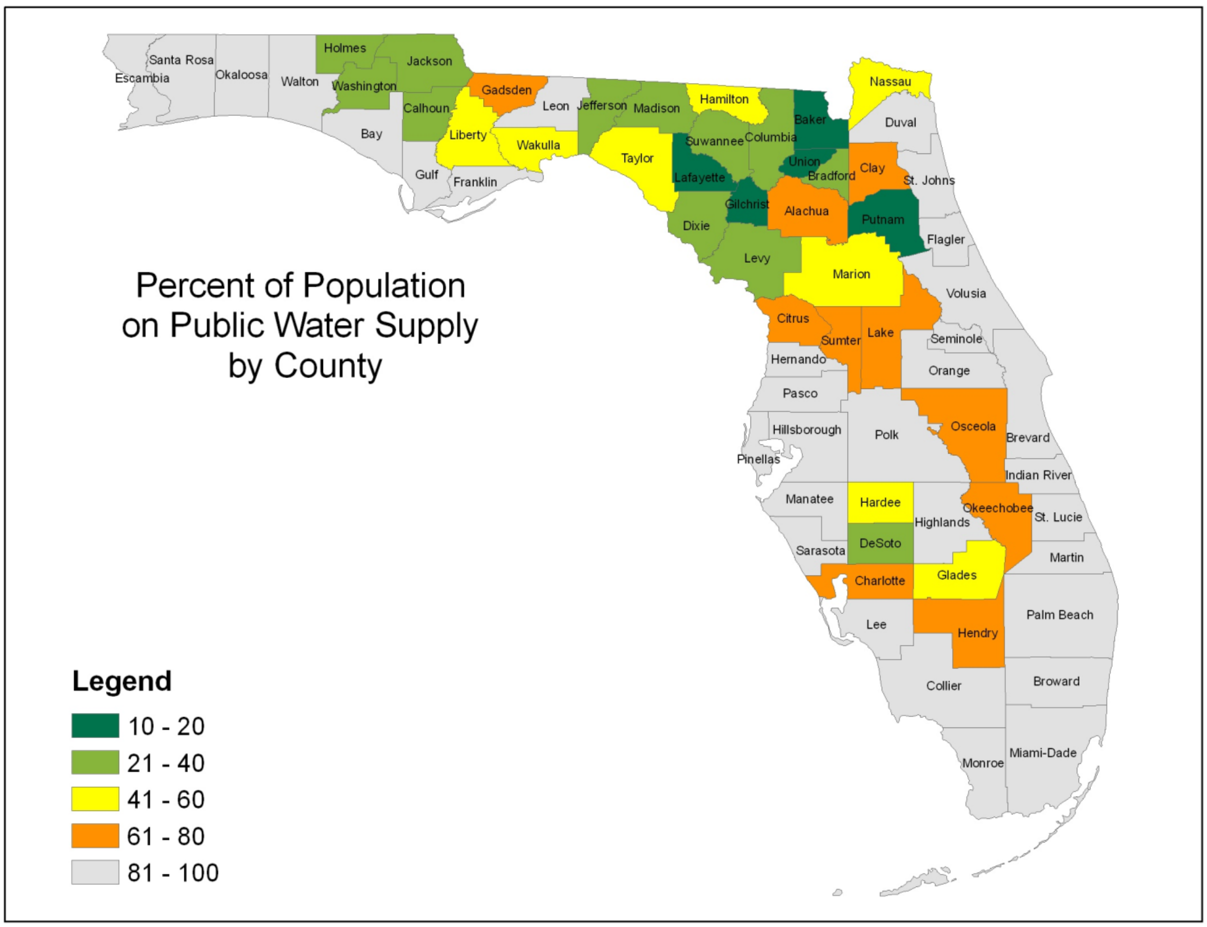

Figure 10.4. Percent of population on public supply by county, 2005. Data from USGS Water-Use Data Tables, 2005. Calculated as public supply population/total population x 100%.

10.4 HURRICANE AND SEA LEVEL RISE SYNERGY

No area in the state of Florida is beyond reach of hurricane strike which means that both people and property are potentially vulnerable to hurricane-related damage. Sea level rise will exacerbate the problems associated with storm surge as higher storm tides are expected to reach farther into low-lying areas and in some instances will overwhelm flood control and salinity structures. Using NOAA's historical storm tracks data for 1851-2003, Esnard et al. (2011) estimated that Monroe, Miami Dade, Martin, Collier, Broward, and Palm Beach counties are among the top 10 counties (out of a total of 158 counties on the Atlantic coast and the Gulf of Mexico) with regard to the highest probability of hurricane strike. As a result, Florida has enforced one of the strictest building codes in the nation, but the 2004 devastation associated with the combined effect of Hurricanes Charley, Frances, Ivan, and Jeanne indicated that the regulatory measures did not make Florida "hurricane-resistant" (Barnes, 2007). The hurricane season of 2004 was considered the most expensive year for hurricanes in U.S. history. Despite the widespread damage across Florida, the demand for new construction in the shore-adjacent counties continues to rise based on the number of building permits issued in 2009-2010.

Along Florida coasts, wave action, including storm surge from hurricanes, and the combined effects of inlet development and long-shore drift, as well as sea level rise, have been identified as major factors affecting coastal erosion (Ruppert, 2008). These effects are particularly pronounced in southeast Florida due to higher exposure to hurricane strikes. Barrier islands are particularly vulnerable to sea level rise, as they are composed mainly of sandy substrates which are highly erodible. Many barrier islands in Florida are highly developed with a variety of residential, commercial and recreational uses which impede the movement of sand and therefore, islands ability to migrate landward (Titus, 2000). As the seas rise, these islands would eventually be severely eroded from the ocean side and inundated from the bay side (Titus, 2000). According to the Federal Emergency Management Agency (FEMA), over the next 60 years the most damaging effects of coastal erosion nationally will be felt in low-lying areas exposed to wave action and flooding (Heinz Center, 2000). By 2060, nearly 87,000 homes and other buildings will be lost to erosion which is equivalent to roughly 1,500 structures a year at a cost of $530 million annually (Heinz Center, 2000).

According to the Florida Department of Environmental Protection, 485 miles or nearly 60 percent of Florida's beaches are under a threat of erosion (FDEP Beach Erosion Program website). Despite multi-million dollar re-nourishment projects, critically eroded areas persist on both the Atlantic and Gulf coasts. The erosion rate of the beaches on the Atlantic coast can reach up to three feet a year, while the beaches on the Gulf Coast retreat on average by six feet per year (Heinz Center, 2000). From 1960 to 2007, Florida has used 223 million cubic yards of sand for beach nourishment at a total cost of $44 billion which is around 40 percent of the overall cost of beach nourishment projects nationwide (NOEP, 2008). According to the U.S. EPA, the cost of replenishing Florida's beaches under a 1.5-foot (0.5 m) rise in sea level would be $1.7 billion, and as much as $11.8 billion under a 6-foot (2 m) rise (USEPA, 2008). Additionally, a Tufts University study finds that economic losses due to climate change, such as decreases in tourism revenue, hurricane damage costs, and potential loss of real estate, could cost Florida $327 billion by 2100 (Stanton and Ackerman, 2007). While there is very little evidence that hurricane frequency is going to increase with climate change, the intensity is likely to be enhanced by elevated ocean temperatures, which could enhance hurricane damage from both wind and storm surge, particularly as sea level rises.

10.5 GROWTH MANAGEMENT ISSUES

Global warming and its related impacts, including sea level rise, are likely to challenge several aspects of well-established and efficient approaches of coastal hazard management such as shoreline protection, coastal hazard areas delineation, and emergency response. Unlike hurricane storm surge flooding, high waters resulting from rising seas are not likely to recede; thus, changing not only a baseline environmental condition, but also the assumptions on which models and policy commitments are built. The flood insurance program, for instance, requires knowledge of the extent of the coastal floodplain which currently does not take into account projections of sea level rise (USCCSP, 2009). Given that the population in coastal areas is growing twice as fast as the national average, present development pathways can potentially make future adaptation planning in these areas significantly more challenging (Nicholls and Lowe, 2004; Purvis et al., 2008). Jacob et al. (2008) emphasized the importance of the risk-based approach to climate change adaptation due to three factors: (i) longevity of urban infrastructure; (ii) substantial socio-economic and ecological costs; and (iii) a need for long-term planning.

With more than 8,000 miles of shoreline and some of the most densely populated low-lying coastal areas in the nation, Florida is at the forefront of climate change vulnerability and need for proactive, assessment-based approach to adaptation. The increase in population, its aging and diversity, pose unique challenges to decision-makers addressing the challenges brought about by climate change. Global and regional models and assessments predict that in the 21st century Florida will experience most of the simultaneous and synergistic effects of the shifting climate such as sea level rise, increased storm activity, rising temperatures, floods and droughts (Rosenzweig and Solecki 2001; Jacob et al., 2008; SFWMD, 2009).

11.0 CONCLUSIONS

Climate change, including, sea level rise, increased extremes in weather, increased temperature, and changes in patterns of precipitation and evapotranspiration will effect water resources and their management and ultimately Florida's population. One of the primary themes throughout the paper is that climate change impacts on water resources will have to be managed as one system and across multiple sectors, and include an understanding of science, engineering, and human demography and behavior. In addition, there will be a real need to undertake cost benefit analyses to determine the best approach to solve the water resources challenges of the state now and in the future, and examine the benefits of conserving water resources, rather than paying for more costly technologies in both infrastructure and their higher energy demands.

The direct effects of climate change on water resources include increased threats on the sustainability of water supplies, flooding, salt water intrusion in coastal areas and threats to water quality. Most of the state currently relies on groundwater. However, it is clear that groundwater resources are inadequate now to meet future water demand in many parts of the state, and climate change adds to the vulnerability of groundwater supplies and uncertainty of supply and demand. Therefore, developing alternative water supplies is a priority. While a few municipalities and counties are planning to develop new surface water sources, the difficulties of storing water in regions with little topographic relief, porous geology, and shallow water tables limits the viability of developing significant surface water sources. Because of these limitations on traditional surface and groundwater sources, alternative sources, such as desalination and reuse, will be significant components of Florida's future water supplies. Conservation measures will also become increasingly important in the state's effort to maintain sustainable water supplies.

In addition to the challenge of developing alternative water supplies, sea level rise poses several threats; most notably flooding of low-lying coastal areas, salt water intrusion into coastal aquifers, and migration of salt water inland through coastal canals and rivers that will be difficult to control. The same infrastructure that has allowed the habitation of coastal Florida, the construction of canal and drainage systems, may in the future be a problem in staving off the effects of sea level rise. Sea level rise will allow saltwater intrusion into surficial aquifers and their recharge systems, such as coastal wetlands and in south Florida the low elevation of the Everglades and its underlying peat soils make it particularly susceptible. If tropical storm intensity increases, storm surges in coastal areas, and added flooding on top of a higher groundwater table, may impact infrastructure systems. More intense storms will add to localized flooding of infrastructure systems in the built environment and natural systems. Elevated temperatures are a further confounding problem because water loss from evapotranspiration increases with increasing temperature.

The appropriate water management approach is important to the long-term sustainability of the valuable water resources of Florida. The past management practices have primarily centered on flood control, which means discharge of excess water offshore. These practices are increasingly being questioned because they do not assist in meeting current and future water needs of Florida. The management of water will need to vary across the state. The use of stormwater as raw water, indirect potable reuse of wastewater, alteration in irrigation, re-plumbing canal systems, a more highly managed stormwater systems to control groundwater levels, are all issues that will need to be pursued to varying degrees across the state to address local needs. Florida's water resources along the coast, and in south Florida in particular, are immediately threatened by the ancillary impacts of climate change and sea level rise.

All counties and cities are required to do comprehensive planning under the Land Development Regulation Act of 1985. Last year, Senate Bill 360 required local comprehensive plans to now include energy efficient land use patterns, energy conservation strategies, the promotion of renewable energy, and greenhouse gas reduction strategies. Concurrently, there are many efforts currently underway in the state to help with climate change adaptation. Florida

Atlantic University has developed adaptation strategies, with a focus on water management, while building outreach and education program for policy makers and the public. The most important take-away from this synthesis is that different areas of the state will require unique regional solutions that will take time, many decades in some cases, to implement. The current economic reality and other financial challenges in meeting the water needs of Florida, and protecting its infrastructure, in the face of climate change will require an unprecedented level of resource leveraging and coordination among academic, governmental, non-governmental, and private sector entities. There are multiple institutions and organizations that are currently working on sustainable water resource issues and the socio-economic implications of water security, and are capable and prepared to work together to increase the resilience of the state of Florida to the present and future challenges of planning and adapting to climate change.

APPENDIX A: SEA LEVEL RISE ESTIMATES

GLOBAL AND FLORIDA

Sea levels globally have been rising slowly over the past few 100 years as indicated by tide gauge data (Maul, 2008). Sea level rise measurements in Florida show an average rate of sea level rise of 2.27 ± 0.04 mm per year from 1915 to 2005 based upon tide gauge readings in Key West, which is the Western Hemisphere's longest sea level record (Maul, 2008). In a recent synthesis of sea level rise data from all the tide gauges in Florida, a similar unified rate of 2.0 ± 0.03 mm was statistically determined and residuals decomposed that resulted in a low regional variation term (Iz et al., in review). This regional Florida estimate was comparable to rates found in the long Key West record evaluated by Maul (2008) and to global estimates of Heimlich (2010) and Vermeer and Ramsdorf (2009).

Recent altimetry data has led to the suggestion that the rate of sea level rise is accelerating (Houston and Dean, 2010); however, these results are difficult to verify with relatively short term data sets. There is a confounding problem with utilizing short-term tide gauge and altimetry data for establishing the trajectory of sea level rise because of the inability to factor out short-term variability from the long-term trend. Thus, using these shorter data sets may not reflect the actual increasing rate or acceleration of sea level rise. It is certain though that as oceans warm, thermal expansion will increase the rates of sea level rise and glacial melt will contribute to ocean volume, most significantly if land ice sheets begin to contribute to the sea level rise term (IPCC, 2007). Because of these uncertainties, it is prudent to plan for some acceleration in sea level rise rates as global carbon estimates are approaching worst case scenarios (IPCC, 2007). The question is what rate of rise to use for planning, as the rate will fundamentally influence actions that will need to be taken and the time frame required to act. Comparisons among estimates from various papers in the literature show a wide range of projections in the rate of change particularly in the latter part of this century (Fig. A.1). Most of the sea level rise estimates predict an increase between 2.5 and 5 feet by 2100 (Fig. A.1), although there exists a wide range of variability in the sea level rise estimates being employed by the various working groups in Florida. For instance, the Southeast Florida Climate Change Compact signed by Monroe, Miami-Dade, Broward, and Palm Beach counties created a unified sea level projection for planning purposes of 3-7 inches by 2030, and 9-24 inches by 2060

(Southeast Florida Regional Climate Change Compact Technical Ad hoc Work Group, 2011). The SFWMD has established sea level rise estimates with "lower and upper bounds for planning purposes" of 5 and 20 inches, respectively, by 2060 (SFWMD, 2009). A 1 to 3 foot sea level rise seems to be an appropriate conservative value for planning purposes for the state of Florida, though this estimate will need regular updates and revisions as more long-term data become available, particularly region-specific data, and new understanding of the forces controlling local rates of sea level rise is attained.

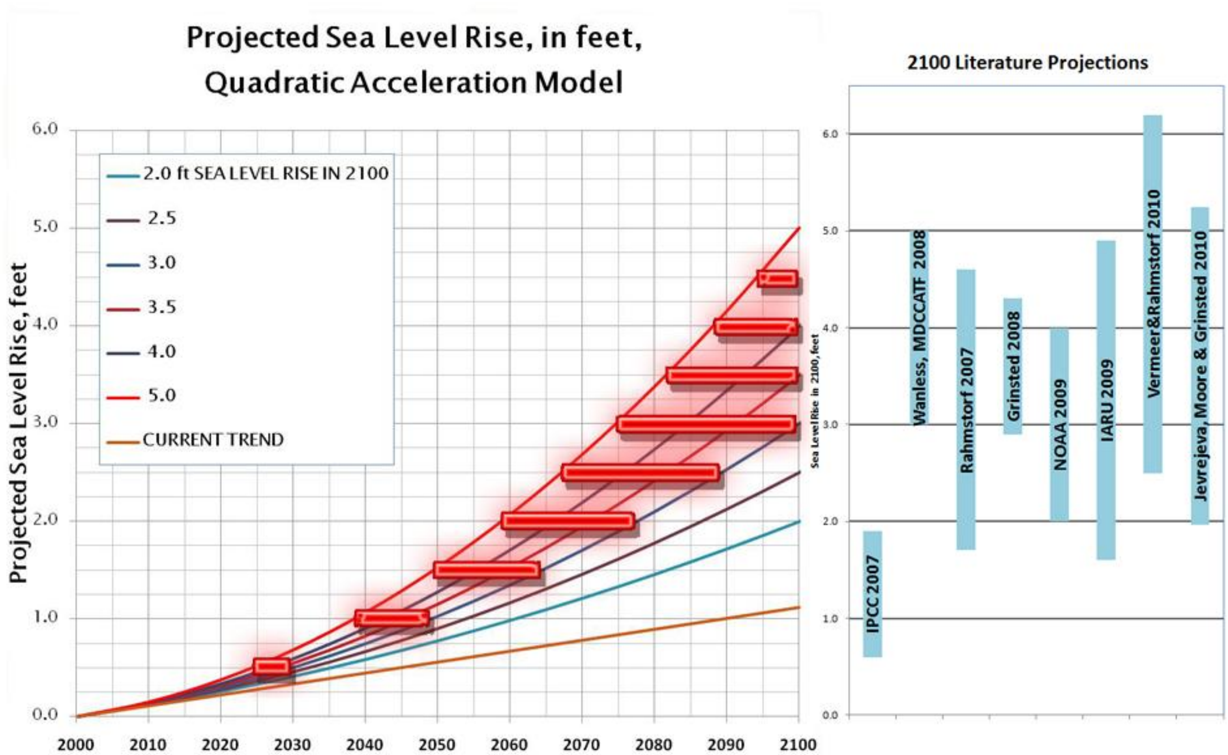

Figure A.1. Prediction of sea level rise using a Quadratic Acceleration Equation (from Heimlich, et al. 2009). The graph outlines the average, and 1 and 2 standard deviations from the average of the current models. The horizontal bars outline the ranges when the sea level rise could occur.

APPENDIX B: FLORIDA'S CLIMATE CHANGE DRIVERS

GLOBAL TELECONNECTIONS DRIVE HYDROLOGICAL VARIABILITY

OSCILLATIONS AND FLORIDA RAINFALL

In addition to sea level rise rates, the changes in precipitation patterns are uncertain. This is primarily because they are dependent on large-scale, global decadal oscillation weather systems (ENSO, AMP, PDO, AO; see below). Some of these are limited to large multi-decadal Sea Surface Temperature (SST) anomalies which have significant impacts on regional and global climate. Linkages of SSTs with the variability in regional hydrologic phenomenon, such as temperature, precipitation, streamflow, and flood and drought, have been well documented. McCabe et al. (2004) reported that the frequencies of drought in the conterminous United States were highly correlated with the Pacific Decadal Oscillations (PDO) and Atlantic Multi-decadal Oscillations (AMO). Rogers and Coleman (2003) also showed that streamflow in the upper Mississippi River basin was consistent with phases of the AMO signal. The strong relationship between SSTs and variability in precipitation over the U.S. and other regions of the world has been discussed in several research studies (Enfield et al., 2001; Goodrich and Ellis, 2008; Lachniet et al., 2004). Enfield et al. (2001) demonstrated that the shifts in cool versus warm AMO phases are directly related to above versus below normal rainfall over most of the US. They also showed that the inflow to the Mississippi River basin, in eastern US, varies by about 10% and the inflow to Lake Okeechobee in South Florida varied by about 40% in response to the changes in AMO phases. These data show the high correlation between global decadal oscillations and regional/local weather inter-annual patterns; thus, it will be important for climate and atmospheric scientists to work with water managers to plan for changes in water resource availability in response to any changes in global decadal atmospheric oscillations. Natural climate variability in Florida and its implications have been studied over several decades (Trimble et al., 2006; Obeysekera et al., 2010 and 2011), and this research has led to optimization of water management taking into account global weather patterns. This research will need to continue as a more comprehensive understanding of how these teleconnections will respond to climate change and how water management needs to respond is imperative.

EL NINO SOUTHERN OSCILLATION (ENSO)

The ENSO is a slow atmospheric-ocean oscillation in which convective cells and major wind systems in the tropical Pacific region interact to produce a slow, irregular variation in ocean temperature. This oscillation has two phases: the warm and cool phase defined by changes in ocean temperatures. Interestingly, ENSO is a major source of inter-annual climatic variability in south Florida. These two phases are more commonly known as El Niño (the warm phase) and La Niña (the cool phase). Although ENSO is centered in the tropics, the changes associated with El Niño and La Niña events affect climate around the world. ENSO events tend to form between April and June and typically reach full strength in December. During El Niño events, south Florida tends to experience above-normal rainfall during the winter (dry season) months because oceans SST are warm along the eastern Pacific bringing warm moist air to Florida (Fig. B.1). During La Niña dry-season rainfall tends to be below normal because SST are cool in the eastern Pacific and air is drier in that region and Florida (Fig. B.2).

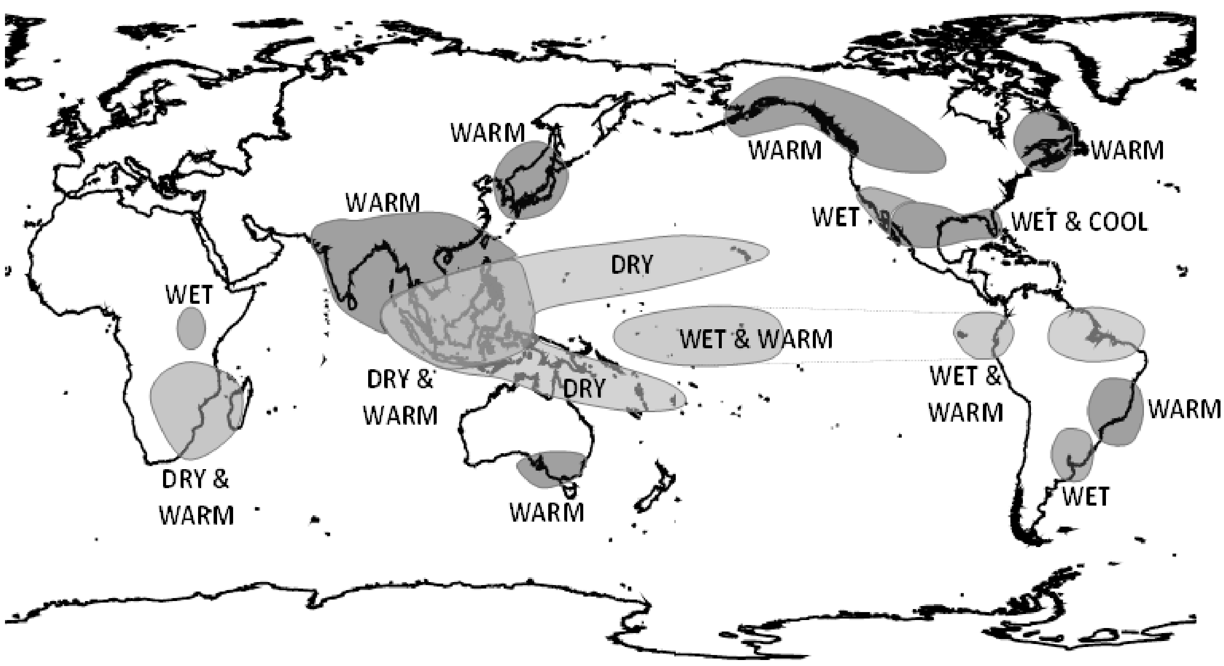

Figure B.1. Conditions for the world and Florida based for El Niño for the months December – February (Teegavarapu & Goly, 2011, using data from NOAA).

During El Niño, the jet stream is oriented from west to east over the northern Gulf of Mexico and Northern Florida leading to susceptibility to severe weather. During this time, rainfall is above average, temperatures are below normal and low pressure systems increase and hurricane frequency is lowered. The La Niña phase promotes dry conditions in Florida in late fall, winter and early spring with increased risks of wildfires, and temperatures are slightly above normal and hurricane activity rises.

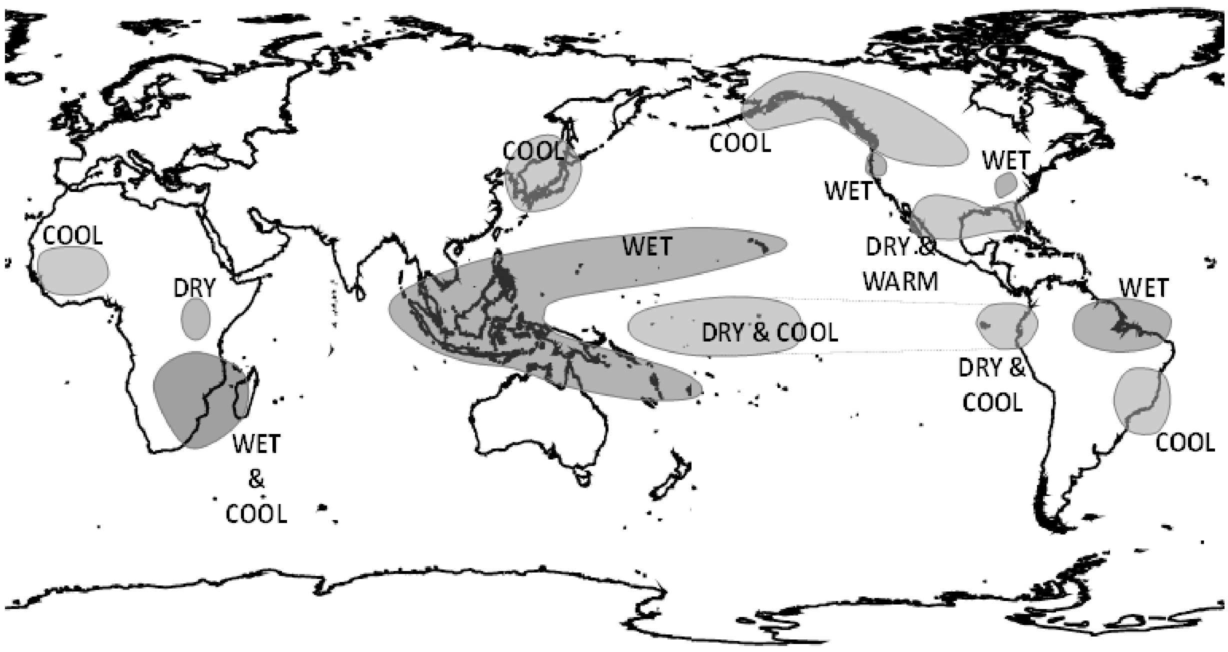

Figure B.2. Conditions for the world and Florida based for La Niña for the months December – February (Teegavarapu & Goly, 2011, using data from NOAA).

ATLANTIC MULTI-DECADAL OSCILLATION (AMO)

In contrast to ENSO with a tropical origin, the AMO is a variable climatic pattern in the Atlantic, detected as sea surface temperature changes over the Atlantic Ocean between the equator and Greenland. It is a long-range climatic oscillation that causes periodic changes in the surface temperature of the Atlantic Ocean, which may persist for several years or decades, usually 20 to 40 years. AMO, as multi-decadal pattern of climate variability, was introduced by Kerr (2000) and Schlesinger et al. (2000). Schlesinger and Ramankutty (1994) and Andronova and Schlesinger (2000) discuss the pattern of global mean temperature pattern with predefined multi-decadal frequency. AMO describes temperature deviations in the ocean surface that appear to be driving shifts ("warm" and "cool" phases) in South Florida's climate (Enfield et al., 2001). The four periods of AMO in the 20th century are: AMO (cool) 1895 –1925; AMO (warm) 1926 –1969; AMO (cool) 1970 –1994; AMO (warm) 1995 – Present. Increased tropical Atlantic hurricane activity is attributed to higher sea surface temperatures (SSTs) and also decreased vertical wind shear (Cronin, 2009). The eastern U.S. and especially Florida has seen an increase in hurricane activity during the AMO warm phases. Kaplan et al. (1998) and Enfield et al. (2001), using long term instrumental records of sea surface temperature (SST), suggested that AMO was a 65-80 year quasi-cycle variability of SST with 0.4^{o}C range. There is a strong statistical correlation between AMO-related SST variability and rainfall in the southeastern United States and Mississippi river flow (Cronin, 2009).

Climate variability due to teleconnections has a major influence on extreme precipitation events in Florida. The South and Panhandle regions of Florida experience variations in extreme precipitation events during AMO warm and cool phases and during El Niño and La Niña cycles. In general, AMO warm phases are associated with increased precipitation intensities of different durations throughout Florida. The temporal occurrence of annual extreme precipitation events also changes in response to the AMO phases, and the magnitudes of precipitation extremes increase in AMO warm phases in south Florida (Fig. B.3).

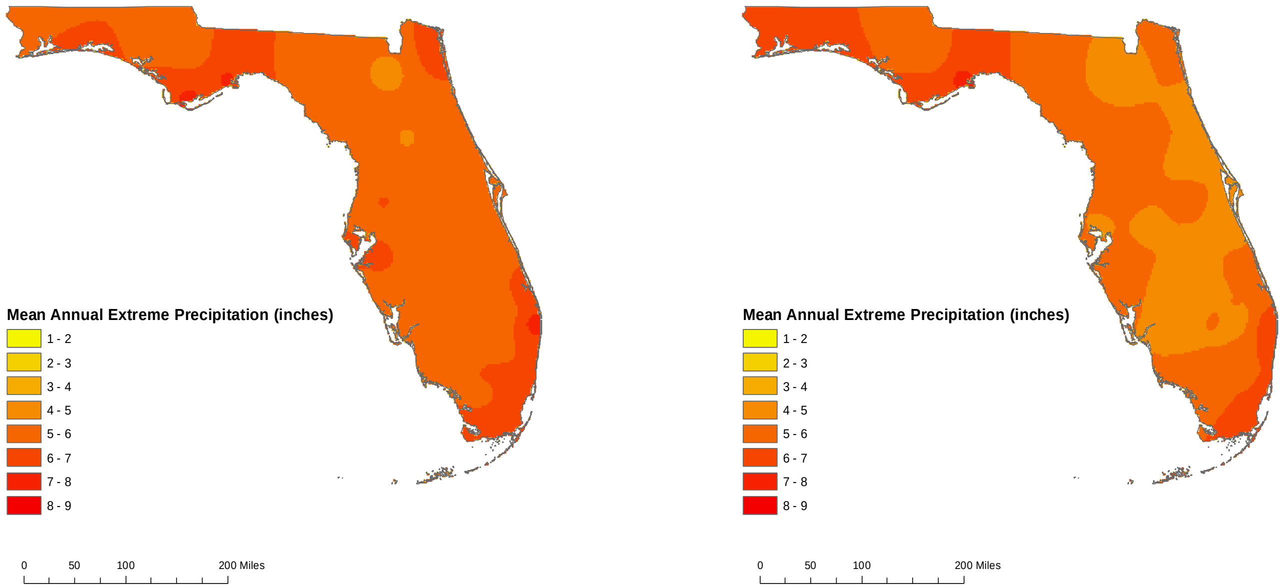

Figure B.3. Spatial variation of extreme precipitation for 72 hours duration in the AMO: (left) warm phase, (right) cool phase (Teegavarapu and Goly, 2011).

REGIONAL PREDICTIONS OF FLORIDA RAINFALL

The U.S. Climate Change Science Program predicts a modest increase in precipitation for the southeastern United States (USCCSP, 2008). Higher southeast U.S. rainfall may be reflected in the western panhandle of Florida, but will not likely control precipitation patterns in the lower Florida peninsula that is driven by local convection and sea breezes. In fact, Marshall et al. (2003) showed a declining trend in rainfall (12%) for the Peninsula based on historical trends from 1925 to 2003, with summer rainfall driven by convection cells accounting for most of the loss in runoff potential. They postulated that alterations in land cover of the peninsula may also have influenced the sea breezes driven primarily by contrasting thermal properties between the land and ocean. This mechanism may have implications for the observed changes in the distribution of convective rainfall, which accounts for the primary wet season precipitation and over 70 percent of rainfall for a given year in South Florida (Obeysekera, 2009). There is a need to understand how global climatic oscillations (ENSO, AMO, PDO, AO) and local processes will respond to climate change and affect Florida resources.

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