

PREDICTING ECOLOGICAL CHANGES IN THE FLORIDA EVERGLADES UNDER A FUTURE CLIMATE SCENARIO

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FINAL REPORT



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The preparation of this report required dozens of conference calls and email exchanges and an additional briefing webinar December 2012. The steering committee included a range of scientists spanning representatives from six federal agencies, water management representatives and five universities. They convened biweekly to examine the program and explore the best ways of moving the discussion of climate change issues from the more abstract science into the venue of decision-making, adaptive management, and operations. The South Florida Water Management District (SFWMD) played a special role in providing technical backup and staff time while Center for Environmental Studies (CES) provided staff and logistical support, partly under a US Geological Survey (USGS) cooperative grant.

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I. ABSTRACT

For resource managers, a major point is that climate change needs to be explicitly considered while the multi-billion dollar Comprehensive Everglades Restoration Plan (CERP) is implemented, or else that project may not achieve its intended outcomes. A careful process is needed that: (1) acknowledges that climate change is likely to affect the outcome of CERP; (2) makes use of new information, as it becomes available, about the expected changes in temporal distribution and intensity of RF so that modeling exercises can be updated and rerun as appropriate, so that (3) ecologists, engineers and water resource managers working together can identify solutions to future climate scenarios with balanced impacts on regional ecosystems and public & private uses of fresh water.

The Predicting Ecological Changes In The Florida Everglades Under A Future Climate Scenario meeting was held at Florida Atlantic University's Boca Campus in February 2013 with the purpose of bringing scientists and resource managers together to discuss these issues. More specifically, experts in Everglades ecology were asked to identify how hydrologic changes associated with possible future climate change regimes might influence ecosystem services, and to identify research gaps where it currently is not possible to make such projections with acceptable certainty. To do this, they were provided with output from the South Florida Water Management Model (SFWMM), a 2 x 2 km regional hydrologic model that was used in the planning process of CERP.

On day one of the meeting, participants first heard about the six model scenarios that were compared to the 2010 baseline. This was followed by presentations from a range of ecologists. Different assessments of the impacts of climate changes under scenario conditions were made for three distinct regions: Lake Okeechobee, Freshwater Wetlands, and Marine and Coastal areas. The assessments included discussions on peatlands, fish and aquatic fauna, plant species and plant communities, and wildlife. Marine and Coastal assessments were divided into Florida Bay, Coral Reefs, with additional presentations on particular species.

On day 2, meeting participants were divided into three breakout groups, each one having a diverse mix of scientists and resource managers. Each group was asked to answer three questions and record the results for presentation back to the full group with discussion. Additionally, the groups were asked to consider dynamics associated with ecosystem feedbacks that span the boundaries of Lake Okeechobee, freshwater wetlands and coastal and marine ecosystems. The ideas discussed in these break-out groups were synthesized into a list of Considerations for Restoration and Resource Decision Makers which is provided on page 14 of this report.

II. INTRODUCTION

Changes in climate and sea level are already having an impact in South Florida and projections for the future suggest that these changes will accelerate over the next several decades. Associated changes in rainfall, runoff, temperature, evapotranspiration and sea surface elevation will impact the hydrological and ecological systems of the natural and built environment.

Predicting Ecological Changes In The Florida Everglades Under A Future Climate Scenario is the latest in a series of meetings over the past three years. These meetings examined the current and future potential impact of sea level rise and other hydrological changes on select regions and processes of the greater Florida Everglades, and on the potential outcomes of implementing the Comprehensive Everglades Restoration Plan (CERP).

The first meeting, held in April 2011, examined the ecological models established for the southernmost Everglades which, for the most part, did not incorporate sea level rise into their projections. The meeting explored the needed revisions to those models based on the current projections of sea level rise. (Download the [meeting summary](#))

In March 2012, a second meeting addressed hydrological changes, and focused primarily on technical issues of downscaling climate change models to Florida and examined other aspects of atmospheric variability. In addition, the participants explored major gaps in knowledge of current hydrological understanding of the Everglades system, particularly the role of evapotranspiration and ground flow. (Download the [meeting summary](#))

The steering committee (Appendix A) that planned and delivered these meetings realized that ecologists had not been sufficiently represented and that a modified approach was needed to provide more actionable science that could directly aid the planning and mechanics of Everglades Restoration. In a series of brainstorming meetings, the following strategy evolved:

Step 1: Bring key ecologists into the discussions and update them on the process and findings thus far.

Step2: Develop realistic scenarios of future conditions upon which ecologists and hydrologists could base their predictions of future climate change impacts on the Everglades environment. This includes considerations of climate change interactions with and effects on restoration strategies, actions, and expected outcomes under different climate change scenarios, which while hypothetical, provide a specific and quantitative basis for calculations and judgments.

Step 3: Involve managers and decision-makers from various agencies in the full discussion. Keep the National Research Council's Everglades Oversight Committee fully aware of the technical meeting and its conclusions.

To implement these steps, a webinar was organized and delivered (August 2012) to approximately fifty ecologists and hydrologists who had not attended the March 2012 meeting. The goal of the webinar, coordinated by the SFWMD, was to provide an overview of the March meeting and featured presentations by several key representatives from water management, University of Florida (UF), Florida State University (FSU) and the USGS. A second webinar in December 2012 was used to discuss model outputs with paper presentations.

The most recent meeting, in February 2013, was conducted in order to have experts in Everglades ecology identify how hydrologic changes associated with possible future climate change regimes might influence ecosystem services, and to identify research gaps where it currently is not possible to make such projections with acceptable certainty. Experts were provided with output from the South Florida Water Management Model (SFWMM), a 2 x 2 km regional hydrologic model that was used in the planning process of CERP. Different future climate scenarios were run and the ecologists were asked to answer three questions:

- How would key attributes of the ecosystem respond to the changes in hydrology provided in the model output?;
- What are the gaps in scientific information leading to unacceptable levels of uncertainty in both climatic and ecological predictions, including changes in environmental parameters needed to predict how these ecosystems may respond?
- What are some options for future resource management, and what are the scientific capabilities to support that management?

The South Florida Water Management District (SFWMD) used a set of climate change and sea level rise scenarios to run the SFWMM. This run was completed by December and made available for the hydrologists and ecologists to utilize two months prior to the February 2013 meeting. The organizing committee also believed that the presence of agency managers would enhance the impact of the presentations and discussions. Together with four representatives from the National Research Council, the manager's participation greatly enhanced the process and outcomes.

III. CLIMATE SCENARIO RUNS

Current projections of climate change and sea level rise have shown that the concept of "stationarity", previously used in traditional planning efforts, is no longer appropriate. Using the SFWMM, a study was undertaken to provide a set of climate change and sea level rise scenario runs. These runs were the basis for conversations among scientists and decision makers in order to identify the future work necessary to understand the implications of potential changes in the climate and sea level on Everglades Restoration. The results of this analysis should not be viewed as definite projections of what will occur, but as reasonable examples of what could happen in the greater Everglades region, based on best available information at this time.

A. SFWMM - The Model

The SFWMM is a regional-scale computer model that simulates the hydrology and management of water resources system from Lake Okeechobee to Florida Bay, covering an area of 7,600 square miles. The model simulates the major components of the hydrologic cycle in South Florida (see Figure 1) on a daily basis using climatic input. The components include rainfall, evapotranspiration, infiltration, overland and groundwater flow, canal flow, canal-groundwater seepage, levee seepage and groundwater pumping. The SFWMM also incorporates water demands of all sectors and simulates current or proposed water management control structures and operational rules. The output of the model includes a myriad of performance measures covering urban, agricultural and environmental sectors that had been the basis of previous planning efforts.

B. The Scenarios

Six scenarios were developed. These scenarios were compared to a 2010 baseline, which included no changes except the planned components of CERP and their effects on regional hydrology. The scenarios included the following:

- +ET -- 1.5 ft sea level rise (SLR) plus increased temperature by 1.5 degrees C and associated increase in evapotranspiration (ET).
- +ET+RF – same increases in SLR, temperature and ET, plus a 10% increase in rainfall.
- +ET-RF – same increases in SLR, temperature and ET, plus a 10% decrease in rainfall.
- The above scenarios with changes in coastal canal levels to reduce the risk of saltwater intrusion.

Hydrologic output from the model runs of these scenarios was provided to teams of researchers with expertise in particular regions of the Everglades or particular processes (e.g., biogeochemistry), and they were asked to answer the three questions listed above and present their findings in oral presentations.

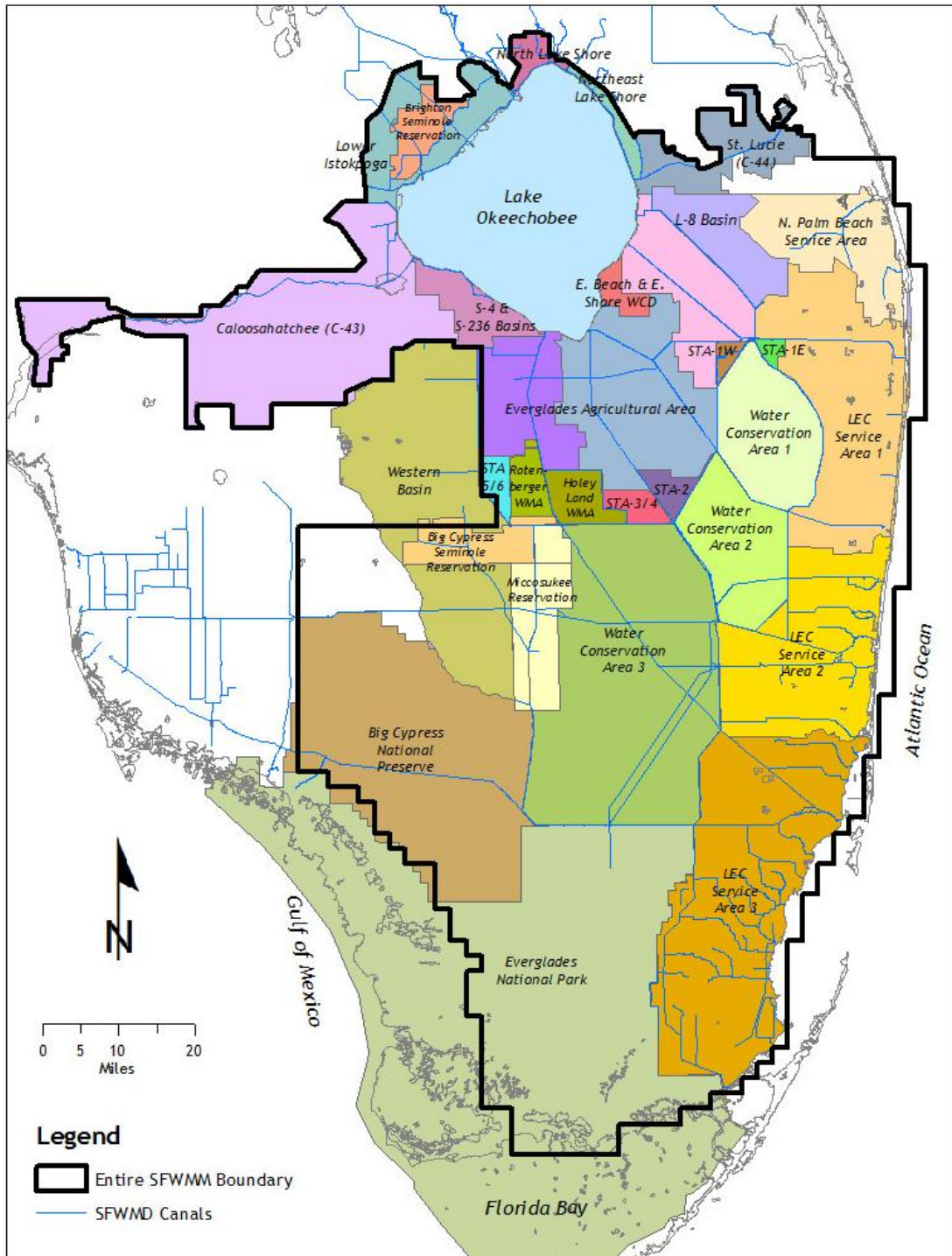


Figure 1. Regions within the Domain of the SFWMM

C. Rationale

Temperature and precipitation projections are based on the previous work reported in Obeysekera et al. (2011). This report is available from www.sfwmd.gov (->Scientists & Engineers->Technical Report and Publications-> [Climate Change in South Florida](#)). A summary of expected changes by circa 2050 is reproduced in Table 1. The sea level rise estimate is based on the SE Climate Compact report available from <http://southeastfloridaclimatecompact.org/>. Some of the relevant figures from these reports are reproduced in Figure 2.

Table 1. Summary of Median Climate Change for Circa 2050

Variable	GCM	Statistically Downscaled Data	Dynamically Downscaled Data
Average Temperature	1 to 1.5°C	1 to 2°C	1.8 to 2.1°C
Precipitation	-10% to +10%	-5% to +5%	-3 to 2 inches
Reference Crop Evapotranspiration			3 to 6 inches

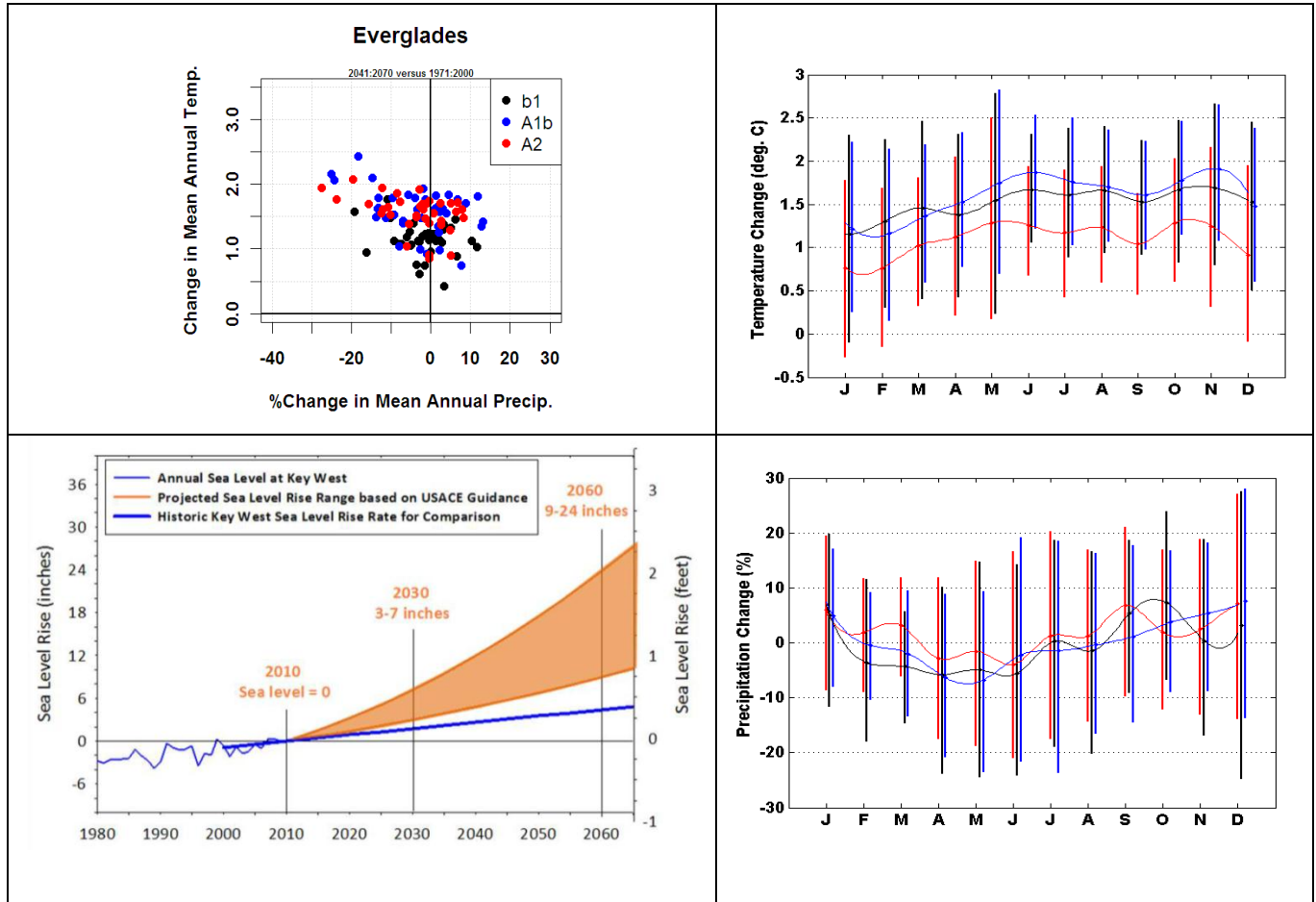


Figure 2. Projections of precipitation, temperature, and sea level rise for the 2050-2060 time frame from (a) analysis of statistically downscaled data (upper left panel); (b) GCM data for the SE region (two right panels); and (c) unified sea level rise projections of the SE Climate Compact (lower left panel). The temperature and precipitation projections are from Obeysekera et al. (2011) and the Sea Level Rise projections are from the unified sea level rise projections produced by the SE Climate Compact Working Group.

IV. DAY ONE: ANALYSIS OF ECOLOGICAL AND HYDROLOGICAL RESPONSES TO CLIMATE SCENARIOS

The meeting was held on the Florida Atlantic University Boca Raton Campus and with almost 100 people in attendance. Participants represented a diverse group of organizations including non-profits, consulting firms, US Fish and Wildlife Service, US Army Corp of Engineers, SFWMD, NOAA, Natural Resources Council, the National Wildlife Refuge and Park Service, FL Fish and Wildlife Commission and representatives from nine universities. PowerPoint presentations are available [online](#) and the abstracts for each presentation are given below. The agenda for the two-day meeting and each of the speaker's biographies are provided in Appendices B & C, respectively.

A. Setting the Stage

As a basis for predicting ecological change under future climates as developed in the scenarios, scientists can use our extensive knowledge of hydrological/ecological relationships and project changes in future plant and animal relationships that may ensue. Such projections can be based not only our understanding of current dynamics, but also draw on the information gleaned from the geological record, using the impact of past climatic changes on ecosystems and on individual species. To provide this background initial presentations by Lynne Wingard (on the past) and Jayantha Obeysekera (on the projected future) opened up the session.

- **Florida's History in Context: Past Patterns of Climate Change and Ecological Responses to Change—Lynne Wingard**

Climate change is one of the most discussed subjects among the public today, and scientists are working together to predict what affects climate change could have on our planet in the future. One way to do this is to look at the climate data from the past. Past data, also referred to as paleodata, goes back thousands, and sometimes millions, of years. Over the last 3-4 million years, the floral and faunal communities have not changed much in response to climate change. This leads us to believe that the main drivers of habitat loss in the 20th century are land use and water management. Past records are not always the key to predicting future impacts of climate change. However, using both past and current records makes it easier to make predictions. There is a need to fill in information gaps in the paleodata in order to help us identify these indicators of climate change. In addition, we must compile, synthesize and analyze existing data sets from a variety of ecosystems to understand interconnections, and feedback mechanisms.

- **Screening analysis of Climate Scenarios—Jayantha Obeysekera, Jenifer Barnes, Moysey Ostrowsky**

In the current projections of climate change and sea level rise, the concept of "stationarity," that past climate is indicative of future climate, which is traditionally used in Greater Everglades Ecosystem restoration efforts, may no longer be appropriate. In this study, downscaled regional climate information derived from the General Circulation Models and sea

level rise projections were evaluated to provide a reasonable set of initial scenarios for impact analysis. Based on the analysis for the 2060 planning horizon, a 1.5°C increase in temperature, ±10% change in precipitation, and a sea level rise of 1.5 feet were used to develop eight scenarios as input to a comprehensive hydrologic simulation model for the Greater Everglades. Depending on the particular scenario, the modeling results show significant changes to the water budgets with implications for water supply and ecosystems of the Greater Everglades. This preliminary screening of climate change and sea level rise demonstrates the need to incorporate their implications in ongoing restoration, system operations and water supply planning efforts. The subsequent abstracts are based on the Climate Scenario Runs previously discussed in this report.

B. Predicting Ecosystem Change in Response to Specific Climate Change Scenarios

Different assessments of the impacts of climate changes under scenario conditions were made for three distinct regions. These regions are:

1. Lake Okeechobee,
2. Freshwater Wetlands, and
3. Marine and Coastal areas.

The assessments included discussions on peatlands, fish and aquatic fauna, plant species and plant communities, and wildlife. Marine and Coastal assessments were divided into Florida Bay, Coral Reefs, with additional presentations on particular species.

1. Lake Okeechobee

• *Climate Change Sensitivity Analysis—Karl Havens*

Based on prior observational and experimental research on Lake Okeechobee, and work on other lakes and wetlands experiencing varying hydroperiods, we projected how Okeechobee might respond to climate changes projected for 2060. Right now, Lake Okeechobee has an average low water level of about 12 feet and an average high water level of about 15 feet. To predict the future water levels of Lake Okeechobee, future scenarios were created by predicting what would happen if rainfall was increased or decreased, along with either an increase or a decrease of evapotranspiration. In a future scenario with a 10% increase or decrease of rainfall, along with an increase in evapotranspiration, the temperature of the water increases by 1.5 C° and the water level raises by 0.5 m. In this same scenario, there was a counter-balanced effect on lake water budget, and no real effect on hydrology. Another future scenario that had a decrease in rainfall and an increase in evapotranspiration resulted in large changes in hydrology, along with major negative effects on the water level. One of the most noticeable negative affect would be a 2 m, or more, decrease from the average high and low water levels, which could possibly last for multiple years. This drop in the water level, and duration of low water levels, goes outside the range of any prior prediction that has been made. If the water levels do drop that low, the marsh lands could be prone to fires and vegetation would be killed off periodically. It is difficult to predict what type of effect these predicted changes would have on the fish habitat, as well as the submerged aquatic vegetation. Such conditions however, would dramatically alter the lake's ecology and its services.

2. Freshwater Wetlands

Four separate groups of researchers looked at the impacts of how our Freshwater Wetlands might respond to climate changes projected by the model output. One group analyzed how the Everglades landscape might respond and determined that there would be major impacts to soils, vegetation, fish, wildlife, invasive species and that increased drought conditions would lead to reduced peat production, an increasing rate of peat loss and increased risk of fire. Another group analyzed the fish and aquatic fauna and determined, among other findings, that decreased rainfall scenarios dramatically decreased aquatic fish production with likely implications for apex predators that depend on these for prey. Yet another group of researchers analyzed plant species and community responses and found that the Everglades ecosystems are currently declining due to changes in the range of water-level fluctuations over a wet-dry cycle, and this cycle may be exacerbated by a decline in rainfall and increase in evapotranspiration. The final group researched the landscape scale responses to biogeochemical factors and, among their findings, determined that decreased rainfall and increased evapotranspiration would lead to more frequent drying events and organic soil oxidation and release of mercury and sulfate from soil, and an increase of methylmercury production.

- ***What Can the Everglades Landscape Expect from Climate Change? —Martha Nungesser, Colin Saunders & Carlos Coronado***

The Everglades is a large patterned peatland. Peatlands form and are maintained in areas where precipitation exceeds evapotranspiration, as is true of south Florida; the climate change scenarios predict a 7% increase in evapotranspiration and a 10% increase or decrease in precipitation. With an increase in evapotranspiration and a 10% decrease in rainfall, the Everglades could experience water level decreases of 0.5 feet to 3+ feet and a decrease in duration of surface water from 10-50% across the Everglades. This scenario would cause drought conditions leading to widespread fires, reduction of peat production, and elimination of peat accumulation. As peat dries out, it oxidizes and mineralizes, emitting CO₂ into the atmosphere. Previous drainage has led to widespread loss of patterning in the Ridge and Slough landscape, and additional drought would eliminate more patterning. Major shifts in flora and fauna could include a loss of hammock and tree island species and an increase in the growth of *Lygodium microphyllum* and other invasive exotic plant species in response to altered hydropatterns. Fish habitat would decrease with lower water levels over extended periods of time, altering community structure and prey species availability for wading birds and other aquatic predators. Paleoecological evidence indicates that changes of this magnitude have not been experienced in the 5000 year history of the Everglades. Climate change should be incorporated into restoration planning to help mitigate these impacts wherever possible.

- ***Fish and Aquatic Fauna—Joel Trexler, Mandy Banet & Chris Cattano***

Small fish, shrimp and crayfish communities play an important role in the Everglades as a food source for wading birds. When comparing the baseline population of these aquatic communities with the predicted results from the climate change scenario, it is apparent that there could be a major impact on these communities. All climate scenarios with decreased rainfall showed decreases in fish density when considered system wide, the scenario with a 10% decrease in rainfall yielded negative impacts in all seven regions considered. In Water Conservation Areas 3A and 3B, the small fish population could decrease by over 35%. The scenarios with a decrease in rainfall increased the frequency of drying events, which is well documented to result in decreased fish biomass. In these drier conditions, there could be an increase in the frequency of one of the two species of crayfish present, the Everglades' crayfish. However, it typically sustains a lower biomass than the slough crayfish, which prefers wetter conditions. With a decrease in rainfall and an increase in evapotranspiration, some areas see a dramatic decrease (70%) in small fish density/m². Sea level rise is another factor associated with climate change and could also have an impact on the aquatic communities. In the Taylor Slough area, sea level rise affected only a small number of sites in these simulations. In the affected areas, sea level rise lengthened hydroperiods, which generally increases aquatic productivity; however, the brackish fish communities that are favored by such conditions are known to sustain less biomass than the freshwater fish communities. This could negatively affect the birds that rely on these small fish communities as a source of food.

- ***Predicting Ecosystem Change in Response to Climate Change Scenarios: Plant Species and Community Responses—John Volin, Arnold van der Valk, Paul Wetzel***

The annual and interannual water level fluctuations are the main variables that control the development of plant communities in the Everglades. When looking at future scenarios of climate change, the data show that there will be a small impact on the plant species that grow in the Everglades. Some species of vegetation, such as the wet prairies and sawgrass flats, are expected to be more widespread by 2060. The baseline interannual water level fluctuations are at about 1.95 m (6.5 ft.). These conditions appear to remain the same even when looking at the most severe climate change scenarios, which include a 10% decrease in rainfall. However, the average range of water level fluctuations is predicted to drop from 0.55 m (1.8 ft) to only 0.24 m (0.8 ft). Under the most severe climate change scenarios, there is a possibility that the length of interannual cycles may shift to longer dry phases in the Everglades. These longer dry phases could result in more frequent fires, which could have an overall negative effect on the Everglades vegetation. One aspect of the Everglades vegetation that may be effected is the length of time that a certain plant community may be there. The Everglades are currently declining because of a compression in the range of water-level fluctuations over a wet-dry cycle. Climate change will not reverse the compression, but it may be exacerbated by a decline in rainfall and increase in evapotranspiration.

- ***Landscape Scale Response to Climate Change: A Biogeochemical Perspective— Susan Newman, William Orem, Todd Z. Osborne, K. Ramesh Reddy***

Climate change can affect the landscape and the habitat of the Everglades in numerous ways. By using future scenarios of climate change, it is possible to predict what will happen to the biogeochemical properties of the Everglades. When examining the worst case scenario, a 10% decrease in rainfall and a 10% increase in evapotranspiration, there are major impacts on the carbon, nitrogen, phosphorus, sulfur, and the mercury cycles in the Greater Everglades area. In this scenario, the carbon cycle data shows that the northern and central peat lands could become overly dry even in wet years. Dry years are predicted to be even worse as drought would cause system-wide peat loss. The effects on the nitrogen cycle are closely related to the effects of the carbon cycle in this scenario. In this same scenario, there would be a greater phosphorus input as well as a conversion of organic to inorganic phosphorus. The sulphur and mercury cycles are closely tied together. With a decrease in rainfall and increased evapotranspiration, soils in the water conservation area would be at risk due to the release of sulphur from oxidation. Decreased rainfall and increased evapotranspiration would also lead to more frequent drying events, the release of mercury ions and sulfate from soil, and the increased production of methylmercury. The effect of increasing temperatures is important to consider as it could cause an increase in the microbial activity. However, there are uncertainties with this data. Some uncertainties include, the effect of increase saltwater on the stability of organic material, as well as if the increase sea level rise will cause erosion of accumulated carbon due to tidal flux or increase C due to mangroves expanding northward. To answer these uncertainties, research needs to be done to know what the salinity limits for the freshwater Everglades are, as well as researching whether peat growth can be manipulated with SLR.

3. Coastal and Marine Ecosystems

Increasing sea-level by 1.5 feet will make Florida Bay salinity more like that of the ocean, with salinity increasing in fresher areas and decreasing in hypersaline areas. This salinity response will be influenced by the potential growth or erosion of the bay's western mud-banks, which are biogenic and currently inhibit water exchange with the Gulf of Mexico. Both salinity and temperature strongly affect biota; higher summer temperatures may negatively affect seagrass habitat and fish. The Florida Keys' coral reef already has experienced negative effects. The most dramatic future changes likely will occur in coastal wetlands. Current rates of soil accretion and soil elevation increase are far less than the workshop scenario's sea-level rise rate. If inundated by the sea, coastal systems will expand and be disturbed by increased nutrient and turbidity releases from the former Everglades.

- ***Climate Variability and the Coastal Physical Environment (Florida Bay) - Erik Stabenau-***

The salinity regime sets the ecological environment in coastal ecosystems such as Florida Bay with extreme events leading to shifts in ecological communities. Salinity is variable and trending upward in Florida Bay and changes in salinity act in conjunction with other factors, including currents, temperature, and light with various feedback cycles. Sea level rise is expected to play an increasingly important role in coastal ecosystems. In Florida Bay, the rate of sea level rise relative to changes in bank height has an effect on mixing between basins, changing salinity levels and impacting the marine life that lives in the Florida Bay. The data show a clear signal

that sea level rise in the coastal zones of Florida Bay is already affecting salinity. While salinity is highly variable, it has been increasing since 1995 and conditions are becoming more 'marine-like'. There are a few factors that need to be considered but perhaps the most important is changes in bank height. Banks are long narrow sills, stabilized by seagrass that limit exchange between basins. Using a coastal ocean model, when bank heights are projected to increase in conjunction with increase in sea level, there is not much change to salinity. However, if you run the same scenario without changing the height of the banks, you reduce estuarine habitat size and duration. Thus, if sea levels rise and the banks do not increase at the same pace, estuarine habitat will be lost and the ecosystem of Florida Bay will change with unknown consequences on its resiliency.

- ***Climate Change Effects on Mangrove, Seagrass and Macroalgae Communities of the Coastal Everglades— Marguerite Koch, Carlos Coronado***

Marine plant communities, including mangrove forests, seagrass meadows and macroalgae of the Everglades provide the foundation for numerous ecosystems. Using a 2060 scenario of sea level rise, temperature increases and elevated CO₂, various drivers were examined that could lead to a restructuring of these foundation plant communities. We also considered adaptation potentials and highlight areas of future research and modeling needs. At a 9.5 mm rise in sea level, coastal mangrove forests would not likely keep pace with rising sea levels. In this scenario, the rate of elevation change in the water level would be about 1.25 millimeters per year. In addition to the rise in water level, there would also be an increase in temperature. If there is a sustained increase of 1.5°C by 2060, then there will only be a slight impact on the plant communities. However, if temperature increases by 4°C by 2060, then there could be major impacts to the plant communities. The drivers of submerged plant communities are salinity, nutrients, and light. Shifts from benthic to open-water communities are predicted under 2060 sea level rise rates. There are scientific needs that must be addressed in the near future that can help better predict the impacts that could occur on the plant communities. There needs to be regional measurements and estimates of potential sea level rise rates. In addition, the models used for predicting climate change impacts should include the major drivers of seagrass, phytoplankton and carbonate sediment processes, as these plant communities provide the foundation for their associated ecosystems. These drivers include: light, nutrients, temperature and sea level rise. It is certain that climate change will have an impact on major ecosystems in the Everglades, but there are thresholds that need to be better understood, particularly sea level rise rates, in order to better predict the exact impacts that will occur in these ecosystems.

- ***Climate Change Impacts on South Florida Coral Reefs— Margaret Miller, Bill Precht***

Much is already known about the effects of climate change on coral reefs. For example, increasing ocean temperature extremes cause mass coral bleaching, as well as disease and reproductive impairment. Some coral reefs off the coast of the Florida Keys have experienced almost 50% of the reef being bleached. Bleaching of coral reefs every 5 years could possibly lead to extinction of reef-building corals. Coral reefs in waters that are between 30-31°C, could result in abnormal embryonic development. Ocean acidification also has an effect on the coral

reef communities, impairing the growth and reproduction of corals, as well as increasing the bioerosion of coral skeletons. Seagrasses could help ameliorate the effects of ocean acidification by absorbing excess CO₂. It is still unknown whether sea level rise will have a major impact on South Floridacoral reefs. An 18 inch increase in sea level is not enough to “drown” coral reefs. There has been research that shows that coral reefs have been displaced by a sudden 10-36 mm/yr change in water level, but this does not imply that the coral reefs have been negatively impacted by the increase. More likely, impacts of sea level rise on coral reefs will occur via changes in coastal water quality via inundation as deteriorating water quality is expected to further impair corals’ capacity to endure warming stress. Adaptation potential of corals, as well as the effectiveness of “reef resilience” strategies, is uncertain. More research is needed to determine the impacts future climate change will have on coral reefs.

- **Climate Changes Impacts on Marine Ecosystems (*Holistic Analysis & Faunal Response*)**
—*Chris Kelble, Pamela Fletcher, Geoff Cook*

Saltwater recreational fishing is one of the most important revenue sources in the Everglades. Annually, saltwater recreational fishing produces about \$880 million, along with about 6,000 jobs. The Spotted Seatrout is the 2nd most caught fish in the Florida Bay. Another important fish in the Everglades and in the Florida Bay is the Bay Anchovy, which occupies a key role in the food web. As an important revenue source, it is valuable to understand what impacts climate change will have on fish communities. A 1.5 foot increase in sea level rise and a 1.5°C increase in the temperature would impact the Spotted Seatrout community, as well as Bay Anchovies. If salinity levels increase, there would be a decrease in Bay Anchovy populations and an increase in mesozooplankton. The reason for the increase in the mesozooplankton is because the Bay Anchovy makes up 81% of the zooplanktivorous community. In addition, these increases could decrease the juvenile Spotted Seatrout population in the summer. However, it could also increase the juvenile Spotted Seatrout population in winter. Most of all, climate change pressures will have a dominant impact on ecosystem sustainability and service production. Even though predictions can be made on what could happen to the Spotted Seatrout and the Bay Anchovy in isolation under certain climate change predictions, this does not take into account ecosystem interactions that we know are important. The only way to accurately predict what could happen is by using ecosystem models.

- **KEYSMAP (*Florida Keys Marine Adaptation Planning*)** —*Robert Glazer*

The Florida Keys are among the most highly vulnerable coastal areas in the U.S. with respect to a changing climate due to the low-lying topography, the reliance of the economy on a fragile coastal ecosystem, and the high degree of endemism. Yet the response of the ecosystem and its components under a changing climate is poorly understood. To investigate these responses, we coupled sea level rise and sea surface temperature models and used the results to examine a suite of alternative future scenarios. The scenarios were used to envision the first order response of key ecosystem components (Spiny Lobster, Loggerhead Turtles, Goliath Grouper). The project was designed to best inform managers as they develop responses to climate-driven impacts.

V. DAY TWO: DISCUSSIONS OF THE IMPLICATIONS OF SCENARIO RUNS

A. Evaluating Information Needs and Uncertainty Scenarios – Breakout Groups

The oral presentations by experts concluded on day 1 of the meeting. On day 2, meeting participants were divided into three breakout groups, each one having a diverse mix of scientists and resource managers. Each group was asked to answer three questions and record the results for presentation back to the full group with discussion. The three questions addressed in the breakout groups were:

Question 1: In evaluating the response of the various ecosystem components to climate change, what research gaps exist that led to lower than acceptable certainty in your projections?

Question 2: In evaluating the response, what additional information (from model output, etc.) would have helped you make your projections?

Question 3: What are the greatest needs by management?

Additionally, the groups were asked to consider dynamics associated with ecosystem feedbacks that span the boundaries of Lake Okeechobee, freshwater wetlands and coastal and marine ecosystems. The ideas discussed in these break-out groups have been synthesized into a list of ***Considerations for Restoration and Resource Decision Makers*** which are detailed in the next section of this document.

B. Considerations for Restoration and Resource Decision Makers

Climate change will affect the outcome of Everglades restoration in a number of ways: through direct and indirect consequences of sea level rise and associated saltwater intrusion into the peninsula; through increased temperature and evapotranspiration that will impact the availability of water for both the natural and urban environment; and through changes in the amount, timing and distribution of rainfall. Rising seas may threaten the integrity of coastal peat soils and flood coastal plants. Increased temperature and longer-lasting droughts may severely reduce available freshwater. In addition, fire, invasive species and disease may interact with these changes to have unexpected adverse impacts to Everglades flora, fauna and ecosystem services.

The workshop identified that the effects of climate change must be carefully considered and that those effects deemed most likely to influence the outcome of CERP should be taken into consideration in the planning and implementation of regional projects. The workshop also identified that major uncertainties exist, from those associated with climate projections to those about specific changes in ecological structure and function. These uncertainties must be prioritized and then reconciled with timely research that can support decisions by resource managers.

The following list provides some examples of research and management needs.

Scientific Information and Understanding Gaps:

- Major factors determining the availability of freshwater in the greater Everglades are the future rainfall and the magnitude of evapotranspiration. Currently, evapotranspiration is estimated as a simple generic function of temperature. Site-specific relationships between all climate variables, including air temperature and evapotranspiration, need to be developed. Better rainfall scenarios also need to be developed.
- There is a potential for large-scale peat collapse and land loss due to intrusion of salt water at the southern end of the Everglades. To understand the magnitude and timing of these impacts, research is needed regarding the status and dynamics of factors influencing elevation change - especially the magnitude and variability of salt-water intrusion.
- The Florida Bay mud-banks are barriers that protect the Bay and the Everglades from wave energy and storm surges. Information is needed regarding how they will be affected by climate change, including their current elevation, rates of erosion, sedimentation, and net elevation change.
- Integrated hydrologic-ecological models are needed to evaluate current status and dynamics in response to climate change scenarios.
- Information is needed about how key processes like peat accretion and loss, and viability of seed banks, will be affected by prolonged periods of drying.
- We need to understand the vulnerability and resilience of populations to changing patterns of landscape connectivity.
- We need to learn how to build ecosystem resilience. We need to gain understanding of community and ecosystem dynamics and management influences on these dynamics sufficient to identify mechanisms that increase resilience. This need includes research to identify tipping points and to develop early-warning indicators.
- We need to understand the role of fire, invasive species and disease as they influence ecosystem responses to climate change.

Scientific Applications: A Path to More Effective Ecosystem-Based Management

- There is a need for improved communication, outreach and education, which engages both managers and the general public. Scientific understanding of the impacts of climate change must be communicated openly and honestly.
- We need to expand the scope of ecosystem analysis to encompass societal needs and dynamics, including economics and water demands. For South Florida, integrated ecosystem-human system planning and analysis should include consideration of the entire Kissimmee-Okeechobee-Everglades system and the adjacent marine system.
- Adaptive management is a recommended approach to build resilience needed to deal with climate change. A better understanding of the ecosystem resilience to change is also necessary.

- In collaboration with managers and the public, we must build an understanding of the importance of environmental variability in natural ecosystems, including recognition of the importance of pulsed events.
- Management decision support should incorporate indicators that minimize the risk of reaching critical tipping points.
- One recommended focus for management is the appropriate delivery of freshwater flows to coastal wetlands, which provide a critical defense of the Everglades landscape and water supplies in the face of sea-level rise. For South Florida, sea-level rise appears likely to be the element of climate change that will most strongly and quickly alter our environment and society.

VI. NEXT STEPS

A. Final Report and 4-Page Summary

This final report and a 4-Page Summary were drafted and circulated among the steering committee members for input. This report summarizes the two-day technical meeting and the [4-Page Summary](#) was created to present the more significant highlights in an ‘at-a-glance’ format.

B. Recommendations by Steering Committee for next technical meeting

A general consensus emerged from the meeting on two main points.

1. The basic principle of Everglades Restoration, “getting the water right” by restoring as much as possible of the original hydrologic system, is even more important in the face of sea level rise and other climate changes;
2. Adaptive Management is critical in order to maximize management efficacy in the face of complexity and uncertain timing and magnitude of climate change.

A number of follow up actions currently are being planned:

- A meeting that will include a small number of managers and scientists to identify immediate follow up action items, including key information gathering and monitoring that should be initiated immediately. Also, work will be done to identify adaptation actions that might be built into ongoing CERP projects.
- A technical meeting of a small number of scientists and managers is being planned for November 2013 to hone in on the key knowledge gaps tentatively identified at the February technical meeting. In addition, a short priority list of vital research activities will be created. This is research needed to allow for a better understanding of potential medium term threats and adaptation opportunities.
- The research findings from the February technical meeting will be published as a special series in Environmental Management in 2013.