CLIMATE CHANGE

Issue Definition

There has been significant discussion in the popular media on the topic of climate change. While there are a number of possible causes that contribute to changes in the world-wide climate, much of the scientific community is in agreement that climate change is occurring. The International Panel on Climate Change (IPCC) concluded in 2007 that the "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007). The conclusions of the 2007 IPCC report most relevant to water resources and groundwater are (IPCC 2007):

- Projected warming in the twenty-first century shows geographical patterns similar to those observed over the last few decades;
- Warming is expected to be greatest over land and at the highest northern latitudes, and least over the Southern Oceans and parts of the North Atlantic Ocean;
- Snow cover is projected to contract;
- Widespread increases in thaw depth are projected over most permafrost regions;
- The more optimistic globally averaged rises in sea level at the end of the twenty-first century are between 0.18 - 0.38 meters (Dragoni and Sukhija (2008), but an extreme scenario gives a rise up to 5 meters;
- Temperature extremes, heat waves and heavy precipitation events will continue to become more frequent; and
- Increases in the amount of precipitation are very likely at high latitudes, but not as snowpack, whereas rainfall decreases are likely in most subtropical land regions.

It should be noted that there is significant uncertainty in the predictions of the models used to prepare the IPCC reports to predict the actual intensity, spatial and time variability of rainfall and temperature for a given region in part because the models can only be calibrated against a very short period of time, and that as time has proceeded, the predicted changes have moderated to some degree to comport with observed changes. In any case, the main concern raised by global warming is that climatic variations alter the hydrologic cycle, and that the current data indicated that hydrological cycle is already being impacted (Dragoni 1998; Buffoni et al. 2002; Labat et al. 2004; Huntington 2006; IPCC 2007; Dragoni and Sukhija, 2008). This issue is of critical concern because the predictions that the temperature will rise by several degrees and the warming trend will last for centuries may portend dramatic consequences that cannot be predicted today (Dragoni and Sukhija, 2008).

This report noted the following as evidence of this conclusion:

- Ocean CO_2 uptake has lowered the average ocean pH (increased acidity) by approximately 0.1 since 1750. The acidification of the world's oceans will continue and is “directly and inescapably coupled to the uptake of anthropogenic CO_2 by the ocean” (Denman et al. 2007, p. 533).

- Eleven of the twelve years from 1995 – 2006 rank among the twelve warmest years in the instrumental record of global temperature data (since 1850). The 100-year linear trend of global surface temperature (from 1906 – 2005) indicates an increase of 0.74 ± 0.18 °C (see Figure 1).

- Average Northern Hemisphere temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1300 years.

- Rising sea level is consistent with this warming. Global average sea level has risen since 1993 at 3.1 + 0.70 mm/year, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets (see Figure 2).

Enfield and Cid-Serrano (2006) report that decadal to multi-decadal climate variability is associated with environmental changes that have important consequences for human activities, such as public health, water availability, frequency of hurricanes, etc. Important effects of climate change that will affect Florida include the impacts of increasing temperature on seal level rise, evapotranspiration and seasonal rainfall patterns, increased rainfall variability and frequency of extreme events.

Temperature changes will have two effects – uncertainty in the amount and timing of precipitation, and sea level rise resulting from melting polar ice caps and thermal expansion of seawater. It is reasonable to expect that Florida’s existing climate zones will move northward and the zones of more tropical climate will enlarge. The direction and magnitude of precipitation changes for the Florida peninsula are uncertain due to limitations in existing global climate models (Mulkey, 2007). There may be “slightly increased runoff in the southeast [United States],” but it is unclear if such a trend would apply to the Florida peninsula (U. S. Climate Change Science Program). Freas, et al suggest there is a potential for lower overall annual average precipitation in subtropical areas similar to peninsular Florida.

Background

The hydrologic cycle continuously cycles water through precipitation, runoff, soil percolation, evaporation and condensation. Precipitation patterns vary naturally from year to year, and over the decades and centuries. The challenge for water suppliers is to determine how the hydrologic cycle provides water to service areas, in what quantities and with what level of reliability (Bloetscher and Muniz, 2006). Water supply reliability and sustainability are closely linked. Water supply sustainability has been defined by the American Water Works Association’s (AWWA) Water Resource Division as: “The planning, development, and management of water resources to provide an adequate and reliable supply of water with a quality suitable to meet their economic, environmental and social needs for current and future generations,” while Murley (2006) added “in a manner that will not diminish the ability of future generations to meet their needs.”

Since the production and delivery of drinking water and the treatment of wastewater are recognized as vital functions of society, long-term viability and development of water supplies is required to sustain long-term economic viability and public health despite competing interests that may include agriculture, ecosystems, recreation and industrial demands. Unfortunately there are many examples where water supplies in a given basin are overcommitted, or where as a result of changing precipitation and temperature patterns, may lead to a reduction in the water supply "pie". Prioritizing water use under such scenarios should include water quality needs so that lower quality waters can be prioritized for lower quality use needs like agriculture. However, ecosystem water supply needs have historically been ignored, as has their intrinsic economic value. As a result, large scale clearing and filling of coastal wetlands, bayous and mangroves has subjected coastal areas to damage from storm events and sea level rise. Securing reliable water supplies for future generations is important in the face of changes in climatic patterns. Water supplies can become more reliable and sustainable through a comprehensive approach to water planning which includes using alternative water sources and planning future infrastructure needs with long-term trends in mind. Systems need to be adaptive to changing conditions as past long term trends are expected to be altered as a result of climate impacts.

Already, there is strong evidence that global climate change is having an impact upon the world's water resources. These impacts include changing precipitation patterns that may result in more severe drought or floods, varying stream flow patterns, rising sea levels along the coasts, and contamination of freshwater aquifers and coastal water bodies as a result.

Impacts to the Hydrologic Cycle on Groundwater Recharge

The hydrologic cycle continuously replenishes water through precipitation, runoff, soil percolation, evaporation and condensation. We know that precipitation patterns vary naturally from year to year, and over decades. As a result, runoff varies in some relationship to rainfall quantity and intensity, depending on surface conditions. As a result, the change in land use from forests to agriculture or urban uses can have significant impacts on runoff characteristics. Hydrologists point out that areas with higher CN numbers, a reference to the imperviousness of the surface, will accelerate runoff. Urban land use increases the CN number as buildings, parking lots, roads and other improvement replace forest or grassland cover. The result is an increase in the peaks for runoff and a shortening of the time of runoff (see Figure 3), and a decrease in the amount of time available for infiltration. Therefore the amount of infiltration is less. In many environments, the time for recharge to occur is measured in years – in some cases many years. Where the CN number is high, recharge can be virtually eliminated, thereby creating a basin where recharge does not occur. Coupling land use changes with change in intensity of storms, US Environmental Protection Agency (USEPA) (2008) indicates that the "primary impacts of increasing storm intensity on water resources is coastal and inland flooding, complicated in the case of coastal storms by storm surges which may be influenced by other factors such as the level of development in the watershed. In addition to flooding, increased storm frequency and/or intensity may result in adverse effects in surface and ground water quality and contamination of water supplies; an increase in "[w]ater-borne diseases will rise with increases in extreme rainfall" (Kundzewicz et al. 2007, p. 189); and "greater rates of erosion unless protection measures are taken" (Kundzewicz et al. 2007, p. 189).

Scanlon et al (2005) reported that understanding impacts of land use/land cover change on the hydrologic cycle is needed for optimal management of water resources. Increased evapotranspiration because of large-scale irrigation alters regional climate through precipitation recycling (Moore & Rojstaczer, 2002; Scanlon et al 2005). Evidence from other studies indicates that deforestation increases runoff. For example, the Mekong River basin suffered large flood and drought damages in the second half of the 20th century. Rischey and Coast-Cabral, 2006 reported concerns about possible stream flow trends resulting from the land cover and use changes of this period, especially those changes resulting from deforestation or property in the Mekong basin.

Changes in the surface cover will change surface temperatures which can affect evapotranspiration. Open water bodies have higher evapotranspiration rates than land. Forest lands are known to maintain cooler temperatures on the surface (with accompanying high evapotranspiration and longer runoff times), while open areas have generally higher temperatures (heat island effect). Salmun and Molod (2006) modeled changes in land cover in their climate models. While they note that the magnitude of the changes in climate due to deforestation differs from model to model for comparable experiments, they reported "that with a reduction in precipitation ranging from 15 to 640 mm per year, the reduction in evaporation ranged from 25 to 500 mm per year and suggested an increase in surface temperature is from 0.1 to 2.3°C" (Salmun and Molod 2006). Their modeling suggests that in a deforestation simulation, "lowered surface roughness (grasslands) *may* result in an *increase* in evaporation if the surface is wet enough," which makes sense given that evapotranspiration can occur as deep as 4 feet below the surface. Once the land is dried out completely, their modeling suggests some degree of decreased evapotranspiration, but this does not necessarily mean that recharge is increased (via cracks in the surface).

The issue has been studied in Florida with an indication that changes are currently occurring. As Florida water managers know, abundant water supplies are present as a result of an average of over 54 inches of rain each year. The surface hydrologic budget of the Everglades was dominated by evaporation and transpiration, with surface runoff into Florida Bay composing a relatively small percentage of the annual rainfall. Historically, the Everglades were a giant marsh fed by rainfall. During the rainy wet season, sheets of water would move down the state from Orlando, through the Kissimmee River, to Lake Okeechobee, then to the Everglades (see Figure 4). Because the land was so flat, water could flow from lake to lake, spill over natural river channels and spread into floodplains which are the recharge areas for the Biscayne aquifer (see Figure 5). There were no barriers or canals to direct or control the path of water. In the aftermath of large storms, water could stand for weeks and months. When few people lived here, that wasn't a problem. But with the extensive development that started in the early 1900s, there was a demand for controlling the water and opening Florida for agriculture and development.

Figure 6 shows the 1900 land use pattern and the 1993 land use developed by Marshall, et al (2003). This shows the dramatic change in land use cover from marsh land to agricultural and urban land cover. Figure 7 shows the temperature changes by season reported by Marshall, et al (2003). This figure shows the temperature changes for south Florida – they are cooler in winter which increases freezes in the winter due to loss of moisture from the swamp lands, and both higher temperatures and more evapotranspiration in the summer. Both the observed and predicted patterns match. The variation is projected to worsen.

Rainfall has also changed over the period. Figure 8 shows the accumulated precipitation average prior to 1973 versus 1994. Marshal et al (20030 postulated that "because the sea breezes are driven primarily by contrasting thermal properties between the land and adjacent ocean, it is possible that alterations in the nature of the land cover of the peninsula have had impacts on the physical characteristics of these circulations". This mechanism may have implications for the observed changes in the distribution of convective rainfall (see Figure 9), which accounts for the primary wet season precipitation and over 70 percent of rainfall for a given year. Their modeling indicated that the land use changes from 1900 to date have reduced total rainfall by 12 percent, much of it in the summer. This confirms the finding of Pielke, 1999 which reported that “it appears that development has exacerbated their severity since landscape changes over south Florida have already appear to have reduced average summer rainfall by as much as 11%” (Pielke, 1999). Future changes in climate will add to the existing impacts. This is occurring at the same time as the population of the state is expected to nearly double by 2030.

Figure 10 shows the 2-month average of the simulated 2-month daily maximum and minimum temperatures. Marshall, et al (2003) report that “while there is a great deal of spatial variability in these values, the results show that daytime maximum generally increased with the use of the 1993 land cover”. When converted to heat flux, Marshall, et al (2003) noted that “the latent heat flux difference fields exhibits a consistent decrease of near 10% of the grid-average pre-1900 value”. Figure 11 shows the change in average rainfall and change in average temp 1924 to 2000. Note the reversed trend (higher temperatures and lower rainfall), which means groundwater inputs are lessened (source: Marshall, et al 2003).

Climate Modeling Summary

The Florida State University Nested Regional Spectral Model forms a core part of the regional climate modeling system and regional climate model studies have found the dynamical downscaling approach successful for the southeast region of the United States (Cocke et al, 2007). Cocke et al (2007) conclude that the southeast United States has long been known to have potential predictability during winter because of its strong tele-connection to tropical Pacific sea surface temperatures driving El Nino - Southern Oscillation (ENSO) events.

Enfield et al (2001) have identified relationships between the Atlantic Multidecadal oscillations and rainfall and river flows in the continental United States including Florida. While the Atlantic Multidecadal Oscillations (AMO) include naturally occurring changes in sea surface temperatures in the Northern Atlantic, warming of seas due to greenhouse gases may influence this naturally occurring cycle. Enfield et al (2001) report a 10 to 40 percent peak to peak variation of the long-term mean for inflows in Lake Okeechobee resulting from AMO cycles. They conclude that while the general expectation is that we will have greater extra tropical rainfall under greenhouse warming scenarios, the effect of AMO cycles may influence rainfall amounts to a greater extent (i.e., under a warm AMO cycle, rainfall totals decrease). They conclude that attempts to anticipate the impact of global warming on regional rainfall may prove inaccurate if the models do not reproduce the AMO variability and its impacts.

Enfield and Cid-Serrano (2006) present an approach which shows how probabilistic projections can be developed for a specific climate mode (e.g., AMO). This method overcomes the problem with current climate models not able to predict future phase shifts of decadal to multi-decadal climate models such as the AMO. This approach has potential application for water management; in fact the likelihood of wetter or drier conditions can be determined and adaptive strategies implemented to manage our water resources. They indicate that decadal to multi-decadal climate risk assessment is not only useful when a climate shift becomes imminent. In general, for any policy or measure that can be adopted in anticipation of change, there exists an alternative to be followed if the probability of change is low. They further conclude that the usefulness of these methods for actual applications will depend on the nature of the application, the strength of the connection between the climate mode (e.g. AMO) and the target variable (rainfall), and managers’ ability to utilize the projections in making operational decisions. Understanding the influences on seasonal rainfall in Florida due to changes in sea surface temperatures in both the Pacific and Northern Atlantic Oceans is critical to our ability to predict climate change effects on rainfall across Florida.

Extremes in weather phenomena are not new to Florida, where hurricane occurrence cycles vary every 20 years or so and periodic droughts are noted to occur in roughly seven year cycles. For example, there were droughts that affected much or all of the state in the early 1970s, the early 1980s, the 1998-2001 period, and the 2006-2008 period. Whatever the frequency of dry periods has been in the past in Florida, it appears that development. Future changes in climate will add to the existing impacts. This is occurring at the same time as the population of the state is expected to nearly double by 2030.

It is recognized that rainfall variability is caused by global climate factors outside of Florida (e.g., sea surface temperatures); however, understanding how global climate changes may affect these factors which influence Florida's climate is important. If the cycles peak more, rain will be more concentrated in the wet season, hurricane frequency may increase, and dry season droughts could become more extreme. The concern about climate variability has been heightened due to the active 2004 and 2005 hurricane seasons and ongoing water supply issues in Florida.

USEPA (2008) indicates that the "primary impacts of increasing storm intensity on water resources is coastal and inland flooding, complicated by storm surges which may be influenced by other factors such as the level of development in the watershed. In addition to flooding, increased storm frequency and/or intensity may result in the following:

- adverse effects in surface and ground water quality and contamination of water supply (IPCC 2007b, Working Group II *Summary for Policymakers*, p. 18);
- water quality changes may be observed in the future as a result of "overloading the capacity of water and wastewater treatment plants during extreme rainfall" (Kundzewicz et al. 2007, p. 189);
- "[w]ater-borne diseases will rise with increases in extreme rainfall" (Kundzewicz et al. 2007, p. 189); and
- "[a]ll studies on soil erosion have suggested that increased rainfall amounts and intensities will lead to greater rates of erosion unless protection measures are taken" (Kundzewicz et al. 2007, p. 189)."

USEPA also cautions that water resource managers will face significant challenges as storm intensity increases (USEPA, 2008):

- although there is some uncertainty with respect to climate models addressing storm intensity and frequency, emergency plans for drinking water and wastewater infrastructure need to recognize long-term increases in high flow and high velocity events due to intense storms as well as potential low flow periods;
- damage from intense storms may increase the demand for public infrastructure funding and may require re-prioritizing of infrastructure projects;

- floodplains may expand along major rivers requiring relocation of some water infrastructure facilities and coordination with local planning efforts.

Criticality for Florida Water Supplies

Future changes in climate may affect the water resources upon which the State of Florida depends. The uncertainty caused by climate change relative to its impacts on water resources poses a daunting challenge for water management districts and drinking water, wastewater, and storm water utilities responsible for managing water resources throughout the state and within local communities. These agencies and utilities rely upon historical hydrological precipitation patterns to regulate or manage source water supplies, storm water runoff, and wastewater conveyance and treatment. From the water, wastewater and storm water utilities' perspective there are three critical issues regarding climate change: (1) how increasing hydrologic variability may affect water supply and demand and wastewater collection and treatment; 2) in coastal areas, how sea level rise may impact water supplies, utility infrastructure, and relocation of coastal population centers; and (3) how energy usage, to treat and deliver potable water and to treat and dispose of wastewater, may contribute to climate change or variability.

Water utilities must continue to provide uninterrupted, high-quality service to their present customers, and many must also plan for rapidly growing populations. During the past decade there have been regulatory and water policy requirements to develop non-traditional sources of water supplies (e.g., surface water and desalinated seawater) in west-central Florida. These policies are currently being expressed in the eastern and central areas of the state primarily within the jurisdictions of the Southwest Florida Water Management District and St. Johns River Water Management District. For example, in 1998 Tampa Bay Water (Florida's largest wholesale water supply utility) relied 100 percent upon groundwater, and today receives over 40 percent of its source water from surface water sources. By 2012, this utility will rely on surface water for over 50 percent of its raw water supply. Freas, et al 2008 suggest that generally there may be less precipitation in the subtropics, which may impact the ability to manage water supplies. Current and projected changes in climate change may reduce flexibility and reliability of current water supply operations and may require multi-sourcing and participation in flood protection efforts (Freas, et al 2008).

If municipal water needs are to be reliably met, it will be increasingly important to understand the resource consequences of climate variability and change, especially as the state moves toward more reliance on surface water sources. It is important to examine the relationship between climate change and water quality and quantity issues, and the impacts of climate change at different points in the hydrologic cycle. Increasing hydrologic variability will pose challenges for Florida since topography limits the ability to create artificial areas to store excess river flows for use during the anticipated drier periods.

Sea level rise is expected to be a long-term trend. Figure 12 shows NASA's most likely scenario which predicts 2 to 7 feet of sea level rise, with a range of uncertainty of up to 16.5 ft in the next 100 years depending on whether the sea level rise due to polar melting is accelerating or not. Planning needs to address the accelerated sea level rise many climate change experts are predicting. Encroaching seawater will create additional limits on current freshwater supplies and inundation of coastal areas and the Everglades in south Florida, and inundation of coastal areas in the rest of the state. The economic impact of such changes will be significant including the potential for a significant population migration from south Florida to central and north Florida which currently do not have adequate water supplies to meet such a potential demand. The economic impact of such changes will be significant. The 2007 IPCC report indicated that "spatial planning needs to take a long-term view on adaptation to sea level rise and climate change, especially with regard to …" infrastructure.

The relationships between energy use, now and in the future, sustainable water supplies, and wastewater treatment and disposal with climate change effects need to be defined. The effects of climate change can impact water and wastewater utilities in several ways: the need for more energy intensives technologies to treat water and wastewater to higher standards, the conflict with greenhouse emission reductions, and the potential to develop new sources of water or uses of reclaimed water that require more energy consumption than is currently being used. It should also be recognized that water conservation actually reduces energy use and the attendant greenhouse gas emissions.

Drinking water and wastewater facilities, both public and private, spend billions of dollars a year on energy to collect, treat, and deliver clean water – with much of this cost borne by ratepayers. Energy costs are primarily associated with pumping raw water, distribution of treated potable water, and conveyance of wastewater to treatment plants. Energy is also required to treat wastewater prior to disposal and to treat raw water to drinking water standards. The USEPA estimates that about eight percent of all energy used in the United States is used to pump, transport, treat, and heat water (Grumbles, 2007).

In addition, more exotic treatment technologies (desalination, advanced water treatment) increase power requirements. Advanced treatment requires a great deal of energy, particularly denitrification and membrane filtration processes. The energy required for the handling, transport, and beneficial use of treated residuals increases as the distance from the treatment site to the disposal/application sites increases. Because of the need for more advanced treatment, energy consumption by drinking water and wastewater treatment facilities is likely to continue increasing with or without climate change impacts. New or revised drinking water treatment requirements could also heighten energy consumption (USEPA, 2008).

Nationwide, drinking water and wastewater utilities use 75 billion kilowatt-hours (kWh) (Reardon 1994), resulting in the emissions of approximately 116 billion pounds of CO_2 per year (USEPA, 2008). Drinking water and wastewater treatment facilities have the potential to achieve 15–30 percent energy savings (CEE 2007, p.1) by implementing energy conservation measures alone. Drinking water and wastewater treatment facilities have the capacity to generate and use energy from low-head hydroelectric, solar and/or wind power. Wastewater treatment facilities may also have the capacity to generate energy from capture and use of methane (USEPA, 2008).

The IPCC (2007) indicated that even if we start making some reductions in CO2 emissions now, the kinetics of CO_2 removal will cause it to continue to increase in the atmosphere for tens of decades. Stabilization of CO_2 at current emission levels would result in a continuous increase in CO_2 concentrations over this century and beyond. Unless emissions are reduced by about 80%, CO_2 concentrations in the atmosphere will continue to rise above current levels that in 2006 were about 382 ppm, with a potential to increase to nearly double historical levels (IPCC, 2007; www.epa.gov/climatechange).

To stabilize the concentration of CO_2 in the atmosphere will require a very significant reduction in greenhouse gas emissions. California's Governor Arnold Schwarzenegger and Florida's Governor Charlie Crist have signed Executive Orders requiring the reduction of greenhouse gas emissions by 80% below 1990 levels by the year 2050 for their respective states. This is a huge challenge for Florida and; consequently, a huge goal post for water and wastewater utilities that are faced with mandates for improved but more energy intensive technologies.

Florida 2030 Vision

The 2030 Vision is that all of Florida's water supply needs will be met through a series of planning, infrastructure and policy initiatives. The effects of climate change will present a significant challenge for Florida's population, water supply needs and water resource management. Therefore, to increase the reliability and sustainability of water supplies, utilities must plan for new facilities and future water supplies that consider the potential climate change impacts and adapt to them. To ensure that water supply availability is not a problem in the future, utilities must plan new facilities which can be adapted to future climatic impacts, develop supplies which can be implemented in light of changing conditions, and join with others in reducing the emissions of greenhouse gases by promoting water use efficiency and implementing technologies that have low carbon footprints.

Options and Path Forward to Achieve FL 2030 Vision

Risk Assessments

Utilities must judge the vulnerability of their infrastructure and operating protocols to develop mitigation and adaptation strategies (Wallis, et al, 2008). Utilities are encouraged to use risk assessment to deal with the uncertainties associated with the effects of climate change. Strategies to deal with climate change impacts should include adaptive management techniques employed during planning and operations, as well as infrastructure improvements. The first step should be maximizing water conservation efforts, which is the most cost-effective source of supply and provides both mitigation and adaptation benefits. Determining the appropriate actions or strategies to adapt to climate change involves using a vulnerability assessment approach to evaluate the need for operational changes, and/or to install new infrastructure or "harden" existing infrastructure. Risk assessment requires evaluation of the likelihood of the climate change impact occurring. For Florida, the changes in rainfall patterns and sea level rise are the most pressing concerns. Both should be evaluated with respect to likelihood. The uncertainty is how much and how fast sea level will rise and how precipitation patterns will change.

Freas et al (2008) suggest using risk assessments as a means to determine system vulnerabilities for infrastructure and supply sources, and identify a dual analytical approach – the threshold - scenario risk assessment framework (see Figure 13). The threshold approach is a qualitative based assessment which relies on experience and judgment of professionals to define vulnerabilities and adaptive strategies. Freas, et al (2008) indicate that to set the thresholds for water systems, the experience and judgment of experienced water managers with respect to meteorological and natural systems is required. The threshold impacts are assigned based on the most susceptible infrastructure to climate impacts. For example, the most susceptible infrastructure in Iowa during floods in June 2008 were wellheads that were not above the flood stage. Freas et al (2008) note that setting these thresholds for water systems requires four steps:

1. Define the performance criteria of the water system infrastructure.

2. Establish climate change variables of importance.

3. Define water system component responses to climate change variables.

4. Develop adaptation strategies that will reduce or eliminate the impact based on vulnerability assessment, performance risk.

Threshold analysis should identify the weak areas of the water system that need hardening through either adaptive strategies or infrastructure changes that remove the vulnerability. A diversified approach to water supplies is the best method to minimize future risks.

A more quantitative approach is the scenario risk assessment which identifies the likelihood of failure. The purpose of this approach is to quantify risks of a utility's current system given climate change effects. This type of assessment is similar to other infrastructure risk assessment currently conducted. Freas et al (2008) have identified a series of seven steps for this purpose, and two additional steps have been added here, identifying hardening measures and actually making a decision:

1. Select a range of climate change scenarios based on commonly accepted models.

2. Translate these to local scenarios.

3. Identify climate change variables of importance (e.g. rainfall frequency, rainfall volume, temperature, sea level).

4. Determine system responses locally to projected local climate change scenarios (e.g., incorporate rainfall changes into surface flow models).

5. Develop adaptation strategies (e.g., diverse supply sources, regional interconnections).

6. Evaluate robustness of the adaptive strategies on the climate change scenario analyses.

7. Identify hardening measures.

8. Evaluate overall system performance.

9. Making the decisions needed to adapt to the change.

The Pew Center report on climate change indicates that the socioeconomic implications of climate change on water supplies and demands, or the lack thereof, will be directly related to the ability of water managers and planners to act on required plans, infrastructure and development changes in the near term (Frederick and Gleick, 1999). Planning and implementation for sustainable water supplies will require an understanding of how Florida water resources are affected by climate change. Deyle, et al (2007) outlines that the need for planning for adaptations, protection and potential retreat from climate change impacts will be especially important given the competition for scarce public dollars to develop water supplies that can adapt to climate changes over the next 20 to 100 years. These measures include adaptations for water supplies and adaptations for infrastructure.

Adaptations for Water Supplies

In order to complete risk assessments, a utility (regional or local) needs sufficient knowledge of its local hydrology and water supply needs and the tools to assess changes. In general, a diversified approach to water supplies is the best method to minimize future risks associated with water supplies and climate change uncertainties. Tampa Bay Water provides an example of a utility with diversified water supplies (surface water, ground water wellfields, and a seawater desalination facility). Tampa Bay Water has developed surface water flow forecasting models, demand forecasting models, and integrated surface water – groundwater hydrologic model, which all incorporate rainfall and temperature variables as driving forces. These models can take output of downscaled climate models that provide different rainfall and temperature time series and make assessments of the effects of changes in these parameters to water supply sources in Tampa Bay Water's service area. In addition, demand forecasting models can also use these parameters; updated forecast results can then be used to assess changes in demand due to changes in rainfall and temperature.

These types of planning models provide water supply managers with the ability to evaluate alternatives and provide a basis for making decisions. Once assessments are made and strategies (both adaptive and hardening) identified and evaluated, decisions must be made. Risk-based decision making is one approach that can be used to balance risks and costs and incorporate the uncertainties associated climate change. Diversification of water supplies can also occur through regional interconnections. However, there are several issues associated with diversification of water supplies, including energy consumption and conjunctive management of a multiple source system, that will need to be addressed to balance multiple environmental and climate change objectives.

Water Conservation

Water conservation has been suggested as a mechanism for addressing climate change. Water conservation, or perhaps using preferred the term "water use efficiency," is used to improve water use to modify current user practices to mitigate or delay the need to explore new supplies in the future or to delay the construction of infrastructure. This practice is effective where growth is limited and climate impacts are not significantly altering existing supplies. However, while water use efficiency should not be a temporary measure to address immediate water supply concerns, the alteration of current supplies would reduce water use efficiency measures to shorter-term behavior modifications to buy time to implement adaptation or protection infrastructure.

Conjunctive Use of Water Supplies

Conjunctive groundwater – surface water use is a water supply strategy that western states have practiced for decades. The concept of conjunctive use applies in areas where multiple water sources are present and water supplies have been or could be developed. Surface water supplies will require adequate storage volumes for conjunctive use with groundwater supplies. Conjunctive use provides diversity and flexibility of supply that can improve resistance to droughts, balance climate impacts on source availability, reduce over-use of a groundwater-only source of supply, and improve water supply system reliability to meet demands. There may also be opportunities to improve upon the manner by which a multiple source water supply system is permitted by the water management districts to enhance the conjunctive use aspects of the system and maximize multiple sources while still meeting all rule criteria.

Improved Reliability of Power Systems

Improved reliability of power systems includes implementation of local standby power sources and power sources from sustainable options. Many utilities have addressed or are in the process of installing local standby power measures as a result of the experience with storms in 2004 and 2005. However, the needs for the future are not well covered, so a utility's vulnerability assessment to climate change should include power system reliability.

Sustainable Energy Development

The utilization of renewable or low-carbon footprint sources of power by water and wastewater utilities is necessary in the future because most new alternative water supply technologies involve the expenditure of larger amounts of energy than older technologies. For example, the energy output to treat fresh water using nanofiltration is about 3 kWh/1000 gallons. The treatment of brackish water from the Floridan aquifer using low-pressure reverse osmosis (LPRO) uses about 5 kWh/1000 gallons. Producing freshwater from seawater utilizing high pressure reverse osmosis (RO) requires the output of 15 kWh/1000 gallons. If communities in Florida decide to use seawater as a source of fresh water, the energy required will be about five times that of a typical membrane plant. Operating a 50 million gallons per day (MGD) seawater treatment plant would require at least 35 megawatts (MW) of power. Already Florida Power & Light (FPL) and other power agencies are looking at added power in part because of the potential costs for water and wastewater treatment. Treatment plants in Florida generally do not take advantage of solar, methane or residual power producing options.

To achieve sustainability, increasing our reliance on seawater RO will require that major power plants produce their electricity largely from "green energy" or non-carbon sources such as solar photovoltaics (PV), solar thermal, wind, geothermal, ocean current, or hydropower among others. The energy requirements of seawater RO plants are so large that development of sufficient renewable energy sources on-site is unlikely.

While major power companies in the state are retooling to develop low-carbon footprint power plants, the solution for water and wastewater utilities is to develop distributed sources of renewable energy as quickly as possible. This may include a mix of solar, wind, small-scale hydropower, tidal, as well as use of biogas (digester gas), landfill gas, and waste-to-energy power. Solar energy is abundantly available in the "Sunshine State" yet untapped by utilities to meet their energy requirements. Oddly enough, Germany is the world's largest producer of solar energy with over 3,000 MW in production, but has considerably less sunshine than Florida. The potential of solar energy in Florida has led the State to initiate a Solar Energy Center in Cocoa that is a clearing house of information on how to harness this alternative energy resource. Currently there are few installations using solar photovoltaic energy (PV) in Florida and none at water or wastewater utilities.

Three factors usually are at play in the decision making that leads to solar power: higher energy costs (currently occurring), an incentive program at the state level (Florida has a program), and lots of sun. In the United States, California utilities have been the vanguard for utilization of solar energy even though the availability of solar energy in Florida is similar to its availability in most of California.

Wind power could function as an accessory power system in Florida although winds for most locations in the State are not sustained. Some coastal locations are an exception. Interestingly, the largest seawater desalination plant using renewable energy was constructed in Perth, Australia, in 2006, and uses wind power. The plant produces 34 MGD of fresh water from seawater; capital cost for this plant was $387 million. The plant utilizes power from an 82 MW wind farm that supplies much of the power for the facility.

Miami-Dade Water and Sewer Department is utilizing digester gas as an energy source at the wastewater treatment plants at both Central District (Virginia Key) and South District (Blackpoint) Wastewater Treatment Plants (WWTP). These facilities were constructed in the 1950's and 1960's, and 1970's and 1980's, respectively. Methane gas from the digesters is collected, scrubbed, compressed and stored in methane spheres before being sent to the co-gen units. At South District WWTP, digester gas powers three available reciprocal engines turning their 900 kW generators for a possible maximum total output of 2.7 MW. This power source supplies 10-20% of the energy needs of the plant. At Central District WWTP, digester gas powered generators provide about 20-40% of the plant's energy needs. The cost savings to Miami-Dade Water and Sewer Department by capturing and using biogas is significant.

Solid waste facilities in Florida should not be overlooked as a source of renewable energy from both landfill gas and waste-to-energy (WTE) in order to support water utilities if solid waste and water utilities are in proximity to one another. The use of municipal solid waste for power generation takes advantage of the use of largely green energy from renewable organic materials thus maintaining a low carbon footprint by not using fossil fuels. Within Florida there are at least 14 operational landfill gas facilities producing 58 MW of power. A good example is the Orange County Landfill which produces 6,000 SCFM (Standard Cubic Feet per Minute) of landfill gas (methane) that is delivered to the Orlando Utilities Commission's Stanton Energy Center where it is used to produce electricity. Within Florida there are 11 WTE plants that produce 518 MW of renewable electrical energy. About 700 kWh of energy can be produced per ton of solid waste. The 22.7 million tons per year of municipal solid waste landfilled in Florida (FDEP 2006 data) could be converted to 1800 MW of renewable energy if sufficient WTE plants were constructed.

Adaptations to Address Infrastructure Issues

Sea level rise is the highest risk issue for much of the population of Florida which is located in areas with elevation less than 20 feet above sea level. Adaptation strategies to address sea level rise will be required in light of global changes coupled with funding competition to protect/armor public infrastructure and coastal private property to prevent relocations of population centers. Three categories of adaptation should be considered: protection, retreat, and accommodation (Deyle, et al, 2007). Strategies for infrastructure protection to combat small increases in sea level rise may include:

- Storm water improvements.
- Beach renourishment efforts.
- Protection of sanitary sewer systems.
- Alter wastewater disposal patterns to include beneficial reuse and salinity barriers.

Strategies for infrastructure accommodation to adapt to moderate increases in sea level rise may include:

- Relocation of wells.

- Regionalization of water supply utilities.
- Conversion to new water supplies such as desalination.
- Coastal armoring including lock and salinity structures.
- Artificial recharge scenarios.
- Transfer of resources between regions.

Strategies to adapt to large increases in sea level rise could include extensive diking and relocation of large populations toward the central part of the state, which already faces water supply limitations. Choosing which options to pursue depends on which climate change scenario(s) are deemed most likely during the planning process. Each of these issues is briefly discussed in the following paragraphs.

Storm Water Improvements

In urban areas, storm water collection and management systems may need to be redesigned to increase capacity since current capacity is not likely to address new peaking factors associated with climate change. Development causes the ground surface to become more impervious, which results in greater runoff of rainfall and a loss of infiltration. The heightened runoff patterns increase the likelihood that older infrastructure (piping) will be insufficient to move water from developed areas, resulting in increased funding. Storage areas to delay movement of water to tide and increase infiltration capacity are priorities. The loss of wetlands, mangroves and other coastal ecosystems diminishes the ability to store water or to provide areas to direct excess precipitation to avoid flooding. Conservation of land to prevent development over areas where storm water may collect, in floodplains and low areas should be a land use priority. Reduced development and the migration of development in these areas should be a priority in local communities. The use of low impact development (LID) techniques to delay peak and reduce storm water runoff can be a cost-effective option to consider from a land use perspective. Costs for storm water improvements are difficult to quantify. Costs for changes in development patterns and protection of low lying areas will be costly and highly controversial.

Beach Renourishment Efforts

Beach renourishment is often an expensive and controversial issue. Deyle, et al 2007, suggested that one of the benefits of beach renourishment with respect to climate change is that the beaches become larger, which perhaps stems the approach of wave action and could be a component of a hardening strategy for utilities. Unfortunately in the presence of high winds, hurricanes or northeasters, beach renourishment is a temporary solution which washes away. Beach renourishment requires an appropriate sand, sand density and placement with respect to benthic issues. The activity generally stirs bottom sediments resulting in a temporary pulse of high nutrient-laden water near shore. Beach renourishment efforts limit access to beaches for a period of time, and can cost over $1 million per mile, with the likelihood of needing replacement every 3-7 years. With 1300 miles of coastline, this would entrain billions of dollars spent repetitively to protect the coast. The program is only useful if sea level rises are on the low side of predictions.

Protection of Sanitary Sewer Systems

Increased infiltration/inflow (I/I) due to saturated soil conditions and infrastructure structural issues (e.g., broken pipes, deteriorating pipes) will need to be addressed. Infiltration (see Figure 14) is a direct result of groundwater that migrates into the pipes due to rainfall contributing to groundwater, and causing the pipes to be under water (under water is the normal situation for most of coastal Florida). Most utilities have peaks, as shown in Figure 15, which are likely to become larger if climate change results in increased rainfall volume. Peaks are caused by inflow during rain events – generally surface connections. The protocols for identifying breaches in the system that lead to infiltration/inflow include:

- Inspect all sanitary sewer manholes for damage, leakage or other problems;
- Repair benches in poor condition or exhibiting substantial leakage;
- Repair manhole walls in poor condition or exhibiting substantial leakage;
- Repair/seal chimneys in all manholes to reduce infiltration from the street during flooding events;
- Install dishes in all manholes to prevent infiltration;
- Install LDL plugs where manholes in the public right-of-way or other portion of the utility's system is damaged;
- Identify sewer system leaks, including those on private property (via location of smoke on private property);
- Perform a low flow inspection;
- Document all problems in a report that identifies problem, location and recommended repair;
- Ongoing manhole inspection and dish.

There are an estimated 1,300,000 manholes in Florida, and over half of those are in areas vulnerable to flooding. The cost to seal manholes is estimated at $100/manhole or a cost of $130 million. Such improvements include installation of rain dishes, LDL plugs, chimney seals, and ancillary corrections to service lines on both public and private property (see Figures 16-18).

Over 10 percent of sewer service lines are believed to be damaged based on south Florida experience. Assuming there are an estimated 3 million service lines, 10 percent of which need repairs at $200 each, the cost is $60 - 100 million. FDEP's 2004 survey of statewide needs for domestic wastewater facilities estimated that work needed statewide for infiltration/inflow correction would cost $311 million, collection/transmission system rehabilitation would cost $960 million, new collection systems (gravity lines) would cost $1.752 billion and new transmission systems (force mains, pump stations) would cost $1.392 billion (USEPA, 2004).

New sanitary sewer systems will need to be designed to meet predicted future conditions which could include increased infiltration potential resulting from either increase rainfall or sea level rise. New and existing systems will need to adapt to these different hydrologic conditions.

Coastal armoring including lock and salinity structures

There are many areas of the state where there are no structures to prevent the migration of seawater inland, including much of Miami-Dade County and southern Broward County where the salinity control structures may be 5 miles inland. There are several issues that after water supply infrastructure as a result of this problem. The loss of freshwater to tide is especially significant in areas where canals or channelization of natural riverine systems have occurred – the best examples are the extensive canals in south Florida. This loss of water to tide includes both runoff and groundwater that is drains until its levels match the water levels in the canals. Hence along the coastal ridge in southeast Florida is reduced from historical levels of 6 or 7 feet to 2 ft which matches mean high tide. This loss of water accounts for billions of potential storage that can only be recaptured with infrastructure improvements.

With the start of development in the early 1900s, there were demands made of the State to control the water and open south Florida for agriculture and development. Today, water supply for nearly half the state is managed through a "controlled" system, consisting of 1,800 miles of canals and levees, 200 water control structures and 16 major pump stations that controls the movement of water south and through waterways to both coasts. Drainage improvements to the Kissimmee River were channelized and Lake Okeechobee was bermed to manage the water.

Before development, during the rainy wet season, sheets of water would move down the state from Orlando, through the Kissimmee River, to Lake Okeechobee, then the Everglades, which in reality is simply a very wide, slow moving river. Because the land was so flat, water could flow from lake to lake, spill over natural river channels and spread into floodplains. The native surficial sediments are highly permeable and capable of absorbing significant percolation of the water into the soil, which is underlain by porous limestone that is the outcropping of the Biscayne Aquifer. The Biscayne Aquifer is a water aquifer system that extends from land surface to approximately 250 feet in depth in southeast Florida. As shown in Figure 19, the Everglades serve as the recharge area for the Biscayne Aquifer and water supply for much of the southeast coast (Bloetscher and Muniz, 2008). When the Everglades are dry, aquifer levels decrease, which may lead to saltwater intrusion (i.e., migration inland and upward below wells – Bloetscher, and Muniz, 2008).

During winter months, the surficial aquifer's water level continues to decline without some form of supplemental recharge. The canals operated by the South Florida Water Management District (WMD) are designed provide flood protection, but also serve to limit aquifer drawdown induced by the canals by delivering water stored in Lake Okeechobee or the water conservation areas during the dry season to prevent aquifer flows to the canals (see Figure 20). Proximity to the water conservation areas benefits western wellfields, but little help is available for eastern wellfields because most of the coastal canals are open to the ocean without salinity barrier/control structures (Bloetscher and Muniz, 2008). As a result, the aquifer levels in eastern wellfields steadily decline during the winter months, which subject the Biscayne Aquifer to contamination from saltwater intrusion.

Ten years ago, the South Florida WMD was approached by at least one eastern utility about the possibility of installing coastal lock structures closer to the coast than the current systems. The WMD did not pursue this because of concerns regarding inverse condemnation suits from people who no longer would have open ocean access, thus claiming a loss of property values. However, for the billions of dollars that may need to be spent to relocate wells and intakes, this issue needs to be revisited. A lock structure would cost $10 to 20 million, and dozens are potentially needed to protect the aquifer. Models for this scenario and more advance solution lie in Venice Italy and the Netherlands.

Tampa Bay Water uses several rivers as water supply sources; the Hillsborough River, the Tampa Bypass Canal and the Alafia River. The Hillsborough River and Tampa Bypass Canal both have structures that prevent saltwater from mitigating up stream thus protecting the drinking water source. However, the Alafia River does not have a salinity barrier. Rising sea levels, even minor rises, could potentially push the saltwater wedge further upstream which could impact Tampa Bay Water's ability to withdraw fresh water from this river. Monitoring and additional modeling activities are recommended to improve our understanding of how sea level rise may affect this water supply source.

These are but two examples. Utilities and the water management districts throughout the state should look for similarly situated canals without locks and address them if the long-term climatic issues will adversely impact groundwater supplies or create potential flooding that can be prevented.

The Need to Alter Wastewater Disposal Patterns

Wastewater disposal practices will need to be evaluated in light of climate change. Wastewater dischargers may need to change treatment to reflect the increased degree of difficulty in meeting current standards or relocate discharge outfalls. Some standards (i.e., pollutant-specific goals) may need to change to reflect more sensitive environmental conditions (USEPA, 2008). The effects of climate change may lead to relocating sewage treatment plants and discharge outfalls. One alternative to discharging effluent is the use of treated wastewater (i.e., reclaimed water). The use of reclaimed water is a stated goal of the Comprehensive Plan for the State of Florida; Florida is among the leaders in reclaimed water use in the United States, with some 400 facilities using reclaimed water for a variety of uses, including the irrigation of agricultural land, golf courses, roadway medians, landscaping and residential homes and industrial uses such as cooling towers.

Receiving Water Quality Issues

Lettenmaier et al, 2008, noted that water quality is sensitive to increased water temperatures, changes in patterns of precipitation, and changes in pollutant loadings. If stream temperatures increase due to climate, there will be both direct and indirect effects on aquatic ecosystems, especially during low flow periods. Water quality impacts to surface waters due to climate change are currently difficult to quantify. Lettenmaier et al, 2008, noted that there are no current hydrologic observing systems for purposes of detecting climate change or its effects on water resources, and limited studies of hydrologic trends in the southeast or Florida. Lins and Slack showed generally increasing stream flow over most of the southeast in the second half of the 20th century while Czikowsky and Fitzjarrald (2004) analyzed stream flow patterns related to increased evapotranspiration at the beginning of spring. USEPA (2008) notes that lower flows in streams during the summer and fall could substantially reduce available dilution in those streams, thereby concentrating salts and other pollutants. Temperature will reduce dissolved oxygen (by increasing temperature and increasing metabolism). As a result, it may become more difficult to meet or maintain current surface water quality standards for receiving water bodies. There are three principal responses to climate change with respect to water quality standards: expand efforts to meet current standards, modify criteria to protect uses; and, modify designated uses.

Use of Reclaimed Water

Currently, most reclaimed water use occurs on the west coast of Florida and central Florida. A major reason is that many wastewater treatment plants originated as small developer-owned systems designed to serve their development, and later were deeded to local governments. Conventional disposal methods (e.g., stream discharges or ocean outfalls) are not easily permitted or have proven to not be sustainable in this part of the state. The costs of injection wells for small systems cannot be justified either, so the reuse (usually by percolation ponds) of small quantities of wastewater was the chosen alternative for disposal. With the advent of federal funding in the 1970s, larger systems like St. Petersburg pursued larger scale reuse efforts.

Concurrently, municipal (potable water use associated with development) and agricultural usage have increased demands on groundwater sources in the southwest and central regions of the state. The Floridan Aquifer system (groundwater source for southwest and central Florida) is hydrologically much different than the Biscayne Aquifer located along the southeast coast. In many parts of west-central Florida, there is a strong hydrologic connection between lakes and wetlands and the Floridan aquifer. As wellfield development moved inland due to saltwater intrusion into coastal supplies, significant groundwater pumping caused the lowering of lake and wetland water levels and stream flow declines, resulting in local terrestrial changes in flora, fauna and wetland characteristics. This led to a proactive regulatory encouragement of reuse to supplement or replace groundwater use for non potable purposes in developed areas. A positive outcome has been reducing inland groundwater withdrawal, especially in sensitive ecological areas. The cost of implementing reclaimed water use systems is $3-5/gallon in capital costs. However, locally the costs, particularly in developed urban environments are much higher than the cost of traditional groundwater supplies. To help offset these higher costs and as a means to provide incentives to develop reclaimed water systems that offset the need for potable water supplies in west-central Florida, the Southwest Florida WMD has budgeted approximately $19 million dollars per year over the last ten years to co-fund reclaimed water projects. Since the majority of the co-funded projects are 50/50 District cost share, a minimum of at least $38 million dollars per year has been expended over the last ten years to develop reclaimed water systems within the Southwest Florida WMD.

Beginning in 1990, the Southwest Florida WMD placed a special permit condition on all water use permits in Water Use (Resource) Caution Areas to require the use reclaimed water if it is technically, environmentally, and economically feasible. The result has been a lowering of the per capita water use associated with lawn and landscape irrigation while providing both a wastewater disposal option and a water supply benefit. Within this region the focus of reclaimed water use has been on irrigating lawn and landscapes, agricultural sites, and providing reclaimed water to meet industrial and commercial needs, and not providing recharge to groundwater wellfields. In virtually all cases, the wellfields are inland, while development is more coastal. As a result the raw water supplies are generally up-gradient from the reuse application sites.

The situation is much different in southeast Florida. The southeast coast has historically had a much older and denser development pattern than the west coast or central Florida. The same programs that created funding for St. Petersburg to implement a reclaimed water use system within an urban setting encouraged southeast Florida utilities to pursue injection wells and outfalls to move treated wastewater away from developed land. Many injection wells are currently under development. As a result, reuse on top of water supplies has not been favored by local officials. There is a limited amount of large acreage upon which to use reclaimed water, so the alternatives generally migrate to residential reuse. The cost to install a dual distribution system similar to the City of St. Petersburg's system has been estimated at nearly $10,000 per lot and a total in excess of $30 billion, and thus not cost effective. The number of golf courses has decreased with time leaving power plants as the most likely use for reclaimed water. The recharge area for the Biscayne aquifer is the Everglades. Cost and feasibility of applying treated wastewater to this recharge area needs to be evaluated.

The Southwest Florida WMD and the water conservation program outlined by FDEP in 2002 indicated the most likely large scale reclaimed water use option was canal recharge. The Legislative ban on outfalls by 2025 also sets up utilities in southeast Florida to produce reclaimed wastewater. However, there are significant challenges to using reclaimed water for canal recharge, including: chlorides in excess of 100 mg/L, local limitations to nutrients in canals and the reefs, and the potential for recharge directly adjacent to local water supplies (indirect potable reuse), which can face public resistance. These challenges need to be thoroughly reviewed and potential mitigation efforts evaluated. All three of these limitations will force the canal recharge option to pursue removal of chlorides and phosphorous, at a cost of an additional $6 billion (see artificial recharge section below).

Relocation of Wells

Water supply issues are a potential problem throughout the state since so much of the state relies on groundwater. With the exception of north Florida, Tampa Bay and West Palm Beach, virtually all of the rest of the state relies on groundwater, most of which recharges outside the immediate service area. The central part of the state relies on the Floridan aquifer which recharges from Georgia on south through Gainesville (and perhaps further). This water is a fresh water supply, and is expected to continue to be so. However, changes in precipitation patterns, especially lessening precipitation, coupled with added demands will potentially affect aquifer levels, and springs in the area requiring pursuit of other supplies that are unclear at this time. Mass migration northward would exacerbate the problem.

In Pinellas County, the freshwater supplies are gone. Tampa Bay Water is charged with water supplies for the region, which include planning for climate change and conjunctive use of surface and groundwater's and the installation of appropriate protective devices. So wellfield relocation is already underway, and conjunctive use appears to be part of the solution. South Florida is a much different problem. Wellfields located in other coastal areas of the state will need to be evaluated to determine if sea level rise will potentially require relocation of production wells. Current indications are that sea level rise in the Tampa Bay region is not sufficient to require relocation of existing production wells.

The Biscayne Aquifer is located adjacent to Florida's southeast coast and is susceptible to the effects of sea level rise. As previously described, the highly managed water control system in south Florida has permanently reduced groundwater levels along the coast which enabled the development that exists today. As a result of reduced groundwater levels, combined with lessened historical flows to the Everglades and less water standing in the Everglades during the summer months, the Biscayne Aquifer does not recharge as it once did. The net result is a reduction in available fresh water supplies during the dry season, which coincides with increased winter population and peak irrigation season for lawns and agriculture. Another impact of reduced recharge of the Biscayne Aquifer is the increased potential for contamination due to saltwater intrusion. As noted in Figure 12, sea level rise of a modest 5 feet will inundate much of the lower Everglades, rendering many Miami-Dade wells, along with many coastal wells, salty and unusable. The cost to relocate wells inland is approximately $1 million per well plus piping. For relocation of 500 MGD, this cost exceeds 0.5 billion dollars, and is unlikely to receive permits under current circumstances. As a result, new supplies or alternative recharge mechanisms as described below would need to be employed.

Regionalization of Water Supply Utilities

Regionalization of water supplies is one way to diversify supplies and reduce risk related to climate change. The cost of joining a regional organization needs to be evaluated against the costs of developing new sources of supply by a single utility. Economies of scale and cost sharing among multiple parties can reduce the cost to a single utility. Relying on others to provide a utility with its water supply is uncomfortable for many utilities due to a loss of local control. However, the regional entity assumes the regulatory and construction risks which can be burdensome for individual utilities. This can be viewed as a benefit to the local utility, especially small utilities. Regionalization shifts risk for water supply generation to another entity and can extend existing supplies delaying capital expenditures.

Regionalization of water supply development offers an opportunity to develop more diverse supply sources while minimizing the incremental impacts to water utility rate payers. Examples of successful existing regional water supply partnerships are Tampa Bay Water, the Peace River/Manasota Regional Water Supply Authority, and the Withlacoochee Regional Water Supply Authority, among others. Currently, a central Florida group of local governments are evaluating (1) the feasibility of a new desalination plant to be located on Florida's northeast coast and (2) the feasibility of taking surface water withdrawals from the upper St. Johns River. In addition, Polk County has established a new working relationship with the municipal governments within its borders to work together to explore alternative water supplies and to minimize competition for the scarce remaining ground water resources

Conversion to New Water Supplies

There are several ways coastal communities with current supplies that may be potentially threatened by sea level rise can meet long term potable water supplies. One option is to implement water efficiency practices as discussed previously. However in growth areas, water use efficiency effort can delay the need for system expansions. Alternative water supplies need to be investigated. In Florida, the first alternative is to treat brackish surficial aquifer supplies or tap deeper Floridan aquifer supplies. In either case, reverse osmosis technology would likely be used, at higher energy and financial cost than freshwater supply. This technology is used at a number of plants throughout south Florida, including Hollywood, Jupiter, Marco Island, Collier County, Englewood, Gasparilla Island, Sarasota, and Venice, without placing unreasonable burdens on utility rate payers. While relatively expensive, reverse osmosis technology is one of a number of options to consider in planning for 2030 water supply needs.

Use of deep Floridan Aquifer production wells as a source of brackish water needs to be evaluated locally due to hydrogeologic differences that may limit the use of this source. For example, test wells in Hollywood showed aquifer drawdown in excess of 80 feet per well under pumping rates of less than 1.5 MG. This can lead to deterioration of water quality over the long-term because there is no local recharge to offset the pumping effects. Several coastal communities, most notably Marco Island, have suffered from this phenomenon. The cost of these wells is upwards of $1 million/2 MGD of flow. Replacing 0.7 billion gallons per day (BGD) of fresh water supplies with Floridan aquifer deep production well sources, plus adding another 0.5 BGD of Floridan aquifer wells, would cost ratepayers $600 million dollars and create the need to develop reverse osmosis plants at $3-5/gallon in capital – a cost of an additional $4 to 6 billion dollars. The long-term reliability of using the Floridan Aquifer as a source of raw water in south Florida is questionable.

Another choice for coastal communities is desalination of sea water. Desalinated seawater can be a sustainable water supply option if regulatory issues associated with concentrate management, intakes and energy demands can be overcome. For example, a 50 MGD desalination plant could required 30-40 MW of power to operate, the equivalent of burning 3000 tons/day of garbage in a waste to energy plant. The power cost to operate such a facility would approximate the cost of the facility itself and is not likely to be available in excess on the current power grid.

The need for water infrastructure will compete with the need for armoring and other technologies to protect private property and the potential relocation of population centers. The cost of desalination for 6 million people in coastal areas may exceed $10 billion plus the cost for intakes and disposal of concentrate, plus another $10 billion for power supplies. Under a scenario where significant existing water sources such as the Biscayne aquifer in south Florida are negatively impacted by sea level rise, a combination of both conversion to new supplies and increasing treatment, such as reverse osmosis, will likely be necessary.

Another option is conversion to surface water sources that are not expected to be impacted by sea level rise. Implementation of this option by coastal communities may require regional cooperation or building additional infrastructure to bring treated surface water into the local distribution system.

Artificial Recharge Scenarios

Artificial recharge of groundwater using reclaimed water has been proposed as a solution to protect coastal fresh groundwater sources from sea level rise and create additional sources of water to meet the growing water needs in some regions of the state. The Biscayne aquifer is considered a G-1 sole source aquifer and the current rules provide the very highest protection for sole sources aquifers. Current legislation (62-610.560 - Ground Water Recharge by Injection) provides the opportunity to recharge aquifers in the state. The rule is as follows:

> “(1) Injection of reclaimed water into Class F-I, G-I, or G-II ground water shall be considered as ground water recharge.
>
> (2) Reclaimed water injected into Class G-II ground water containing 3000 mg/L or less of total dissolved solids or into Class G-I or F-I ground water shall meet the full treatment and disinfection requirements contained in Rule 62-610.563(3).” (FDEP, 2008)

Full treatment is defined by 62-610.563 Waste Treatment and Disinfection (3) as:

> “(a) The principal treatment and disinfection requirements described in Rule 62-610.563(2), F.A.C., (which means a reclaimed water that meets, at a minimum, secondary treatment and high-level disinfection, shall not contain more than 5.0 mg/L of total suspended solids before application of the disinfectant… filtration for total suspended solids control “… “ and as the primary barrier for removal of protozoan pathogens (Cryptosporidium, Giardia, and others),”…,chemical feed facilities for coagulants, coagulant aids, or polyelectrolytes shall be provided and maintained, and total nitrogen ... limited to 10 mg/L as nitrogen as a maximum annual average limitation (FDEP, 2008).

The rule notes that “surface water discharges, WQBELs established under Chapter 62-650, F.A.C., may place additional limitations on nitrogen or other parameters (FDEP, 2008)”. Also more stringent requirements may be enacted by local governments for protection of the reefs, canal systems, etc, as has occurred n Broward County. Please see the Appendix B for additional information on state regulatory requirements for waste treatment and disinfection.

Canal recharge, noted above is one suggested reuse option, especially is southeast Florida. The current suggestions for canal recharge are likely to be too expensive to receive serious traction because approximately 300 MGD of the south Florida wastewater has chlorides in excess of 1,000 mg/L which means it cannot be used for reuse or recharge purposes without reverse osmosis treatment. A variance for high chlorides is not likely to be viewed as acceptable by any regulatory agency. The chlorides cannot be reduced significantly in the long term as sewer pipes have allowable leakage and beach properties, which tend to be older, will leak more than inland areas, and yet may still remain in the tolerance for leakage on the system.

Fortunately a facility exists that has done precisely this kind of treatment - Water Factory 21 in Orange County, California. Water Factory 21 has been used to recharge groundwater in western Orange County 30 years. After 30 years this facility was recently reconstructed with reverse osmosis and ultraviolet disinfection. Based on the costs for the construction of the new Water Factory 21 in Orange County California, construction costs for similar facilities in southeast Florida would approach $12 per gallon treated (CDM report), yielding a total cost above current treatment, with piping costs, exceeding $6 billion, plus over $10/1,000 gallons for water treated. With this concept in mind, and assuming the need to meet the indirect potable reuse requirements, Miami-Dade County has embarked on a similar canal recharge project. The cost estimate for Miami-Dade’s current 22 MGD canal recharge project is $700 million ($35/gallon); for 500 MGD, the costs may exceed $15 billion.

The Comprehensive Everglades Restoration Plan (CERP) program offers the option to pursue regional RO plants that discharge to the canal system in the Everglades. This solution should be considered since little “new” water has been added to the Everglades, which was an original goal of the CERP project and the solution may address a number of other perceived issues. If the water managers and the State truly believe that reuse is the answer to south Florida’s water supply needs, there is 500 MGD of wastewater created everyday that needs treating. Rather than spend additional money on ASR wells (now estimated at $1.8 billion), reservoirs that may not efficiently retain sufficient water to matter, land and utility improvements ($40 billion), a more cost-effective option might be found in the original Everglades restoration planning documents: the South Florida WMD can build regional recharge facilities that treat secondary wastewater. While details would need to be worked out, the concept is this:

- Construct a piping network to pump secondary effluent to one of several regional 50-100 MGD recharge facilities.

- Recharge facilities would consist of filtration, cartridge filtration, UV disinfection, reverse osmosis, and advanced oxidation. The resulting water quality would approach distilled water, so post chemical stabilization could be provided.

- Use existing canals and / or add additional conveyance systems to discharge the treated recharge water to the feeder canals to recharge the surficial aquifer system.

- Assuming permitting and legal issues could be overcome, the water could also be discharged directly to the Everglades which would have the benefit of providing a consistent source of water to the Everglades system.

- Adding water to the Everglades (or feeder canals) would recharge the Biscayne Aquifer, which would increase available water supplies on the southeast coast.

- Current wells and treatment facilities could continue to operate, maximizing local investments.

- This matches the current natural system.

Benefits to this option are far-reaching despite the potential costs:

- Centralization of facilities would lower costs of operation and likely construction due to economies-of-scale.

- Reduction and potential elimination of ocean outfalls.

- Reduction in the number of injection wells.

- Improved ecosystem conditions, including recharge of water to the Everglades (and Biscayne aquifer) that may help stem saltwater migration.

- Increased efficiency in the utilization and retention of local and regional water resources.

The suggested concept does not envision South Florida WMD operation of these facilities, but a partnership between utilities and regulators to address water supply and permitting to meet the growing demands of the region (Bloetscher and Muniz, 2008). The barriers to the implementation are mostly local and political will at the present time. Other possibilities for water storage and water quality enhancement lie in the current effort to purchase the 187,000 acres owned by the US Sugar Corporation in and near the Everglades Agricultural Area.

Tampa Bay Water and its Member Governments are continuing to explore using treated wastewater from the City of Tampa’s H.F. Current plans to augment either river flow or to recharge the groundwater system. Currently, on an annual basis, approximately 50 MGD of wastewater effluent is discharged from this plant into Tampa Bay. The goals would be to reduce or eliminate the coastal discharge of this highly treated wastewater and provide additional fresh water capture to meet growing potable needs. At this time costs are not available. However, permitting the discharge of this highly treated wastewater into a river is not easy. Tampa Bay Water spent over five million dollars attempting to permit a similar project in 2004-2005, and failed to receive a favorable recommendation from FDEP. Changes in water policy are likely needed to facilitate this type of project moving forward.

Transfer of Resources between Regions

The transfer of water between areas of the state is an ongoing political issue that is more fully discussed by others. The synopsis is this – Florida's "Local Sources First" legislation provides that such transfers may be considered only after a local area has exhausted all its options (including conservation and alternative sources) to provide for its own water supply needs. It is not beyond the realm of possibility that in the face of climate change and increasing demand for water, such transfers may become a part of Florida's future plans. However, before this option of last resort is exercised, other options such as forming regional partnerships to address large-scale water supply issues could be considered to minimize potential conflict and competition for limited water resources and reduce the need for legislative directives.

Issues for Consideration

Impacts should be expected to vary regionally, but in general, climate change could result in increased demands on our infrastructure systems, both in terms of operations & maintenance costs and the need for capital expenditures. Changes will affect drinking water, wastewater, and storm water systems and range in scope from physical damage, to changes in treatment costs and treatment infrastructure, to changes in drinking water supply. Utilities and water management need to work together to develop the State’s risk profile and develop mitigation and adaptation strategies. In attempts to move our systems and the sector as a whole towards greater sustainability, USEPA (2008) focuses on:

- Better management;
- Water efficiency;
- Full cost pricing; and
- Watershed approaches to water supply planning and infrastructure delivery.

Climate change is predicted to impact Florida through sea level rise and changes in precipitation patterns; in addition to statewide planning, current planning efforts by utilities should incorporate climate change issues. From the water, wastewater and storm water utilities’ perspective there are three critical issues regarding climate change: (1) how increasing hydrologic variability may affect water supply and demand and wastewater collection and treatment, 2) in coastal areas, how sea level rise may impact water supplies, utility infrastructure, and relocation of coastal population centers, and (3) how energy usage, to treat and deliver potable water and to treat and dispose of wastewater, may contribute to climate change or variability,

A number of tools and outreach efforts can be adapted or created to foster the consideration of climate change in planning for infrastructure sustainability including advanced asset management; requirements of utilities examine their environmental footprints, and constantly work towards improvements in environmental systems.

Short-term options for limited sea level rise include protection of coastal systems, by building public infrastructure like beach renourishment, flood protection works, armoring infrastructure to protect coastal property, manhole sealing, flood protection and pipe sealing and marsh building. Larger and more long-term requirements include retreat via the movement of development and infrastructure away for the coast. Adaptation to climate change involves inland movement of wellfields, deeper wells, desalination, reclaimed water use alternatives, and development of additional surface water supplies. Three categories of adaptation should be considered carefully: protection, retreat, and accommodation.

If Figure 12 occurs, armoring infrastructure to protect current coastal property may be a bigger issue than water supplies, and options for disposal may prove even more limiting. While armoring is an option to protect coastal property, this does not address water supply challenges associated with sea level rise. This may require a wholesale plan for migration of millions of residents to the central part of Florida, which has stressed water supplies at present. Competition for limited resources will become a major issue for water purveyors. The following subsections outline the regulatory actions, policy/ legislative direction, and short- and long-term goals required to facilitate climate change adaptation in Florida with respect to water supply sustainability.

The major concern for addressing impacts due to climate change from a regulatory perspective is limited. USEPA (2008) identifies the following goals for USEPA and utilities for addressing climate change scenarios:

- Improve Energy Efficiency at Water and Wastewater Utilities.
- Implement the WaterSense Program. EPA will continue its current efforts to implement the WaterSense program and will incorporate educational information about related reductions in energy use.
- Water Conservation and Management for Drinking Water Systems. USEPA will explore opportunities with States and drinking water systems to better address expected impacts of climate change on water supply and water usage rates through water conservation and water resources management.
- Water Conveyance Leak Detection and Remediation. The National Water Program will promote technologies to identify and address leakage from water pipes and other conveyances.
- Industrial Water Conservation, Reuse, and Recycling Technology Transfer. The National Water Program will identify industries and facilities that best maximize their water efficiency and develop a technical guide for control authorities and industry for promoting water minimization, re-use, and recycling.
- Federal Agency Water Conservation Guidance. The National Water Program will develop Water Efficiency Implementation Guidance for all Federal agencies under Executive Order 13423.
- Increase Watershed Sustainability and Resilience.
- Address Impacts of Climate Change on Potential Contamination of Drinking Water Sources. The National Water Program will evaluate, as part of the contaminant

occurrence analyses supporting the EPA 6 year review of drinking water standards and the contaminant candidate list, the potential for projected climate change to increase the nature and extent of contaminants in drinking water supplies and systems.

- Assess Clean Water Microbial Criteria and Risks of Waterborne Disease. The National Water Program will assess the potential for increases in waterborne disease and other water-related disease vectors as a result of climate change.
- Develop Biological Indicators and Methods.
- Link Ecological and Landscape Models.
- Review Existing Effluent Guidelines. Review the existing effluent guidelines to identify needed changes based on industrial production or treatment changes related to climate change.
- Assess Fresh Waterbody Spatial Changes Due to Climate Change. In cooperation with USGS, develop an assessment of the potential for change in the spatial characteristics of waters due to climate change and issue a report describing findings.
- BASINS Climate Assessment Tool. The Office of Water will develop training sessions in Washington, DC, and selected Regions to assist EPA, State, Tribal, and other government staffs in using the CAT element of the BASINS decision support tool.
- “Climate Ready Estuaries”. The National Water Program will establish a Climate Ready Estuaries Program in partnership with the Office of Air and Radiation’s Climate Change Division.
- Review/Revise Nonpoint Pollution Guidelines and Methods.
- Review and Adapt NPDES Permit Program Tools. Conduct an internal review of the flexibilities and tools in the NPDES program.
- Evaluate Opportunities to Address Wet Weather/Climate Impacts at Municipal and Industrial Operations.
- Implement the Sustainable Water Infrastructure Initiative and Adapt Decision Support Tools to Include Climate Change.
- Develop a Sustainability/Vulnerability Analysis Handbook for Climate Change Impacts.
- Clarify Use of the Clean Water and Drinking Water State Revolving Funds (SRF) to Support Adaptation to Climate Change. Work with State partners to clarify what types of climate change–related infrastructure expenditures are eligible for SRF assistance.”

USEPA, FDEP and the water management districts would have primary responsibility to implement strategies to address climate change. Water use permit regulations in the state should be evaluated for improvements to facilitate conjunctive use of groundwater and surface water sources.

Direction to planning agencies is the major focus. Planning for climate impacts should occur in 5, 20 and at least 50 year intervals and be a requirement of comprehensive plans for local government, regional water supply plans of the water management districts and regional water supply plans for regional water supply authorities. Ignoring climate change impacts is not acceptable, but common according to (Deyle et al 2007). If the long-term sustainability of a program is not possible, short-term development or investment should not be considered. Policy discussions aimed at balancing competing environmental and climate change objectives need to occur. Currently, the push to develop energy intensive alternate sources to meet environmental goals in west-central Florida is in conflict with the state's goal to reduce greenhouse gas emissions.

Blanket policies or legislation about water supply options, should also be avoided if possible as there are many possible solutions to solve water issues locally. For example, the use of horizontal wells to capture water that otherwise runs to tide, is a prudent investment of local dollars and should be acceptable, especially for small utilities on the east coast near canals that otherwise drain the aquifer. Protocols could be developed to permit water resource capture. Current regulatory barriers should be removed to encourage such innovative technologies. Much of the cost of local sources could be lessened with the appropriate consideration of local solutions.

Additional development in flood prone areas should not be permitted without local solutions. State and local agencies have been averse to such regulations due to private property rights arguments, but there is no sense in developing or rebuilding projects in areas that are flood prone or predicted to be flooded in the future. Lending agencies will ultimately seek relief from the state if properties will not have long term potential or default due to climate change impacts.

Depending on the likelihood of climate change impacts, borrowing agencies may be disinclined to lend money where there is a potential for investments to be under water. Hence, state funding should be secured to help communities and the water management districts identify and proceed with construction of long-term infrastructure to overcome the potential effects of sea level rise so as not to adversely affect local economies. At the same time, smart decisions based on quantitative risk assessments with uncertainty must be made.

Blanket legislation to accomplish a given solution, that provides neither funding nor access to a regional solution should be evaluated further. Mandates from legislative directives are a cause for concern for county and municipal governments who are under increasing pressures from budget constraints. The outfall legislation is such an issue and a solution is offered herein. Careful analysis of the likely impacts of such decisions is needed as local funds will be limited due to constitutional restrictions on property taxes, legislative limitations of revenue raising potential, and limits on bonding capacity due to affordability concerns.

Preventative measures cost less than reactive measures. Hence, pumping, piping, hardening and power grid reinforcement are needed. Local utilities have invested millions to harden their systems, but the water supplies remain vulnerable. Disaster funding is needed to help utilities who make investments but suffer losses. They should receive first priority as an inducement for all system to make such investments.

References

Bloetscher, F. (2008), The Potential Impact of Climate Change on Groundwater Recharge, GWPC Annual Forum Proceedings, GWPC, Oklahoma City, OK.

Bloetscher, F. (2008), Basics for Decision-makers: a Local Officials Guide to Water and Sewer Utilities, AWWA, Denver, CO.

Bloetscher, Frederick and Muniz, A. (2008), “Water Supply in South Florida - The New Limitations”, *Sustainable Water Sources (Reno) Conference Proceedings*, AWWA, Denver, CO.

Bloetscher, F. and Muniz, A. (2006), “Defining Sustainability for Water Supply Purposes”, *Florida Section AWWA Conference Proceedings*, Hollywood, FL.

Buffoni, L., Brunetti, M., Mangianti, F., Maugeri, M. & Nanni, T. (2002), Variazioni Climate Change and Groundwater: A Short Review 7, *Climatiche in Italia Negli Ultimi 130 Anni. Bollettino Geofisico Anno XXIII.*

Cocke, S., LaRow, T.E., and D.W. Shin (2007), Seasonal rainfall predictions over the southeast United States using the Florida State University nested regional spectral model, Journal of Geophysical Research, v 112, D04106.

Corum, Lyn (2008), Solar Cost Controller. Water Efficiency Vol. 3, No. 4. pp. 48-52.

Czikowsky, M. J., and D. R. Fitzjarrald (2004): Evidence of seasonal changes in evapotranspiration in eastern U. S. hydrological records. Accepted to J. Hydrometeor.

Deyle, R.E.; Bailey, K.C.; and Matheny, A. (2007), *Adaptive Response Planning to Sea Level Rise in Florida and Implications for Comprehensive and Public Facilities Planning*, Florida State University, Tallahassee, FL.

Dragoni, W. (1998), “Some considerations on climatic changes, water resources and water needs in the Italian region south of the 438N”. In: ISSAR, A. S. & BROWN, N. (eds) *Water, Environment and Society in Times of Climatic Change*. Kluwer, 241–271.

Dragoni, W. and B. S. Sukhija (2008), Climate change and groundwater: a short review, *Geological Society, London, Special Publications*; v. 288; p. 1-12

Enfield, D. B and Cid-Serrano, L. (2006), *Projecting the Risk of Future Climate Shifts*, International Journal of Climatology 26:885-895.

Enfield, D.B, Mestas-Nunez, A.M., and Trimble, P. (2001), *The Atlantic multidecadal oscillation and its relation of rainfall and river flows in the continental U.S.*, Geophyical Research Letters, v. 28 no 10 p 2077-2080.

FDEP (2008), Chapter, 62-610, F.A.C. Reclaimed Wastewater Rule, accessed 7/1/2008, http://www.dep.state.fl.us/legal/Rules/wastewater/62-610.pdf

Freas, K.; Bailey, R.; Muneavar, A.; and Butler, S. (2008), Incorporating Climate Change in Water Planning, JAWWA v 100 no 6, p 93-99.

Frederick, K. and Gleick, P (1999), “Water and Global Climate Change”, Potential Impacts on US Water Resources, Pew Center on Global Climate Changes, Arlington, VA.

Grumbles, Benjamin H., “Drops to Watts: Leveraging the Water and Energy Connection”, Water Efficiency, July/August 2007, p. 12-13.

Huntington, T. G. (2006), “Evidence for intensification of the global water cycle: Review and synthesis”, *Journal of Hydrology*, 319, 83–95.

Intergovernmental Panel on Climate Change - IPCC (2001), *Climate Change 2001: The Scientific Basis*, Cambridge University Press, New York, NY.

Intergovernmental Panel on Climate Change - IPCC (2007) **–** Climate Change 2007: The Physical Science Basis.

Kundzewicz, Z. W.; Mata, L. J.; Arnell, N. W.; Döll, P ; Jimenez, **.;**Miller**,** K**.;** Oki, T.; Şen, Z. and Shiklomanov, I (2007), **“**The implications of projected climate change for freshwater resources and their management”, *Hydrological Sciences Journal*, Volume: 53, Issue: 1, Page(s): 3-10.

Labat, D., Godde´ Ris, Y., Probst, J. L. & Guyot, J. L. (2004), ”Evidence for global runoff increase related to climate warming”, *Advances in Water Resources*, 27, 631–642.

Lettenmaier D.P. (2008) Chapter 4 - Water Resources, in Walsh, M (ed), The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States, U.S. Climate Change Science Program and the Subcommittee on Global Change Research, USDA, Washington, DC.

Lins, H., and J.R. Slack (1999), Streamflow trends in the United States. *Geophysical Research Letters*, 26, 227-230.

Marshall, Curtis H.; Pielke, Roger A. Sr.; Steyaert, Louis T. and Debra A. Willard (2003), “The Impact of Anthropogenic Land-Cover Change on the Florida Peninsula Sea Breezes and Warm Season Sensible Weather”, 28 *Monthly Weather Review*, vol. 132

McDannel, Mark, E. Wheless (2008), The power of digester gas. WE&T, Vol. 20. No. 6. pp. 36-41.

Moore, N., Rojstaczer S. (2002), “Irrigation’s influence on precipitation: Texas High Plains, U.S.A”, *Geophysical Research Letters*, 29, 2-1–2-4.

Mulkey, Stephen, “Climate change and land use in Florida: Interdependencies and opportunities”, A report prepared for the Century Commission for a Sustainable Florida, September 30, 2007.

Murley, J. (2006), Charting the Course, Where is South Florida Heading, Florida Atlantic University, Boca Raton, FL.

NOAA (2007), Observing Climate Variability and Change http://www.research.noaa.gov/climate/t_observing.html, accessed 3/24/2007.

Pielke, R. A., L. T. Steyaert, P. L. Vidale, G. E. Liston, W. A. Lyons, and T. N. Chase, “The Influence of Anthropogenic Landscape Changes on Weather in South Florida”, Monthly Weather Review, July 1999, p. 1669.

Richey, J E.; Costa-Cabral, M. (2006), “Floods, Droughts, and the Human Transformation of the Mekong River Basin”, *Eos Trans. AGU*, 87(52), Fall Meet. Suppl., Abstract.

Salmun, Haydee and Andrea Molod (2006), “Progress in modeling the impact of land cover change on the global climate”, *Progress in Physical Geography* 30, 6 (2006) pp. 737–749

Scanlon, Bridget R., Robert C. Reedy, David A. Stonestrom, David E. Prudic and Kevin F. Dennehy (2005), “Impact of land use and land cover change on groundwater recharge and quality in the southwestern US”, *Global Change Biology* 11, 1577–1593.

US Army Corps of Engineers (CERP, 1999), *C&SF Comprehensive Review Study Final Integrated Feasibility Report and Programmatic Impact Statement (PEIS)*, ACOE, Washington, DC.

U.S. Climate Change Science Program, “Synthesis and Assessment Product 4.3: The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States”, May 27, 2008.

USEPA (2008), National Water Program Strategy: Response to Climate Change, USEPA, Washington, DC.

USEPA (2004), “*Clean Watersheds Needs Survey 2004 Report to Congress*”, http://www.epa.gov/cwns/2004rtc/cwns2004rtc.pdf, See page A-1 under Florida.

USGS (2005), *Sustainable Water Resources Roundtable – Preliminary Report*, USGS, Washington, DC.

Wallis, Ambrose, M.R., and Chan, C.C. (2008), Climate Change: Charting a Course in an Uncertain Future, JAWWA v 100 no 6, p. 70-79.

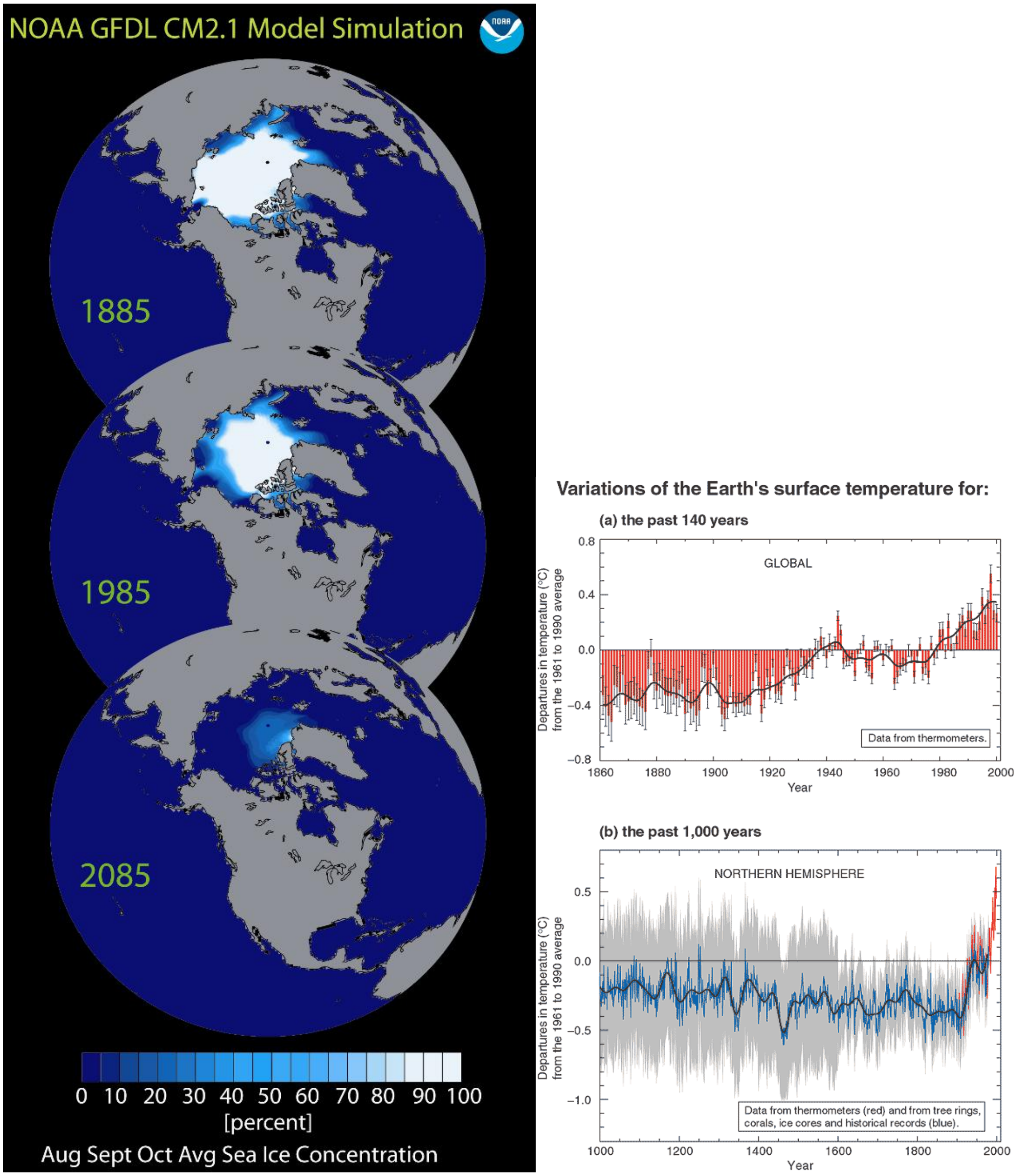


Figure 1 - Variations of the Earth's surface temperature over the last 140 years and the last millennium. Long records of past changes in greenhouse gases show the effects of large and increasing growth in anthropogenic emissions during the Industrial Era (~1750-present). [From the Intergovernmental Panel on Climate Change (IPCC) report, *Climate Change 2001: The Scientific Basis]* *http://www.research.noaa.gov/climate/t_observing.html*. Projected Changes in North Polar ice in 2085 which will lead to an increase in ocean water levels http://www.gfdl.noaa.gov/research/climate/highlights/images/Sea_Ice_3globes_V_1152x2528.png

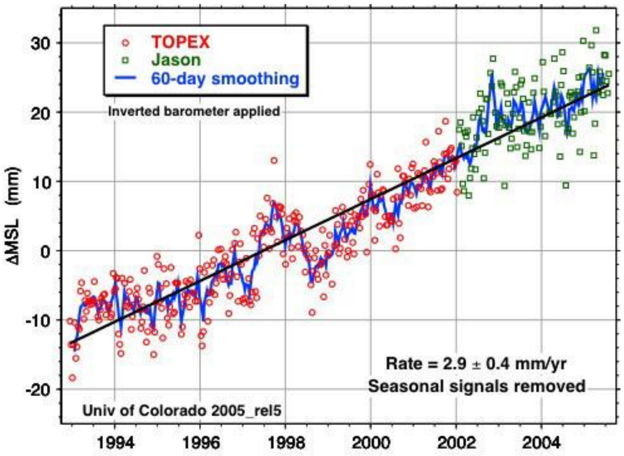


Figure 2 - Sea Level changes 1994 – 2005.
http://www.nasa.gov/centers/jpl/images/content/150218main_sealevel-browse.jpg

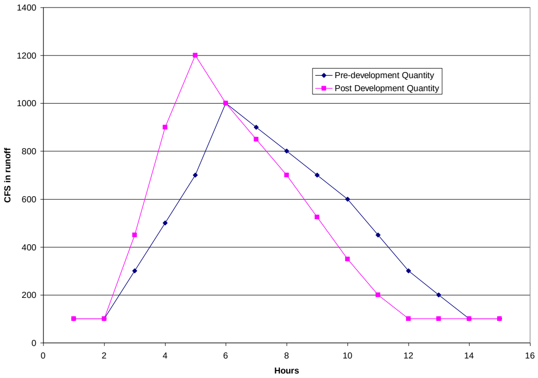
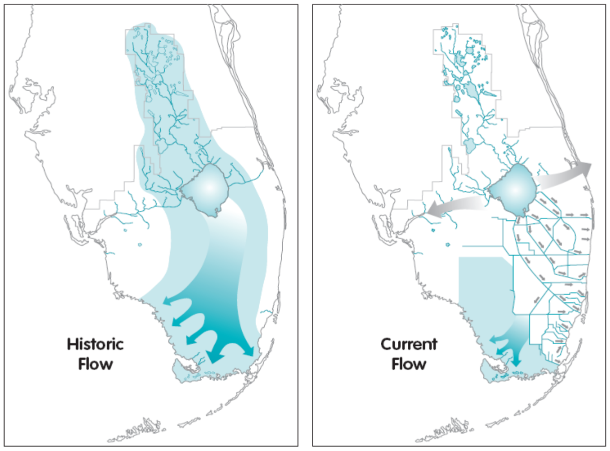


Figure 3 - An example of the difference in runoff characteristics caused by the change in land use cover showing the shorter runoff period and higher peaking amount.



Source: South Florida Water Management District

Figure 4 - Change in Natural flow paths in south Florida (source SFWMD).

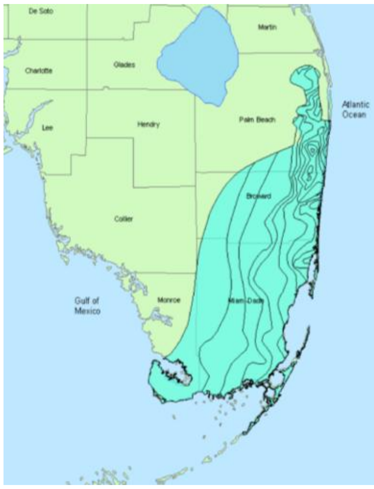


Figure 5 - natural water movement of the Biscayne aquifer (source, Bloetscher and Muniz, 2008)

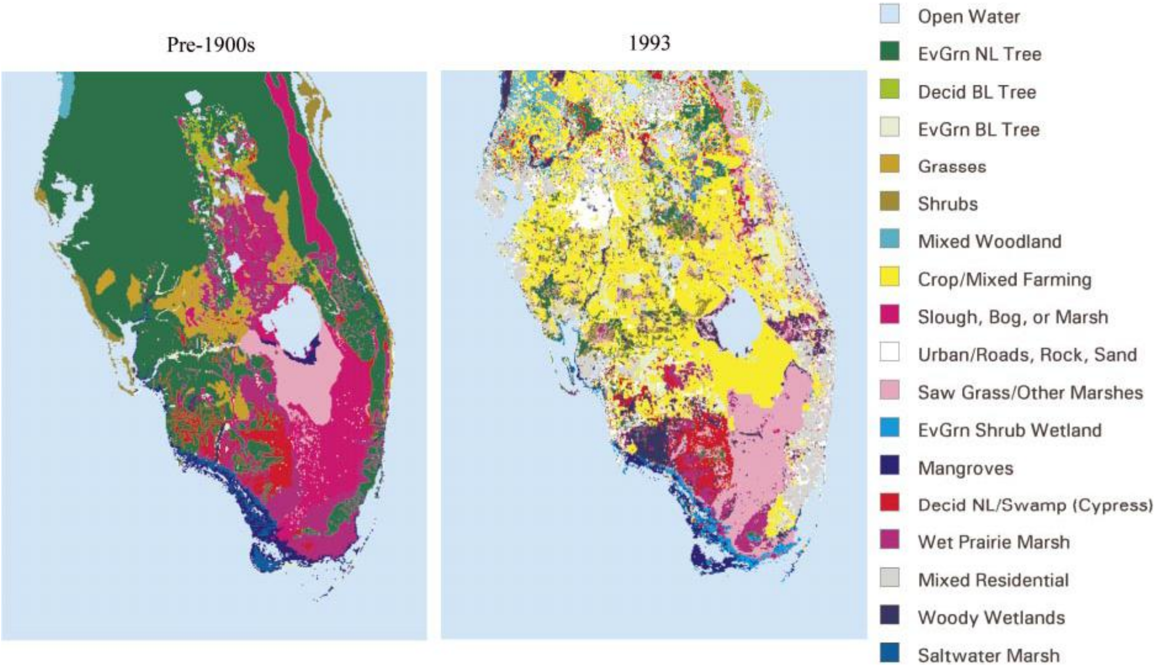


Figure 6 - Land use 1900 vs. 1993; yellow is agriculture and white is urban development (source Marshall, et al 2003).

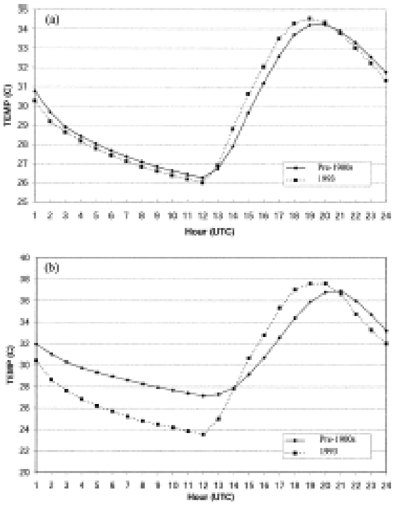


Figure 7 - Temperature changes; hotter in summer, cooler in winter means more freezes in the winter and both higher temperatures and more ET in the summer (source Marshall, et al 2003).

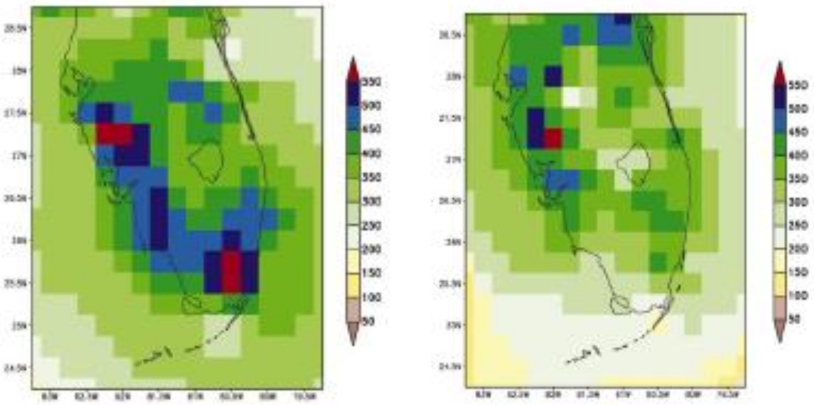


Figure 8 - Accumulated precipitation 1973 vs. change to 1994 (source Marshall, et al 2003).

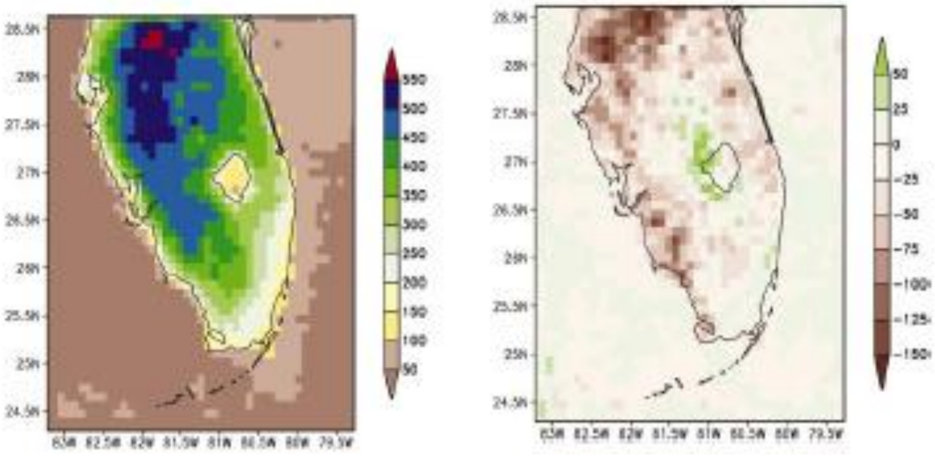


Figure 9 - Accumulated convective (summer rainstorm) rainfall with pre 1900 land use and difference to 1973 (source Marshall, et al 2003).

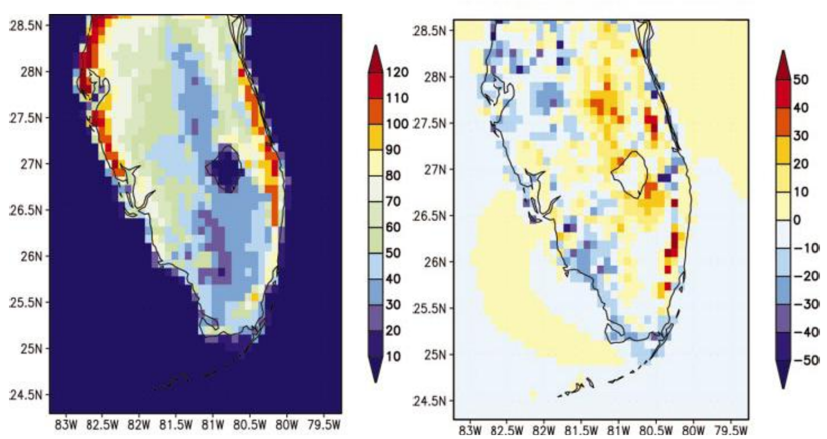


Figure 10 - surface latent heat flux, pre-1900 vs. 1993 (source Marshall, et al 2003).

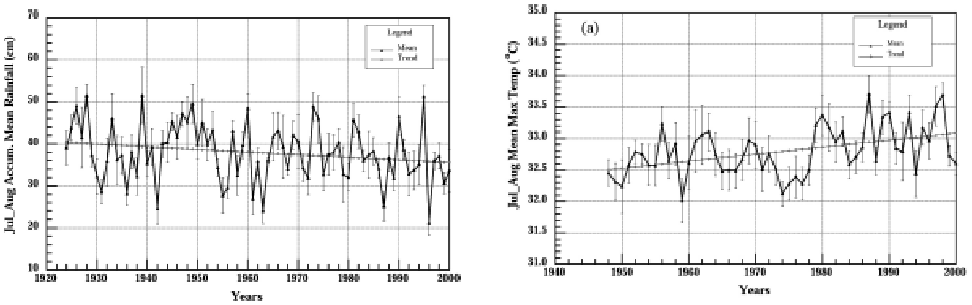


Figure 11 - Change in average rainfall and change in average temp 1924 to 2000. Note the reversed trend, which means groundwater inputs are lessened (source: Marshall, et al 2003).

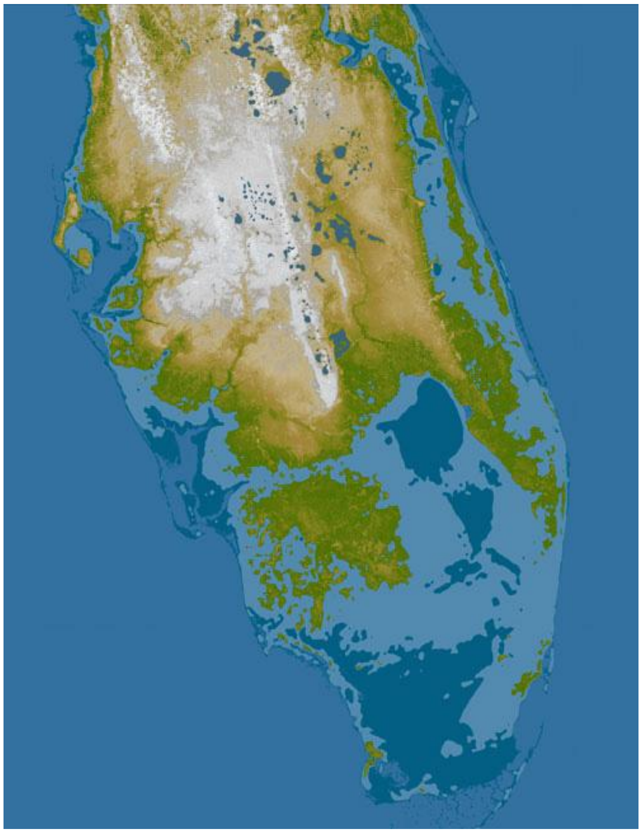


Figure 12 - Sea Level rise impacts in Florida (blue areas 0-5 ft sea level rise, most likely scenario, and the higher risk alternative in light blue 5-16 ft) http://www.nasa.gov/centers/jpl/news/gracef-20060602_prt.htm.

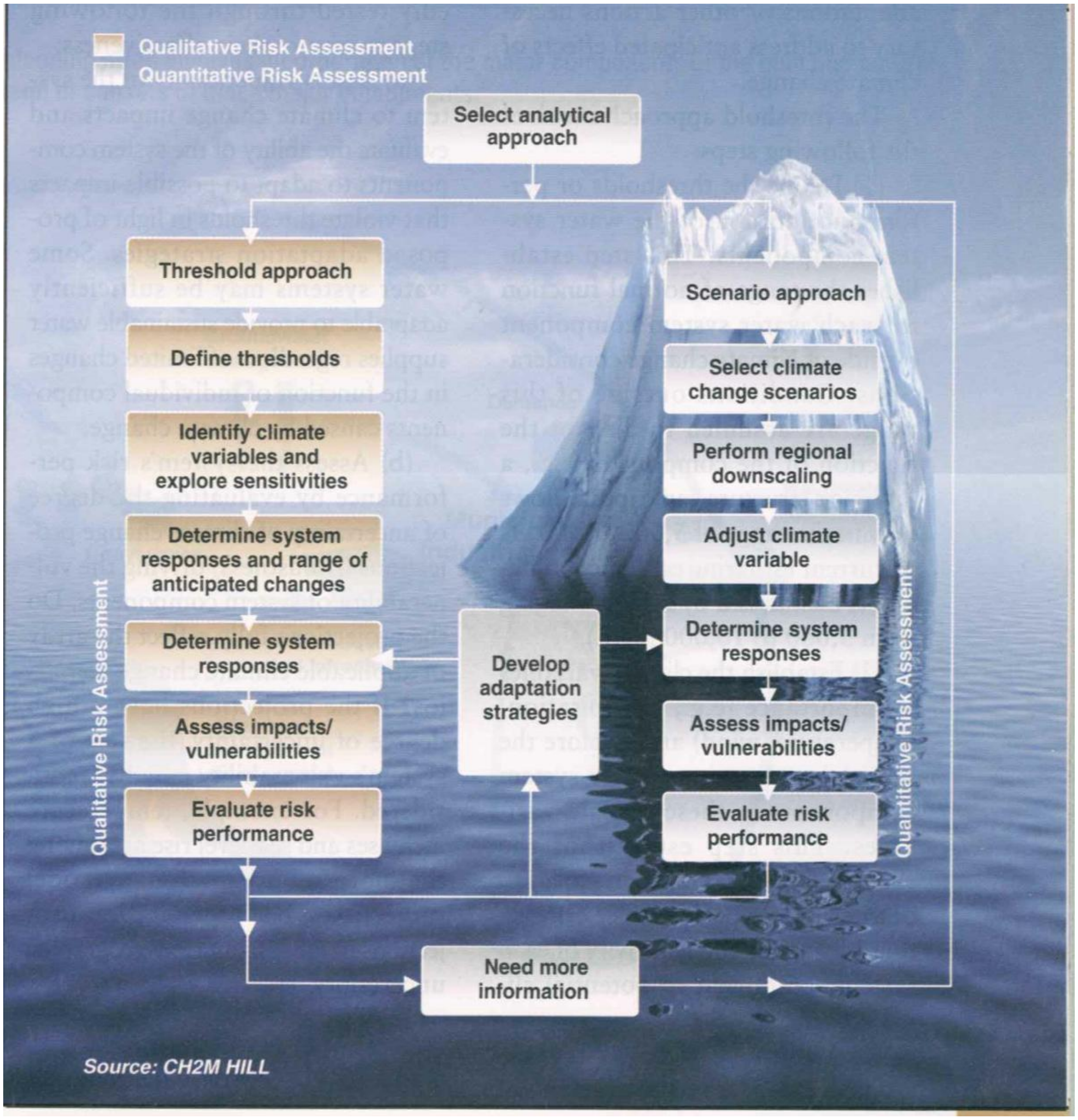


Figure 13 - The threshold-scenario risk assessment framework, which includes qualitative and quantitative approaches to addressing climate changes effects on water systems (source: Freas, et al, 2008).

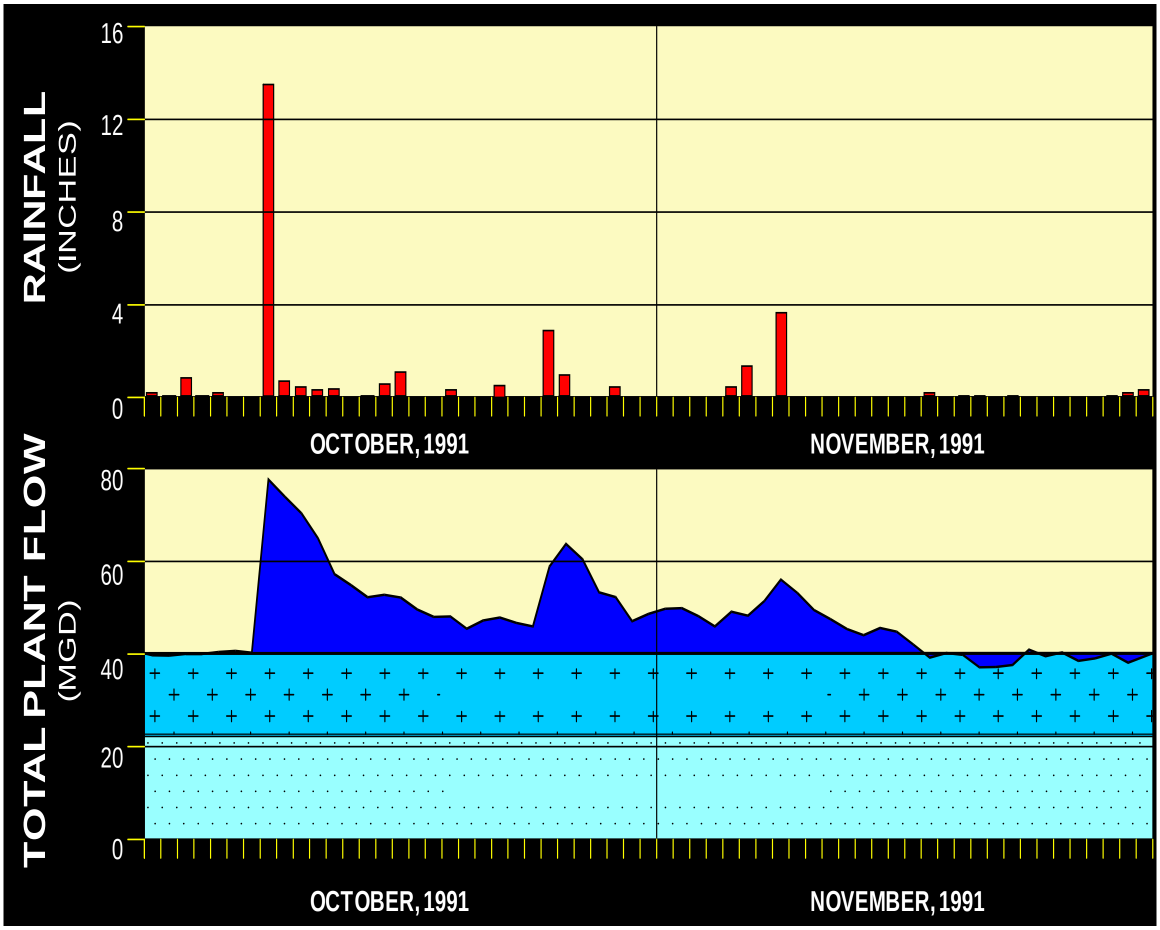
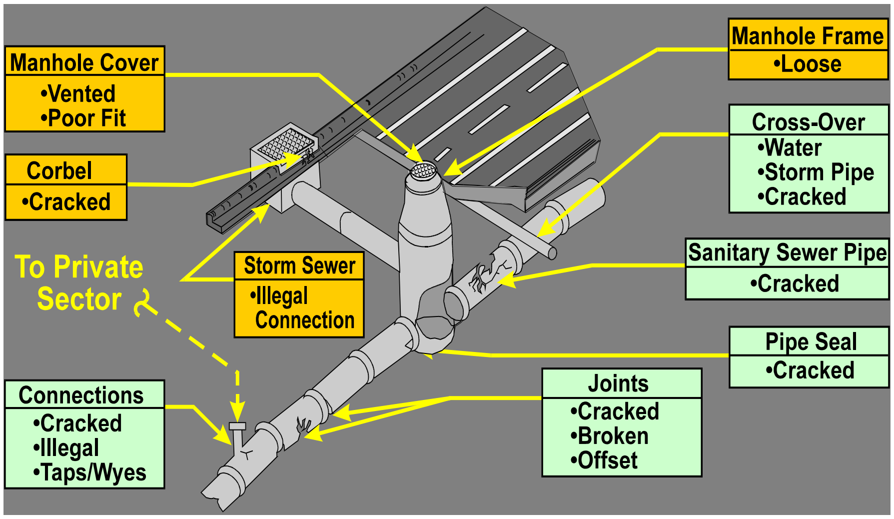


Figure 14 - Spikes indicating inflow into sewer system.



Rain and High Groundwater Affects
Wastewater Collection System

Figure 15 - Potential Infiltration and inflow areas (source Bloetscher, 2008).

Figure 16 - chimney seal installed.

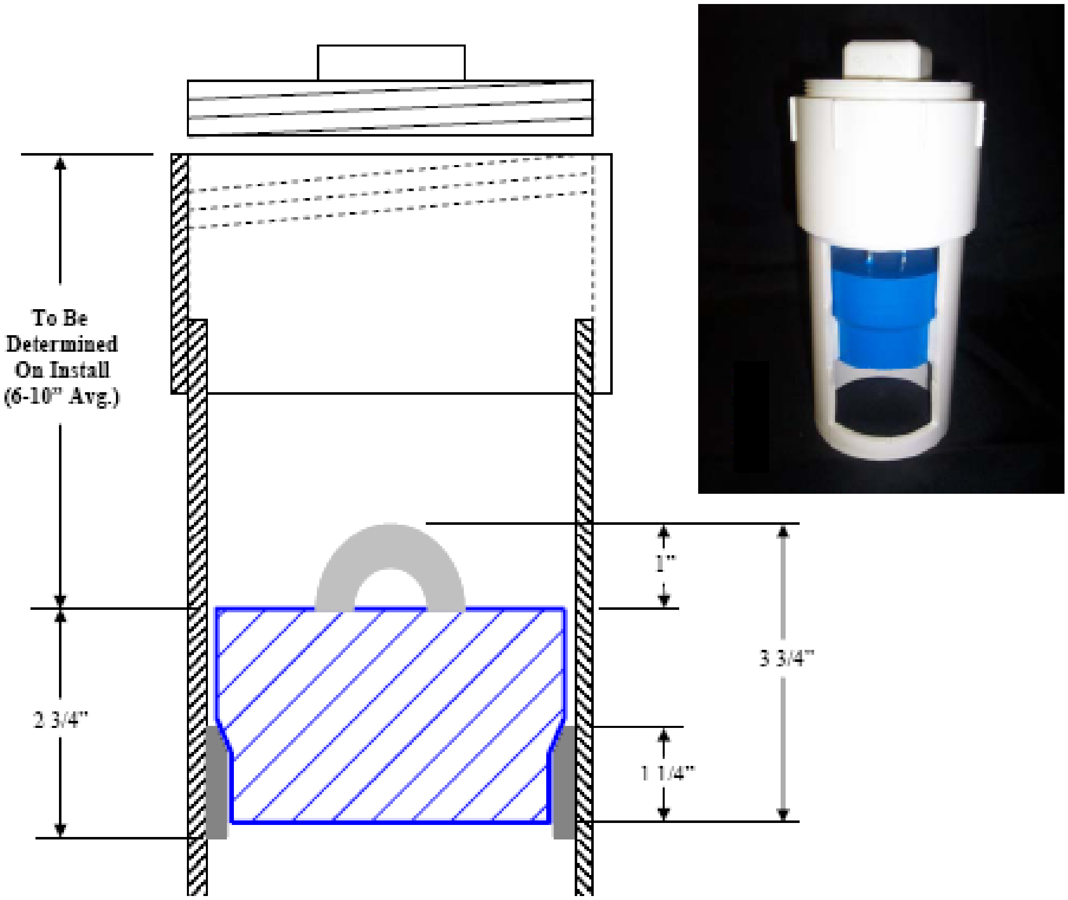


Figure 17 - LDL Plug Design.

Figure 18 - Inflow Defender Manhole Rain Dish.

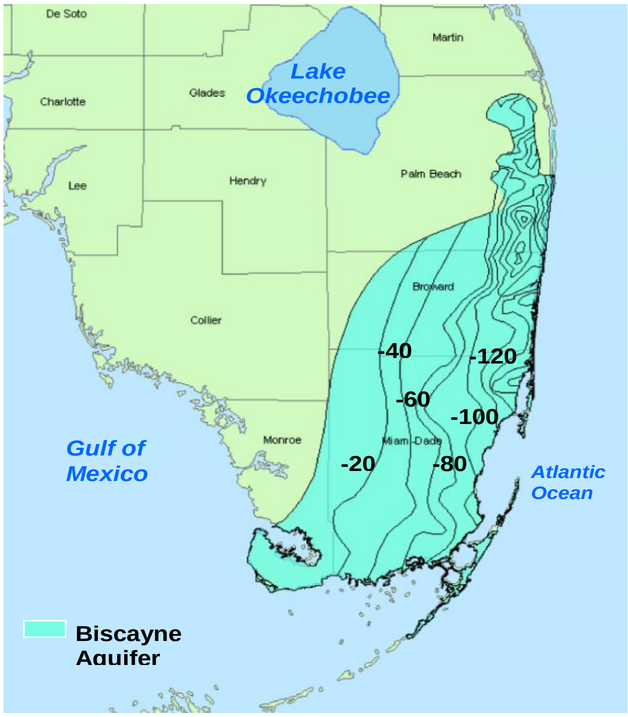


Figure 19 - natural water movement of the Biscayne aquifer.

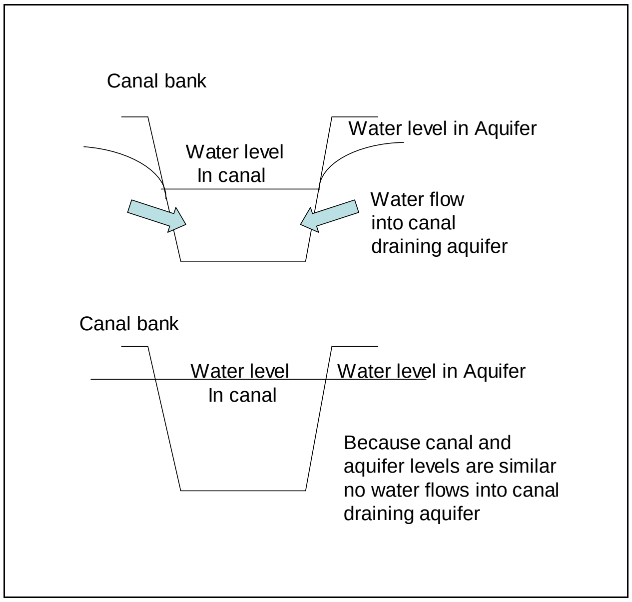


Figure 20 - Comparison of effects of lowered water levels in canals (as a result of inability to recharge canals), versus maintaining canals at a constant (Bloetscher and Muniz, 2008).

Appendix A

Energy Efficiency Additional information

USEPA (2008) believes "several provisions of the Clean Water Act speak directly or indirectly to the question of energy efficiency in wastewater treatment:

- section 313(b) of the Act encourages demonstration of innovative processes and techniques for more efficient use of energy at Federal wastewater treatment facilities;

- section 304(d)(3) of the Act encourages development of innovative processes and techniques for publicly owned (wastewater) treatment works (POTWs), including those processes described under section 201(g)(5), that take into account the more efficient use of energy (e.g., variable frequency drive motors reduce energy use of pumps by up to 50 percent); and

- under sections 304(b)(1)(B), 306, and 307 of the Clean Water Act, the National Water Program develops effluent limitations guidelines (ELGs) for industrial (non-POTW) facilities and the use of energy in these processes is one consideration in the development of the guidelines. Supervisory Control and Data Acquisition (SCADA) system monitors the operation of water-system control points such as pumps, reservoirs, and metering stations, and keeps track of energy usage."

FPL Energy, a subsidiary of FPL Group, has proven to be the nation's leader in the use of renewable energy. FPL Energy owns about half of the world's largest solar thermal field in California's Mojave Desert with a plant capacity totaling 310 MW. It is the nation's largest wind power company with 5,410 MW of installed capacity in 16 states, though none currently within Florida.

Within Florida, FPL is a significant producer of nuclear energy with about 22% of its generating capacity currently coming from both the Turkey Point and St. Lucie nuclear power plants. FPL has requested the uprating of both nuclear plants for a total in-service increase of 414 MW by 2012. Additionally, FPL is asking the Florida Public Service Commission (FPSC) for permission to build two new nuclear units at Turkey Point with in-service dates of between 2018 and 2020.

In the next 15 to 20 years, most of the existing power plants in the state will need upgrading or replacement. Retooling to renewable or nuclear energy will take a considerable amount of time. Besides nuclear, FPL has currently proposed (pending regulatory approval) 110 MW of solar power including: 75 MW of solar thermal capacity in a hybrid design connecting to an existing combined-cycle power plant at their existing Martin County Plant site; 25 MW of photovoltaic (PV) solar capacity on their property in DeSoto County, Florida; and 10 MW of PV solar capacity at the Kennedy Space Center. All of these projects are scheduled for initiation by early 2009 or before. While these additional projects will mean that FPL will be the largest producer of solar energy in Florida, unfortunately, when completed, these projects would constitute only about one half of one percent of FPL's Florida electrical generating capacity.

Increasing energy prices in southern California and Nevada led many water utilities to turn to solar energy. In California, there are 18 installations operating or under construction with a combined total of 11.2 MW and another 20 water districts that are in the contractual process representing over 20 MW. One Nevada water district has six solar installations totaling 3.1 MW (Corum, 2008).

The Desert Water Agency and West Basin Municipal Water District are two examples in California of solar power users. The Desert Water Agency in Palm Springs, California has been using a 300 kW solar photovoltaic (PV) system. The Agency financed the $2.5 million cost of the facility and received an incentive payment that covered 50% of the cost. Payback of the PV was expected to take 10 to 11 years. Currently, it uses about 35 million kWh annually to supply power to pumps, deep wells, reclamation plant and part of its wastewater system.

The West Basin Municipal Water District in El Segundo, California constructed a 564 kW facility. The PV facility consists of three arrays of solar roof tiles covering 40,000 square feet built on top of in-ground storage tanks located just south of Los Angeles International Airport. The facility serves about 10% of the plant’s operating needs including pumps, motors, treatment process equipment and offices. Cost was $4 million but with a $1.9 million grant; payback was expected to be 13 years.

Wastewater utilities have additional opportunities for producing energy through the use of digester gas. The County Sanitation District of Los Angeles County (CSD) is a supreme example of a utility that can make maximum utilization of green energy. It has a long history of using biogas to produce electricity dating back to 1938. CSD provides wastewater and solid-waste services to more than 5 million people in Southern California, treating an average of 520 MGD of wastewater. It has successfully used biogas as a low-cost fuel for power generation technologies that utilize steam-boiler-turbines, gas turbines, internal combustion engine generators, microturbines and fuel cells. Through use of biogas CSD is able to conserve fossil fuels, reduce air emissions and significantly lower costs. CSD produces about 126 MW of electrical power consisting of 23 MW from digester gas, 63 MW from landfill gas, and 40 MW from solid waste. CSD uses 29 MW onsite for daily operations and then sells 97 MW to the local power company.

CSD’s Lancaster Water Reclamation Plant (WRP) uses a 250 kW microturbine. A microturbine is basically a small jet engine designed to drive a generator which produces electricity. The benefits of microturbines are: they can operate on digester gas; emit low levels of air pollutants, produce hot exhaust gas that can be used to heat the digesters (cogeneration), and don’t require extensive operator training. The system’s total cost was $720,000 of which 40% was funded by a grant from the state of California Public Utilities Commission. Power production costs are projected to be $0.043/kWh the majority of which is for capital recovery. Microturbine operations are expected to save $225,000 per year in electricity purchases (McDannel and Wheless, 2008).

CSD’s Palmdale WRP uses digester gas to power a fuel-cell co-generation facility. Fuel cells offer the same benefits as microturbines but have near zero air emissions; on the other hand, they are more expensive to install. A fuel cell generates electricity with no combustion and virtually no air pollution is generated. Hydrogen and oxygen are combined across a membrane which creates an electrochemical reaction that produces electricity. Methane from the digester gas must be first reformed into hydrogen and this takes place internally in the fuel cell so that digester gas can be directly injected into it. The fuel cell produces 225 kW for use on site. The Palmdale system includes waste-heat recovery that uses waste heat from the fuel cell to provide heat for the digesters. The system’s total cost was $1.9 million of which 50% was funding via a state grant. Power production costs are projected to be $0.093/kWh.

Operations of the fuel cell are projected to save $227,000 per year in electricity purchases (McDannel and Wheless, 2008).

Appendix B

Waste Treatment and Disinfection Additional Information

Full treatment is defined by 62-610.563 Waste Treatment and Disinfection (3) as: “(a) The principal treatment and disinfection requirements described in Rule 62-610.563(2), F.A.C., (which means a reclaimed water that meets, at a minimum, secondary treatment and high-level disinfection, shall not contain more than 5.0 mg/L of total suspended solids before application of the disinfectant… filtration for total suspended solids control”… “and as the primary barrier for removal of protozoan pathogens (Cryptosporidium, Giardia, and others)”,…,chemical feed facilities for coagulants, coagulant aids or polyelectrolytes shall be provided and maintained, and total nitrogen...limited to 10 mg/L as nitrogen as a maximum annual average limitation (FDEP, 2008).

The rule notes that “surface water discharges, WQBELs established under Chapter 62-650, F.A.C., may place additional limitations on nitrogen or other parameters (FDEP, 2008)”. Also more stringent requirements may be enacted by local governments for protection of the reefs, canal systems, etc., as has occurred n Broward County.

In addition to primary treatment, the rule continues with the following: “(b) Drinking water standards.

1. Wastewater treatment facilities shall be designed and operated to meet the primary and secondary drinking water standards established in Rules 62-550.310 and 62-550.320, F.A.C.

    a. The parameters listed as primary drinking water standards shall be applied as maximum single sample permit limits. The primary drinking water standard for asbestos shall not apply. The primary drinking water standards for bacteriological parameters shall be applied as the disinfection standard as described in Rule 62-550.310(3), F.A.C., except that public notification requirements shall not apply. The primary drinking water standard for sodium shall be applied as a maximum annual average permit limitation. The multipliers established in Rule 62-600.740(1)(b)2, F.A.C., shall be used to establish maximum monthly and single sample maximum permit limits for sodium.

    b. Except for pH, the parameters listed as secondary drinking water standards shall be applied as maximum annual average permit limits. The multipliers established in Rule 62-600.740(1)(b)2, F.A.C., shall be used to establish maximum monthly and single sample maximum permit limits.

    c. All pH observations in the reclaimed water shall fall within the pH range established in the secondary drinking water standards.

(c). Additional reductions of pollutants which otherwise would be discharged in quantities which would reasonably be anticipated to pose risk to public health because of acute or chronic toxicity shall be required.

(d). Total organic carbon (TOC) shall not exceed 3.0 mg/L as the monthly average limitation. No single sample shall exceed 5.0 mg/L.

(e). Total organic halogen (TOX) shall not exceed 0.2 mg/L as the monthly average limitation. No single sample shall exceed 0.3 mg/L.

(f). The treatment processes shall include processes which serve as multiple barriers for control of organic compounds and pathogens (FDEP, 2008).”