

Restoring a River of Grass: Everglades policy  
recommendations for a climate change alternative

by

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## **ABSTRACT**

One of the largest and most extensive wetland systems in the United States is contained within the Florida Everglades National Park. Like most of the world's wetlands it has been reduced to half of its size and heavily altered by human pressures. The Everglades were heavily drained during the first half of the 1800's for agriculture and development. Further changes occurred after Congress authorized the Central and South Florida Project in 1948. The goal of this project was to provide water and flood protection to the citizens of south Florida however the project has had severe unintended negative impacts on the Everglades' environment.

Historically, the watershed of the Everglades began with the Kissimmee River, which flows into Lake Okeechobee. The water would then naturally overflow the lake's southern edge into the northern Everglades, which in the past was a vast sawgrass plain. From here the water would flow south through a ridge and slough landscape, past mangroves, and finally into the Gulf of Mexico. Regrettably, the network of canals, levees, and roads created by the Central and South Florida Project greatly altered the water regime, starved the Everglades of its natural water flow, and compartmentalized the landscape. In an effort to reverse the impacts of earlier projects and to restore the natural hydropattern, Congress authorized the Comprehensive Everglades Restoration Plan (CERP) in 2000. However, future potential climate change impacts were not taken into consideration during the CERP planning process.

The Everglades are extremely vulnerable to global climate change including: rising sea levels and sea surface temperatures, increased erosion, hurricane intensity and duration, saltwater intrusion and changes in precipitation. Therefore, it is important to consider Everglades' restoration plans in light of global climate change. None of the restoration alternatives evaluated by CERP would be successful as a climate change alternative because global climate change predictions were not considered during the modeling and evaluation process. Failure to include future potential changes undermines any plan's ability to restore the Everglades.

This project investigates the potential climate change impacts for the Everglades National Park and provides policy recommendations regarding the inclusion of climate change predictions in the planning and implementation process. The three recommendations proposed include: the incorporation of current climate change predictions in the hydrologic and ecologic computer-based models, the monitoring and mapping of salinity levels within the Everglades National Park, and the use of the coastal vulnerability index to assess the vulnerability of the coastline of south Florida to future changes in sea level rise. The application of these recommendations will ensure the use of more appropriate models and techniques that will be better able to predict the success of planned restoration efforts.

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## **PART I: A River of Grass**

### **1.1 Introduction**

Seen by early settlers as bleak, unpleasant areas only suitable for drainage, wetlands are now recognized as some of the most productive and species diverse habitats in the world. Humans depend on wetlands for spiritual, cultural, and economic well-being. These unique ecosystems help store and filter pollutants, recharge ground water supplies, buffer coasts from storms, and provide flood and drought protection. Wetlands offer habitat and nursery grounds for many commercial and recreational fish species as well as wintering grounds for migrating birds.

Mangroves, marshes (salt, brackish, and fresh), swamps, bogs, wet prairies, prairie potholes, and vernal pools are all different types of wetlands found in the United States. Unfortunately, half of the wetlands in the lower 48 states have been lost since colonial times due to pollution, drainage for mosquito control and agriculture, and filling for development (USGS, 2007). Humans have also reduced the amount of water flowing into wetland systems by damming rivers and diverting water for agriculture. Louisiana, for example, possesses roughly 40 percent of the lower 48 states' coastal wetlands but it is losing 25-35 square miles a year due to erosion and subsidence (USGS, 2007).

#### *History of the Everglades*

One of the largest and most extensive wetland systems in the United States is contained within the Florida Everglades National Park. The Park includes roughly 1,398,893 acres of land and is recognized as an International Biosphere Reserve, a World Heritage Site, and a Wetland of International Importance (NPS, 2007e). Some of the wetlands found within the Everglades National Park include: sawgrass prairies,

freshwater marl prairies, cypress swamps, coastal marshes, and mangrove stands.

Marjory Stoneman Douglas described the uniqueness of the Everglades in her book, *The Everglades: River of Grass*, as: “There are no other Everglades in the world...The miracle of light pours over the green and brown expanse of saw grass and of water, shining and slow moving below, the grass and water that is the meaning and the central fact of the Everglades of Florida. It is a river of grass.”

Like many other wetlands, the Everglades was once seen as a worthless swamp that could be reclaimed by draining and thus, half of south Florida’s original wetland areas were drained and destroyed for agriculture and development. Draining began during the first half of the 1800’s and rapidly intensified from 1905 to 1910 (NPS, 2007c). The new abundance of agricultural land as well as the construction of railroads enticed visitors and prospective residents to Florida. Developers continued to build drainage canals and roads, destroying vast amounts of native habitat (NPS, 2007c).

In the late 1920’s the degradation of the Everglades became apparent to a local architect, Ernest Coe. Mr. Coe formed the Tropical Everglades Park Association and lobbied Congress to consider designating the Everglades as a national park. The Tropical Everglades Park Association was successful and in 1934 the Everglades National Park Project was authorized by Congress (NPS, 2007b). The state of Florida was then left to the task of acquiring land through public and private donations and purchases (Florida International University Libraries, 2007). It was not until 1947 when the Everglades National Park officially opened to the public (NPS, 2007b).

Unfortunately the Everglades’ problems did not end when the park was designated. In order to protect the park’s surrounding communities from floods and

drought Congress authorized the Central and South Florida Project in 1948 (NPS, 2007c). The goal of the project was “to provide water and flood protection for urban and agricultural lands, a water supply for Everglades National Park, the preservation of fish and wildlife habitat, facilitate navigation and recreation, and the prevention of salt water intrusion” (NPS, 2007c). Run by the Army Corps of Engineers and the South Florida Water Management District, the Central and South Florida Project modified the flow of water through the Everglades by constructing a network of canals, levees, roads, and water-control structures (NPS, 2007c). Regrettably, this system of hard structures greatly altered the water regime and starved the Everglades of its natural water flow, altering the ecosystem and compartmentalizing the landscape.

Increasing population pressures and changing land uses still continue to degrade the natural system of the Everglades and decrease its water supply. The number of wading birds found in the everglades has been reduced by 90% and many species native to the everglades, such as the manatee and the Florida panther, are at risk of extinction (NPS, 2007c). Other indicators of reduced ecosystem health include: massive reductions in seagrass bed area, declining populations of important commercial and recreational fish species, invasive species such as the Burmese Python, increased nutrient runoff, and mercury contamination. The Everglades wetlands landscape once encompassed over 10,000 km<sup>2</sup> (Maltby & Dugan, 1994). Now due to agriculture, development, and drainage the Everglades National Park contains 5,633 km<sup>2</sup> with only a fraction of the original wetland system (Maltby & Dugan, 1994).

## 1.2 Problem Definition

### *Explanation of Hydrology and Geologic History*

The movement of water through a wetland ecosystem is vital to its structure and function. Unlike a river or a stream, the flow of water through a wetland tends to be much slower. The typical flow of water through a river of grass or a slough in the Everglades is less than one inch per second (SCT, 2003). The flow of water through a wetland is important to the overall ecology of the area. Water flow not only transports, mixes, and dilutes nutrients and particulate matter but it also can influence the location and type of organisms in the system (SCT, 2003).

During the Everglades geologic history, it has been submerged and exposed several times due to changes in sea-level. When the land was submerged by the ocean, sediments deposited and when the land was exposed sediments eroded (Robertson, 1959). Thus, the limestone beds now seen throughout much of the Everglades were formed during the third interglacial sea, 100,000 to 75,000 years ago. Since the limestone and above peat deposits are very porous, the Everglades lacks a distinct boundary between its surface water and ground water flows (SCT, 2003). The limestone aquifer under the everglades is the principal surface water recharge system for all of south Florida (NPS, 2007c).

Historically, the watershed of the Everglades began with the Kissimmee River which feeds into Lake Okeechobee. From Lake Okeechobee, the water would often overflow at its southern edge into the northern Everglades, at that time a vast sawgrass plain (SCT, 2003). As the sawgrass (*Cladium jamaicensis*) died each season it added to the layer of peat soil, building and maintaining the elevation of the area (Zeiller, 2005). The water would then flow south through the ridge and slough landscapes into the Shark River Slough, through the mangroves, and finally into the Gulf of Mexico (SCT, 2003)

(Figure 1). The shallow marsh covered river from Lake Okeechobee to the sea was 120 miles long and was called “Pa-hay-o-kee” by the Seminole Indians, which means grassy waters (Robertson, 1959).

The elevation of the landscape, even though it is less than 10 feet above sea level in the Everglades, can greatly alter the vegetation and habitat type of a wetland.

Deposition can cause a mangrove to eventually transform into a buttonwood hammock and erosion can reverse the situation (Zeiller, 2005). For example, prior to drainage the ridge and slough landscape provided three different habitat types based on elevation and water exposure. A slough is a low-elevation area that acts as a water channel and is usually filled with water all year round, even during the dry season (NPS, 2007d). Two to three feet higher than the relatively open sloughs are sawgrass ridges, which maintain elevation through peat accumulation (SCT, 2003). Rising slightly above the sawgrass ridges are tree islands which remain relatively dry throughout the year. The ridges, sloughs, and tree islands form a distinct pattern with the ridges and tree islands oriented parallel to the direction of water flow (Figure 2). There are two distinct sloughs in the Everglades National Park, Shark River Slough and its eastern tributary, Taylor Slough.

#### *Impacts of Historical Draining and the Central and South Florida Project*

From 1905 to 1928, the Federal Government and the state of Florida made aggressive efforts to drain the Everglades. In 1905, Florida created the Everglades Drainage District, which was authorized to build canals, establish drainage districts, and levy taxes (Florida International University Libraries, 2007). One businessman, Hamilton Disston drained over 50,000 acres of wetlands excavated the Kissimmee River so that it was navigable, connected the Caloosahatchee River to Lake Okeechobee and began



digging a canal from Lake Okeechobee south towards Miami (SCT, 2003). Over the next several years, canals were established from Lake Okeechobee to the Atlantic Ocean greatly reducing the amount of water that reached the Everglades.

As the population surrounding Lake Okeechobee grew, so did demands for flood protection. In 1930, Congress authorized the construction of a levee (67.8 miles long) along the south shore of Lake Okeechobee and a second levee (15.7 miles long) along the north shore (Florida International University Libraries, 2007). Now all surface water flows from the lake are controlled by the U.S. Army Corps of Engineers and the South Florida Water Management District via dikes, canals, and water control structures (USGS, 2007b). Lake Okeechobee has a surface area of 1,750 km<sup>2</sup> or roughly 675 square miles making it the second largest freshwater lake in the continental United States (SCT, 2003).

A second structure also blocks the natural flow of water from Lake Okeechobee to the Gulf of Mexico, the Tamiami Trail (Figures 3 and 4). Completed in 1928, the Tamiami Trail is the southern end of U.S. Route 41 and runs for 273 miles. The road was intended to connect the cities of Tampa and Miami (Collier County Museums, 2001). Undesirably, the trail has acted as a dam and has created two distinct landscapes to the north and south, where once the landscape had been contiguous.

The third impediment to the flow of water from Lake Okeechobee to the Everglades is the compartmentalization of the ridge and slough landscape that once spread south from Lake Okeechobee. Beginning in 1954, a system of levees was established to the south of Lake Okeechobee in order to create three Water Conservation Areas (WCAs) (SCT, 2003) (Figure 5). Managed as surface water reservoirs, the goals

of the WCAs include: to store and convey water to agricultural lands, to convey water to the Everglades, to receive and store runoff from the Everglades Agricultural Area, to prevent flooding on urban and agricultural lands, to receive regulates releases from Lake Okeechobee, and to enhance recreation (Light & Dineen, 1994). The creation of Water Conservation Areas 1, 2, and 3 as well as other Central and South Florida Project (C&SF Project) structures have greatly impacted the ridge and slough landscape. Instead of a ridge and slough wetland mosaic, the water conservation areas now contain more uniform stands of sawgrass (SCT, 2003) (Figure 6). Scientists believe that sawgrass stands, compared to the historic ridge and slough ecosystem, support fewer types and numbers of organisms (SCT, 2003).

Unfortunately, the construction of the levees around Lake Okeechobee, the Tamiami Trail, and the Water Conservation Areas have had unintended negative environmental impacts. A description of the containment of Lake Okeechobee and the resulting effects on the Everglades can be found below.

“The lake water, which for so many centuries had flowed southward in the great arc of the saw-grass river, was now impounded. Only the rains could flood the Everglades now. But drainage, some people said around the lake, seeing the great sugar developments, the trainloads of winter vegetables, was a success at last...The Everglades were dying. The endless acres of saw grass, brown as an enormous shadow where rain and lake water has once flowed, rustled dry. The birds flew high above them, the ibis, the egret, the heron beating steadily southward along drying watercourses to the last brackish pools.” – Marjory Stoneman Douglas, *The Everglades: River of Grass*

#### *Role of Freshwater Inflow*

The Everglades and the Florida Bay (the lagoonal estuary between the Florida mainland and the Florida Keys) are not only connected ecologically but also through the

flow of freshwater. Before the Everglades were drained and canals were built, freshwater flowed across the marl prairies of the Everglades as sheet flow and into the Taylor and Shark River Sloughs. Historically, Taylor Slough was the major contributor of fresh water to Florida Bay while the Shark River Slough supplied Whitewater Bay (McIvor *et al.*, 1994). Changes to the Everglades and the Shark River and Taylor Sloughs have greatly reduced the amount of freshwater that reaches the two Bays and as a result has altered the salinity profiles of each Bay.

Evidence of reductions in freshwater inflow can be seen in the fluorescent banding of hard corals in the Florida Bay (McIvor *et al.*, 1994). The fluorescent bands are highly correlated with freshwater runoff. Scientists believe that the fluorescent bands are formed when corals incorporate fluvic acids (found in freshwater runoff) into their limestone skeleton (McIvor *et al.*, 1994). Smith *et al.* conducted a study in 1989 using brain coral from the western part of Florida Bay. The study found fluorescence to be greatest during earlier years with a persistent decrease after 1932 (McIvor *et al.*, 1994). Based on their data set, Smith *et al.* estimate that the flow of freshwater from the Shark River Slough has been reduced by 59% since the management of the Everglades began (McIvor *et al.*, 1994).

Freshwater flow is important for the biotic community of the Everglades and the Florida Bay because it delivers nutrients from upland primary producers and regulates salinity. Flora and fauna are thus located in zones based on salinity. For example, Sawgrass (*Cladium jamaicense*) or marl prairies once covered nearly 2 million acres (800,000 ha) of the Everglades (Uchytel, 1992). Today, only 29% of the original sawgrass prairie remains; the Everglades National Park currently contains 572, 200 acres

(231,500 ha) of sawgrass prairie (NPS, 2006). The reduction in sawgrass prairie is a result of the reduced freshwater flow through the Everglades and increased salinity. Sawgrass prefers freshwater sites that are shallowly flooded for most parts of the year. When water levels increase, sawgrass is replaced by cattails and when water levels decrease or the hydroperiod shortens, sawgrass is replaced by dry climate tolerant species such as the wax myrtle and the buttonwood (Uchytel, 1992). The replacement of sawgrass with the Dominican cattail can be seen near canal inflow gates. In the southern portion of the Everglades National Park, sawgrass prairies have been replaced by saltmarsh species as brackish waters move further inland as a result of reduced freshwater inflows (Uchytel, 1992).

Different mangrove species can withstand differing soil salinity levels. Red mangroves usually do best in soils whose salinities do not exceed 22 parts per thousand (ppt) while black and white mangroves prefer soil salinities near 26 ppt and can tolerate salinities up to 80-90 ppt (McIvor *et al.*, 1994). The seagrass beds within the Florida Bay also depend on freshwater flow. Turtle grass (*Thalassia testudinum*), for example, grows best in waters that are 20-40 ppt (McIvor *et al.*, 1994). The Manatee (*Trichechus manatus*), is a federal endangered species that is highly dependent on seagrass beds for food and habitat. The American crocodile (*Crocodylus acutus*) is another species dependent on the freshwater flow through the Everglades. The optimum growth for young crocodiles occurs at 9 ppt and their survival is greatly reduced when salinities are greater than 18 ppt (McIvor *et al.*, 1994). Crocodile monitoring research suggests that crocodile nesting within the Everglades National Park has shifted from the eastern to the

western parts of the Park (McIvor *et al.*, 1994). This shift may be a result of increasing salinity levels in the northeastern part of the Park due to drought.

The quality of incoming freshwater is another important issue that must be considered when planning to restore a wetland area. The Everglades for example, is naturally oligotrophic or nutrient poor (Clarke & Dalrymple, 2003). Most of the nutrients contained within the ecosystems of the Everglades are held within the vegetation. Unfortunately, runoff from the Everglades Agricultural Area contains high levels of nutrients, especially nitrogen and phosphorus, from the fertilizers used on the crops. Evidence of the impact of runoff can be seen with the replacement of sawgrass (*Cladium jamaicense*) with cattail (*Typha latifolia*, *Typha domingensis*), a more phosphorus tolerant plant species (Clarke & Dalrymple, 2003).

The availability and quality of freshwater flow not only determines where each habitat type is located but also the quality of those habitats and the abundance of species dependent on those habitats. The management of water in the Everglades and surrounding area including the creation of the Water Conservation Areas, the diversion of water away from the Shark River and Taylor Sloughs, and the construction of canals and levees has greatly altered the salinity regime and water quality of the Everglades and Florida Bay and thus has made the ecosystem on average more saline and more nutrient rich.

#### *Policy Problem Definition*

The Central and South Florida Project has failed to provide an adequate water supply to the Everglades National Park and thus has had unintended environmental impacts. The federal government as well as the state of Florida would like to restore the

natural water flow system of the Everglades National Park to its pre-drained condition through changes in the current hydrology. This must be achieved without disrupting the economic and social needs of the South Florida region. In addition, for any alternative to be successful it will have to allow for the right amount of water to be delivered to the Everglades National Park, the water must get to the places that need it most, be of good quality, be delivered at the right time to mimic natural flow patterns, and be distributed to the wetland ecosystem as well as urban and agricultural users (CERP, 2008b).

The alternative that has been chosen to accomplish these goals is the Comprehensive Everglades Restoration Plan. The aim of the Comprehensive Everglades Restoration Plan is to reverse the impacts of the Central and South Florida Project and to restore the natural hydropattern of the Everglades. Hydropattern can be described as the height, timing, duration, and distribution of water levels (SCT, 2003).

### 1.3 Stakeholders and the Process

The Central and Southern Florida (C&SF) Project was first built by the federal Army Corps of Engineers and later managed by the South Florida Water Management District. The C&SF Project provides water to over six million people and roughly one million acres of agricultural lands, prevents salt water intrusion into the fresh groundwater supplies, and facilitates navigation (Orth & McLean, 1999). Unfortunately, the C&SF Project has altered the natural flow of water to the Everglades and has greatly degraded the ecosystem. It has thus become apparent that the health of the Everglades ecosystem will continue to deteriorate unless actions are taken to modify the amount of water allotted to the Everglades.

In 1992 and 1996, Congress instructed the Army Corps of Engineers to review the C&SF Project and to recommend changes to the Project as needed (Orth & McLean, 1999). Since the C&SF Project affected such a large area and such a large number of stakeholders, the C&SF Project Comprehensive Review Study or Restudy was carried out by several federal agencies, local governments, tribal governments, and citizen groups. The Army Corps of Engineers and the South Florida Water Management District were the two main agencies responsible for the Restudy. Other federal agencies involved in the Restudy include: the Bureau of Indian Affairs, the National Oceanic and Atmospheric Administration, the National Park Service, the U.S. Department of Agriculture, the U.S. Department of Justice, the U.S. Department of Transportation, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey (Orth & McLean, 1999). State agencies involved in the process include: the Florida Department of Agriculture and Consumer Services, the Florida Department of Community Affairs, the Florida Department of Environmental Protection, the Florida Department of Transportation, the Florida Game and Fresh Water Fish Commission, and the Florida Legislature (Orth & McLean, 1999). Other groups include: the City of Fort Myers, the City of Homestead, the Governor's Commission for a Sustainable South Florida, the Miami-Dade County Commission, the Miccosukee Tribe of Indians of Florida, the National Audubon Society, the Seminole Tribe of Florida, the South Florida Ecosystem Restoration Working Group, the United States Sugar Corporation, and the World Wildlife Fund (Orth & McLean, 1999).

The agencies and groups listed above as well as several others formed internal teams, external teams, and sub-teams (See Figure 7). The internal team was made up of

federal agencies, state agencies, local governments, and tribal governments. The external team consisted of policymakers, political representatives, and local citizen groups. From September 1997 to June 1998 the Restudy team created several alternative plans to restore the Everglades ecosystem. The team began with the first alternative, evaluated this alternative, collected public comments, and then improved the alternative and addressed its faults. The improved alternative then became alternative two. Thus alternatives one through six are iterations of the first alternative with additions and improvements. The Restudy team then used alternatives 3-6 to create four comprehensive plans, alternatives A-D. The Restudy team finally chose alternative D13R or the Comprehensive Everglades Restoration Plan. Since the collaboration was successful, the Comprehensive Everglades Restoration Plan is managed and implemented by the local, state, and federal agencies that created it.

#### 1.4 Alternatives

As mentioned previously, Congress gave the U.S. Army Corps of Engineers the authority to re-evaluate the performance of the C&SF Project and to provide recommendations in the Water Resources Development Acts of 1992 and 1996 (USACE & SFWMD, 1999). The Water Resources Development Act of 1996 calls for the submission of a comprehensive plan, feasibility report, and a Programmatic Environmental Impact Statement to Congress by July 1, 1999. In addition, the Water Resources Development Act of 1996 authorizes the Secretary of the Army to implement “Critical Projects” that are seen as necessary for the restoration of the south Florida ecosystem (USACE & SFWMD, 1999). Since the Restudy of the C&SF Project, the U.S. Army Corps of Engineers has established two main goals for South Florida and the



Everglades; to enhance the ecological values and to enhance economic and social well being of the region.

Under the goal of enhanced ecological values are three objectives. The first is to increase the total spatial extent of natural areas, second to improve habitat and functional quality, and third to improve native plant and animal species abundance and diversity (USACE & SFWMD, 1999). Under the goal of enhanced economic and social well being are four objectives: to increase the availability of fresh water, to reduce flood damages, to provide recreational and navigation opportunities, and to protect cultural and archeological resources and values (USACE & SFWMD, 1999). Overall, the alternative chosen should improve ecosystem health, improve water quality, improve wading bird habitat, maintain a stable water level for Lake Okeechobee, and create a more natural freshwater flow pattern to the Caloosahatchee and St. Lucie estuaries, the Everglades, and the Florida and Biscayne bays (USACE & SFWMD, 1999). From a management point of view, several of these objectives are conflicting and thus their resolution will require creative and innovative solutions. A description of the possible alternatives and the alternative which was finally chosen, the Comprehensive Everglades Restoration Plan, follows.

*The Alternatives:*

- Status Quo
- Alternatives 1-6
- Alternative A-D
- Comprehensive Everglades Restoration Plan (D-13R)

*Status Quo*

Without a Comprehensive Plan to restore the Everglades, it is projected that current projects outside of the Restudy plan would ultimately prove to be insufficient and

the health of the Everglades ecosystem would further deteriorate (USACE & SFWMD, 1999). The future population of the study area is expected to grow from 6.3 million in 1990 to 11 million by 2050 (USACE & SFWMD, 1999). This increase in population will presumably put further pressure on freshwater supplies and Lake Okeechobee. This in turn would further reduce freshwater discharges to the Caloosahatchee estuary, the St. Lucie estuary, and the Everglades National Park. Reduced flows to the Shark River Slough within the Everglades National Park will not only endanger this ecosystem but also those of the Florida and Biscayne bays. Water demands may become so high that they exceed the available water supply and thus water restrictions could be instated every other year in Palm Beach, Miami, and the Florida Keys (USACE & SFWMD, 1999). (See Figure 8)

#### *Alternatives 1-6*

Each of the following six alternatives is a variation of the previous alternative. The restudy team began with alternative 1 and then built upon this alternative with improvements and modifications. Alternatives 1 and 2 improved surface water seepage management while alternative 3 included aquifer storage and recovery components (USACE & SFWMD, 1999). Alternative 4 improved sheet-flow and connectivity by removing some of the man made physical barriers such as canals and levees. One problem that arose in the model once the team began removing canals and levees was increased water levels in Water Conservation Area 3B and portions of 3A. Alternative 5 was then created to address the problems resulting from alternative 4, increased burden on Lake Okeechobee and decreased water supply to portions of the Water Conservation Areas (USACE & SFWMD, 1999). Alternative 6 improved upon the problems of

alternative 5 and also included wastewater reuse. For a more detailed overview of Alternatives 1-6 please see Figure 9.

#### *Alternatives A-D*

Using alternatives 3 through 6, the Restudy team then created four comprehensive plans, Alternatives A – D, which included operational changes and model improvements to the previous alternatives. There are several components common to all four of the alternatives such as levee seepage management in Water Conservation Areas 3A and 3B and Dade Broward levee improvement. The following describes the main differences between the four alternatives. (See Figure 10)

#### *Alternative A*

The first alternative, Alternative A, proposes the establishment of storage reservoirs at the north, south, and west boundaries of Lake Okeechobee as well as plans for a 20,000 acre aquifer storage reservoir (10 ft max depth) north of Lake Okeechobee (USACE & SFWMD, 1999). This alternative calls for a 10,000 acre storage reservoir (4 ft. max depth) in the St. Lucie basin, a 20,000 acre storage reservoir (8 ft. max depth) in the Caloosahatchee basin, a storage reservoir in the Everglades Agricultural Area (EAA), and 44 aquifer storage and recovery wells (USACE & SFWMD, 1999). Along with increased conveyance between Water Conservation Area 3B and the Everglades National Park, Alternative A also demands increased conveyance from Lake Okeechobee.

#### *Alternative B*

Unlike Alternative A, Alternative B entails breaking the levees and filling in the canals within Water Conservation Area 3. Not only would this de-compartmentalize the area but it would also restore some of the historic ecological and hydrological connections between the Water Conservation Area and the Northeast Shark River Slough. This would also require the Miami canal to be re-routed through the to North New River canal instead of Water Conservation 3 (USACE & SFWMD, 1999). Alternative B also calls for the inclusion of the Palm Beach County Agriculture Reserve Reservoir in the proposed Water Preserve Area in order to increase regional water supply.

#### *Alternative C*

In Alternative C slight changes were made to the compartments of the Everglades Agricultural Area and the de-compartmentalization of Water Conservation Area 3. This alternative calls for the diversion of excess water from Water Conservation Areas 3A and 3B to the Central Lake Belt In-ground Storage Area (USACE & SFWMD, 1999).

Alternative B also includes further lower east coast water conservation, increased reuse of water in South Miami-Dade County with the creation of the South District Reclaimed Water Treatment Plant, increased flow to the eastern Water Conservation area 3B from the Central Lake Belt Storage Area, and the creation of Biscayne Bay coastal canals (USACE & SFWMD, 1999).

#### *Alternative D*

The last alternative, Alternative D further de-compartmentalized Water Conservation Area 3 and further increased the capacities of the Central Lake Belt Storage Area and the Palm Beach County Agricultural Reserve Reservoir. The capacity of the C-

51 Regional Groundwater Aquifer was reduced while the Southern L-8 Reservoir's capacity was increased (USACE & SFWMD, 1999).

### 1.5 Alternative D13R: The Comprehensive Everglades Restoration Plan

The Comprehensive Everglades Restoration Plan (CERP) is fundamentally an update of the Central and Southern Florida Project (C&SF Project), authorized in 1948. The C&SF Project was meant to provide water supply, flood protection, and water management to South Florida through a system of canals, levees, and other water control structures (approximately 1,000 miles of canals and levees and 150 water control structures) (USACE & SFWMD, 1999). However the project has had several adverse side effects on the Everglades as mentioned previously. CERP is the federal government's plan for restoring the south Florida ecosystem through structural or operational modifications to the C&SF Project.

CERP was approved in the Water Resources Development Act of 2000 (CERP, 2008a). Completion of the Plan is expected to take 30 years and cost \$7.8 billion (CERP, 2008a). The CERP admits that the restored Everglades of the future will not be the pre-drained Everglades of the past since irreversible changes have been made to the system.

Components of the CERP (USACE & SFWMD, 1999) (Also see Figure 11):

- Additional surface water storage reservoirs north of Lake Okeechobee, in the Caloosahatchee and St. Lucie basins, in the Everglades Agricultural Area and in the Water Preserve Areas of Palm Beach, Broward, and Miami-Dade counties
  - » 181,300 acres in total and ability to store 1.5 million acre-feet of water (USACE & SFWMD, 1999)
- Creation of Water Preserve Areas:
  - » Used to treat urban runoff, store water, reduce seepage, and improve existing wetland areas
- Management of Lake Okeechobee:
  - » Efforts to maintain a steady lake level and avoid extreme high and low water levels

- » Improve water quality of the lake
- Surface water storage areas
  - » Conveyed to estuaries in times of drought
- Underground water storage wells around Lake Okeechobee, in the Water Preserve Areas, and in the Caloosahatchee Basin
- Creation of 35,600 acres of man-made treatment wetlands
  - » Used to filter urban and agricultural runoff before it is discharged into the natural system (the Everglades)
- Conveyance of 26% more water to the Northeast Shark River Slough (half a million acre-feet of additional water)
- The removal of 240 miles of canals and levees within the Everglades
  - » Removal of most of the Miami Canal in Water Conservation Area 3
  - » 20 miles of the Tamiami Trail will be rebuilt with bridges and culverts to allow water to flow more naturally from Water Conservation Area 3 to the Everglades (Figure 12)
- Reuse Water: Proposal to build two wastewater treatment plants that will make Miami-Dade County's treated wastewater clean enough to discharge into wetlands along Biscayne Bay
- Project Implementation Reports (submitted to Congress) will be created to supplement the CERP and to give more in depth details of the projects that will be undertaken
  - » Pilot projects used to test out new technologies

## 1.6 Choosing the Final Alternative

Each alternative was evaluated using several tools. Four of the tools, the South Florida Water Management Model (SFWMM), the Across-Trophic-Level System Simulation (ATLSS) model, the Everglades Water Quality Model, and the Rivers of Grass Evaluation Method, are described below.

The South Florida Water Management Model (SFWMM) is an integrated surface-groundwater computer model of the water system from Lake Okeechobee to Florida Bay (USACE & SFWMD, 1999). Elements of the hydrological cycle that have been incorporated into this model include rainfall, evapotranspiration, infiltration, overland and groundwater flow, canal flow, canal-groundwater seepage, levee seepage, and groundwater pumping (USACE & SFWMD, 1999). The model is based on historic

climatic data from 1965 to 1995 and allows managers to assess changes made to the water management system because it incorporates current or proposed water control structures and operational rules. For example, if changes were to be made at Lake Okeechobee the SFWMM could provide estimates of how this would impact the water levels in the Water Conservation Areas and the Everglades National Park (USACE & SFWMD, 1999). The model breaks up the 7,600 square mile water management area into 2 mile by 2 mile cells (South Florida Water Management District, 2008) (See Figure 14).

The second tool, the Everglades Water Quality Model, uses information from the SFWMM to simulate water column phosphorus concentrations and transport within the Everglades National Park. This model uses an equation which includes total phosphorus load, rate of flow, volume and net settling rate to determine total phosphorus concentration (Raghunathan, 2001). The model is also based on data from January 1979 to September 1989 from the SFWMM (Raghunathan, 2001). Using the Everglades Water Quality Model, Alternatives B and D-13R proved to be the best alternatives for water quality purposes. Results from this model also suggest that maximizing surface water sheetflow reduces the net nutrient load within the Everglades National Park (USACE & SFWMD, 1999).

The third tool used to evaluate the restoration alternatives was the Across-Trophic-Level System Simulation (ATLSS) model. The ATLSS model uses the outputs of physical systems models, such as the SFWMM, in a variety of other models that attempt to analyze the impacts of the alternative hydrologic scenarios on the biotic community of the Everglades (University of Tennessee, 1996). In essence, ATLSS is a

set of computer models coupled with Geographic Information System maps that predict the effects of each restoration alternative on trophic structure. The models used in the ATLSS include process models for lower trophic levels (benthic insects and zooplankton), structured population models for fish and macroinvertebrates, and individual based models for large consumers (University of Tennessee, 1996). Examples of the individual based models include: the Cape Sable Seaside Sparrow Breeding Potential Index, the Wading Bird Foraging Condition Index, the White-tailed Deer Breeding Potential Index, the Landscape Fish Model, the Cape Sable Seaside Sparrow Individual Based Model, and the Snail Kite Breeding Potential Index (USACE & SFWMD, 1999).

The final tool used to assess the restoration alternatives was the River of Grass Evaluation Methodology (ROGEM). During the final evaluation of Alternatives A-D, this method was used to describe the potential habitat quality of different subregions that would result from each of the alternatives. This method is based on the U.S. Fish and Wildlife Service's Habitat Evaluation Procedure, which uses community models and suitability indices to assess fish and wildlife responses to changes in habitat quality (USACE & SFWMD, 1999). Thus ROGEM used suitability indices, mathematical equations, and professional expertise to describe the relative habitat quality of each alternative (USACE & SFWMD, 1999). The numerical output from the equations ranged from 0 to 1. A score of zero meant the habitat was of low quality and a score of one meant the plan would result in optimum habitat quality (CERP, 2008a). The subregions analyzed using the River of Grass Evaluation Methodology include: Lake Okeechobee, St. Lucie Estuary, Caloosahatchee Estuary, Florida Bay, Biscayne Bay, freshwater



wetlands within the Loxahatchee National Wildlife Refuge, Water Conservation Areas 2 and 3, Everglades National Park, and Model Lands (CERP, 2008a).

After each alternative was evaluated and analyzed using the four tools mentioned above, the alternatives were ranked and graded according to how each plan achieved the ecological, water supply, and water quality objectives set out at the beginning of the Restudy. The results of the grading evaluation can be seen in Figure 13. An A grade means the alternative successfully met all of the performance measure targets for that sub-region (USACE & SFWMD, 1999). A letter grade of F means the alternative failed to meet the performance measure targets for that sub-region (USACE & SFWMD, 1999). Alternative D for example received a D for Water Conservation Areas 2 & 3, a D for the Shark River Slough, a B+ for sheet flow, and a C for Water Quality (USACE & SFWMD, 1999). The Alternative Evaluation Team chose Alternative D as the best plan, with the provision that the weaknesses in the plan would be corrected before finalized (USACE & SFWMD, 1999).

Alternative D was inadequate at meeting performance targets for Water Conservation Areas 2 & 3, the Shark River Slough, and overall water quality. Thus in 1998, the Restudy team set out to improve the weaknesses of Alternative D (USACE & SFWMD, 1999). The final iteration that resolved Alternative D's performance inadequacies was Alternative D-13R. This final alternative removed additional levees and canals between Water Conservation Area 3A and the Everglades National Park. Alternative D-13R also left levee L-67 between Water Conservation Areas 3A and 3B, but created a conveyance canals between the two Conservation Areas to promote high flows and to control the flow during dry seasons (USACE & SFWMD, 1999).

## **PART II: Global Climate Change and South Florida**

### **2.1 Predictions and Impacts of Global Climate Change**

Due to its low elevation and flat landscape, the Everglades National Park will be exceptionally vulnerable to inundation from rapid rises in sea level and other possible future climate change impacts. Therefore, it is important to consider potential climate change impacts when assessing alternatives to restore the Florida Everglades.

Unfortunately, climate change was not taken into consideration during the alternative formulation process and therefore none of the alternatives described in the Final Integrated Feasibility Report for the Comprehensive Everglades Restoration Plan would be sufficient as a climate change alternative, an alternative that would be successful even if extreme predictions become reality.

Over the next few decades the United States will experience changes in temperature, precipitation and extreme weather effects due to global climate change (Field *et al.*, 2007). Wetlands are especially vulnerable to climate change because of their dependence on surface and ground water availability as well as the effects of modern man-made stresses, such as drainage and levees (Burkett & Kusler, 2000). The greatest threats faced by the Florida Everglades that pertain to climate change include: increasing rates of sea level rise, increasing sea surface temperatures, increased hurricane intensity and duration, greater storm surges and flooding, increased erosion, salt water intrusion, and changes in precipitation. (See Figure 15)

According to predictions made by the most recent United Nations Intergovernmental Panel on Climate Change (IPCC), sea-level has been rising along most of North America's coasts and the rate of change will continue to increase in the future

(Field *et al.*, 2007). In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) estimates a 48cm (~19 in) or 5mm/year rise in global sea level by 2100 (Nicholls *et al.*, 2007). Evidence from satellite observations and tide gauges suggests that sea level is currently rising at an increased rate (Bindoff *et al.*, 2007). The IPCC believes that the two main causes of global sea level rise are thermal expansion (the ocean expands as it gets warmer) and the melting of land based ice such as glaciers and polar ice caps (Bindoff *et al.*, 2007). It is important to note that the rate of sea level rise will not be uniform around the world; some areas may experience a greater increase than others.

Naturally, sea level rises and falls as the earth comes in and out of ice ages. Thus, the fact that sea level may rise is not the issue. The real concern is the rate of sea level rise. If the rate of sea level rise accelerates, the morphology of the world's coasts may be unable to keep up (Nicholls *et al.*, 2007). South Florida's sea level has risen 9 inches in the past one hundred years, which is 6 times faster than the per-century rate for the past 2,400 years (NPS, 2008). If sea level rises at the rate that is projected, 10% to 50% of the Everglades freshwater marshes could be lost to salt water inundation because 60% of the Everglades National Park is less than 3 feet above mean sea level (Kimball, 2007).

Wetlands are extremely vulnerable to increasing rates of sea level rise because wetlands naturally accrete sediment as sea levels rise slowly. If the rate of sea level rise exceeds the rate of sedimentation, a wetland may not be able to accrete sediment fast enough and would thus 'drown.' Mangroves, for example, may be unable to accumulate soil at a rate fast enough to keep up with rising sea levels. In addition, mangrove communities may be forced to move inland if the increase in sea level rise also results in

an increase in salinity. Since Mangroves are halophytes they can tolerate waterlogging and higher salinity conditions than most other wetland tree species but even mangroves have a salinity range (USGS, 2003). Mangroves require a balance between freshwater inflows and sea level to maintain an appropriate salinity gradient. As mentioned previously, the salinity range preferred by Mangroves varies by species but most mangroves prefer salinities ranging from 22 to 26 parts per thousand (McIvor *et al.*, 1994). Current research suggests that the mangrove communities along the southwest coast of the Everglades National Park will shift inland and change in species composition due to sea level rise (USGS, 2003). This shift inland will only occur if the rate of change does not exceed the mangrove communities' ability to adapt and migrate.

Along with an increased rate of sea level rise, climate change may also cause sea surface temperatures to rise. Out of all of the earth's climate system components, the oceans have had the greatest change in heat content from 1961 to 2003; more than that of the lithosphere and the atmosphere (Bindoff *et al.*, 2007). The energy associated with the oceans is also responsible for 90% of the earth's heat budget, whereas the energy associated with ice melt only contributes 1% to the earth's heat budget (Bindoff *et al.*, 2007). For tropical environments, an increase in sea surface temperature of only 1 to 3°C could result in increased coral bleaching events and increased coral mortality (Nicholls *et al.*, 2007).

Tropical cyclones or hurricanes typically form over warm tropical oceans. The warm water heats up the air above it and also moistens the air. This hot air then rises and forms an area of low pressure. As air moves toward this area of low pressure, it flows across the warm ocean waters and also warms and moistens, providing fuel to the low

pressure system. Once this hot moist air rises and condenses it releases energy.

Therefore, tropical storms and hurricanes are one way the earth releases energy into the atmosphere and balances the earth's energy budget.

Projected increases in sea surface temperatures and increases in water vapor could provide more fuel for tropical storms and hurricanes. Since Hurricanes typically form when sea surface temperatures exceed 26°C, an increase in sea surface temperatures will expand the area where tropical storms could form (Trenberth *et al.*, 2007). Current evidence suggests that the incidence of category 4 and 5 storms has increased globally since the 1970's, as well as storm duration and intensity (Trenberth *et al.*, 2007). In 2005, for example, the North Atlantic hurricane season had the greatest amount of named storms and was the only season with four category 5 hurricanes (Trenberth *et al.*, 2007). Thus, continued increases in green house gas emissions and rising sea surface temperatures may cause the intensity and duration of tropical storms to further escalate.

Landscape simulation models suggest that increased storm intensity and duration could play a role in the structural composition of mangrove forests. For south Florida and the Everglades National Park, these models predict mangrove forests will become shorter and will be dominated by the red mangrove species (*Rhizophora mangle*) (USGS, 1997). Combination of increasing rates of sea level rise and increased storm intensity and duration could result in greater storm surges, flooding, increased erosion, and salt water intrusion. Low lying areas such as the Everglades will be especially vulnerable to these impacts. If the sea level within the Everglades National Park increases by 23 inches tidal flats, freshwater marshes, and pineland forests could be submerged permanently (Kimball, 2007). Greater storm surges and flooding could lead to erosion events and

rising sea levels could result in saltwater intrusion. Increasing salinity levels within the Everglades may lead to the loss of many of the freshwater marsh species and the complete loss of the sawgrass prairie. If salt water intrudes the aquifer that lies beneath the Everglades, this will also threaten the fresh water supply of Miami and Dade counties.

Currently, south Florida receives 60 inches of rain a year on average but the annual rate of evaporation often exceeds this amount (OTA, 1993). Rainfall is also highly variable and thus the region faces droughts and floods. For example, in 1981 south Florida experienced an extreme drought that led to mandatory water restrictions and water rationing in the Everglades Agricultural Area (OTA, 1993). Precipitation predictions, according to the general circulation models for south Florida are not in agreement but there is a possibility for the area to become even hotter and drier (OTA, 1993).

## 2.2 A Climate Change Alternative

Unfortunately, none of the restoration alternatives described above would be successful as a climate change alternative because global climate change predictions were not considered during the planning process. The National Park Service recognizes the potential impacts of climate change on the Everglades' ecosystems but it did not include climate change in the development of the Comprehensive Everglades Restoration Plan (NPS, 2007a). Failing to include future potential changes such as an increased rate of sea level rise or salt water intrusion undermines any plan's ability to restore the Everglades. For example, if the rate of sea level increases and causes salinity levels within the Everglades National Park to increase, the planned amount of freshwater released into the park may not be enough to save freshwater prairies from saltwater intrusion.

Therefore, if climate change had been considered, the Restudy team would have most likely created a plan that took into consideration the potential impacts of global climate change. Specifically, the Restudy team might investigate how climate change would impact the hydrology of the south Florida, water quality, habitat and species range, habitat quality, and how climate change would impact each alternative's proposed changes to the hydrologic system. For example, will new water storage wells be compromised by salt water intrusion if the rate of sea level rise increases?

Recommendations on how the Everglades restoration planning team can incorporate global climate change into the planning and implementation process are described within two policy memorandums in the following part of this paper.

### **PART III: Policy Recommendations**

#### **3.1 Methods**

Before formulating the two policy memorandums found below, extensive research was conducted on the environmental, geological, and hydrological history of south Florida and the Everglades. The development and management history of the area was also investigated. The focus of this project, the Comprehensive Everglades Restoration Plan, originated from a visit to the Everglades National Park and two in person interviews with employees of the National Park Service, Linda Friar and David Hallac.

Subsequently, the Final Integrated Feasibility Report and Programmatic Environmental Impact Statement for the Comprehensive Everglades Restoration Plan was extensively examined and analyzed. The result of this investigation can be found in Part I of this paper. After reading the Final Integrated Feasibility Report it became apparent that the Comprehensive Everglades Restoration Plan did not take global climate

change into consideration when formulating the restoration alternatives. Therefore, further research was conducted in order to investigate the potential climate change impacts and current predictions for south Florida and the Everglades (Part II of this paper).

When it became apparent that none of the previous alternatives proposed in the Comprehensive Everglades Restoration Plan would be successful as a climate change alternative, ways to incorporate climate change into the restoration planning and implementation process were conceived by the author. Criteria for these recommendations can be found in the following section.

Finally, two policy memorandums were created to formally propose the recommendations to Congress and to the CERP planning and implementation team. The first memorandum is addressed to the House Appropriations Committee concerning climate change and lands administered by the Department of the Interior. This committee has the authority to appropriate funding for the changes recommended in the memorandum into current legislation to be further approved by Congress. Since the audience of this memorandum will not be experts on issues pertaining to south Florida, this memorandum must explain the history of the Everglades and South Florida and potential climate change impacts for the area. It must also contain a short explanation of CERP in case some of the committee members are unaware of the project. A broad overview of the recommendations was provided instead of a more detailed explanation since the committee will most likely not need the technical aspects of the recommendations to make their decision.



The second policy memo is addressed to the United States Army Corps of Engineers, South Florida Restoration Office and the South Florida Water Management District because these two agencies are the main groups responsible for the planning and implementation of CERP. Unlike the House Appropriations Committee, the U.S. Army Corps of Engineers and the South Florida Water Management District are well aware of the history of South Florida and CERP and therefore background information was left out of this memorandum. A more detailed explanation of the recommendations was provided in the second memorandum because the audience would be the ones to carry out these changes and therefore must decide whether the recommendations are feasible or not.

### 3.2 Criteria

The following describes the criteria that were used to formulate and evaluate the recommendations created regarding the incorporation of climate change in the CERP restoration planning and implementation process.

Recommendations must:

- 1) Facilitate the incorporation of potential climate change impacts that will have an effect on the goals of the Comprehensive Everglades Restoration Plan. In other words the impact must be relevant to CERP and the proposed changes to the hydrology of the Everglades.
- 2) Incorporate climate change impacts without compromising the goals of CERP. The recommendation must allow for the continued protection of urban populations from flooding, provision of sufficient water to all users, improvement of habitat function and quality, and protection of recreational opportunities and cultural values.
- 3) Be feasible physically, politically, and monetarily. The U.S. Army Corps of Engineers and the South Florida Water Management District must be able to implement the recommendation with current funds, tools, and technologies. The recommendation must also be politically feasible or acceptable by policymakers. One suggestion that was not included was a recommendation to expand the park's boundaries. This would give species the opportunity to shift their ranges northwards in response to changes in climate if necessary. Unfortunately, this

- recommendation is not politically feasible because it would require relocating urban populations and the Everglades Agricultural Area.
- 4) Be fair and just for all stakeholders involved. The recommendation must treat all stakeholders equally and affect all stakeholders in similar ways. If one group of stakeholders bears a disproportional burden of the costs of the recommendation, this alternative will not be deemed fair and just.

### 3.3 Explanation of Recommendations

The three recommendations proposed in the following policy memorandums include: the incorporation of current climate change predictions in the hydrologic and ecologic computer-based models, the monitoring and mapping of salinity levels within the Everglades National Park, and the use of the coastal vulnerability index to assess the vulnerability of the coastline of south Florida to future changes in sea level rise.

The first recommendation, to incorporate current climate change predictions into the models used to assess the restoration plans, will allow managers to evaluate how climate change will affect the success of restoration efforts and how restoration efforts can be further improved. Currently, several models are used to reproduce the hydrologic cycle of south Florida and how each alternative will affect water quality, trophic structure, and habitat quality. Regrettably, these models are based on current hydrologic conditions and do not take into account possible changes to the hydrologic cycle. Thus, if the rate of sea level rise continues to increase and if precipitation patterns change in south Florida, these models will be inadequate to predict the success of planned restoration efforts. Since the results of the South Florida Water Management Model (SFWMM) are used as input for the other models, only the SFWMM may need to be altered. One way in which this model can incorporate climate change is for the model to be run with three climate change scenarios (a low, moderate, and extreme scenario). For example, the low scenario could include a sea level rise rate of 7 inches by 2100 and

slight reductions in rainfall. The moderate scenario might include a sea level rise rate of 19 inches by 2100 (which is the current prediction of the IPCC), a greater reduction in rainfall, and increased rates of evapotranspiration (the combined loss of water from evaporation and transpiration). Finally, the extreme scenario may include a sea level rise rate of 31 inches by 2100, extreme drought conditions, and increased rates of evapotranspiration.

The second recommendation is to monitor and map the salinity levels within the Everglades National Park. Given that salt water intrusion is currently jeopardizing the existence of the freshwater marsh habitats within the Everglades, the extent and location of salt water intrusion should be monitored. Using the current location of the salinity line as a marker, freshwater can then be released in greater amounts into the Everglades on a need be basis in order to keep the salinity line within a one to two mile boundary. The South Florida Restoration Science Forum has already created a circulation and salinity model for Florida Bay. If feasible, this model should be used as a basis for creating a salinity model for the entire Everglades system.

The third and final recommendation provided by this paper is for the use of the coastal vulnerability index to assess the relative vulnerability of the coastline of south Florida to future sea level rise. If one of the main objectives of the Comprehensive Everglades Restoration Plan is to improve the ecological values of the Everglades, it is then necessary to identify areas that are in need of restoration and improvement as well as areas that will be vulnerable in the future. The Coastal Vulnerability Index (CVI) was created in 2001 by the United States Geological Survey and the National Park Service, Geologic Resources Division in order to assess the vulnerability of coastal areas within

the United States to future changes in sea-level (USGS and NPS, 2007). The CVI ranks input variables such as geomorphology, slope, wave height, and mean tidal range in terms of their contribution to coastal changes associated with sea level rise. Using these ranks it then identifies the regions or sections where change is predicted to be the greatest. The CVI has already been used successfully to assess the vulnerability of the Dry Tortugas National Park and should be conducted for the shoreline of the Everglades National Park. Such an assessment would give managers a better idea of which habitats and parts of the shoreline will be most susceptible to change.

The three recommendations meet the four policy criteria previously described. All incorporate relevant climate change impacts, all are physically, politically, and monetarily feasible, are fair and just for all stakeholders involved and none compromise the goals of the Comprehensive Everglades Restoration Plan.

### 3.4 Policy Memorandums

Please see pages 34 and 36.

## POLICY MEMORANDUM

TO: House Appropriations Committee concerning climate change and lands administered by the Department of the Interior

FROM: Jennifer Krajewski, Analyst

DATE: March 23, 2008

RE: Climate change alternative for the Everglades National Park

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### *Introduction*

According to predictions made by the most recent United Nations Intergovernmental Panel on Climate Change, global sea level is estimated to rise 48cm (~19 in) by 2100. If sea level rises at this projected rate, 10% to 50% of the Everglades freshwater marshes could be lost to salt water inundation. Potential future impacts of global climate change threaten the success of current efforts to restore and enhance the Everglades National Park. This memo will propose three ways in which current efforts, the Comprehensive Everglades Restoration Plan, can integrate climate change predictions into the restoration planning and implementation process. First, current climate change predictions should be included in the models used to assess restoration plans. Second, salinity levels within the Everglades National Park should be monitored and mapped. Third, the relative vulnerability of the coastline of south Florida to future sea level rise should be assessed using the coastal vulnerability index (CVI).

### *Comprehensive Everglades Restoration Plan*

Historically, the watershed of the Everglades began with Lake Okeechobee from which freshwater flowed into a vast sawgrass plain, then through a ridge and slough landscape into what is now known as the Everglades National Park and finally into the Gulf of Mexico. The current flow is drastically different than the historical flow due to the Central & South Florida (C&SF) Project which constructed levees, canals, and water control structures to protect communities on the east coast of Florida from floods and droughts. Thus, the C&SF Project has had unintended negative impacts on the Everglades ecosystem, including reductions in wading bird communities and freshwater marshes. With the aim of reversing the damages of the C&SF Project, the Department of the Interior, the Army Corps of Engineers, the State of Florida, and several Native American Indian tribes created the Comprehensive Everglades Restoration Plan (CERP). The plan aims to enhance the ecological values as well as the economic and social well being of the region by restoring the natural hydropattern of the Everglades.

### *Current climate change predictions for south Florida*

Due to its low elevation and flat landscape, south Florida will be exceptionally vulnerable to inundation from rapid rises in sea level and other possible future climate change impacts. The greatest threats faced by the Florida Everglades that pertain to climate change include: increasing rates of sea level rise, increasing sea surface temperatures, increased hurricane intensity and duration, greater storm surges and flooding, increased erosion, salt water intrusion, and changes in precipitation. If, for example, the rate of sea level rise exceeds the rate of sedimentation, wetlands within the Everglades National

Park may be unable to accrete sediment at a rate that equals or exceeds sea level rise and would thus be lost. Rising sea levels in addition to greater storm surges and flooding could also result in increased salinity levels which could lead to the complete loss of the sawgrass prairie from one of the few areas where it remains. If salt water intrudes the aquifer that lies beneath the Everglades, this will also threaten the fresh water supply of Miami and Dade counties.

#### *Incorporating climate change into CERP*

Since climate change was not taken into consideration during the formulation of the Comprehensive Everglades Restoration Plan, the plan will be unsuccessful if current climate change predictions become a reality. Below are four ways in which climate change predictions can be incorporated into the restoration planning and implementation process.

#### *Improving water and ecosystem models*

The models used to assess each of the restoration alternatives examined how each alternative would affect the hydrologic cycle, water quality, trophic structure, and habitat quality of south Florida. The models used to assess the restoration alternatives are commendable and successfully reproduce the hydrologic cycle. However, the hydrology of these models is based on current conditions (current sea levels, precipitation records from the last 30 years, etc.), which cannot be assumed for the future. For example, if the rate of sea level rise continues to increase and if precipitation patterns change in south Florida, then the models will be inadequate to predict the success of restoration efforts. Global climate change should be incorporated into the models by adding future predictions of sea level rise, rainfall, and evapotranspiration.

#### *Monitoring salinity levels*

As sea level rises, salt water will push further and further inland increasing salinity levels within estuaries and wetland systems. The consequences of saltwater intrusion are already being felt within the Everglades National Park, as sawgrass prairies are being replaced by more salt tolerant marsh species. In order to protect the remaining freshwater marsh habitats from saltwater intrusion, plans to monitor salinity levels within the Everglades National Park should be incorporated into the Comprehensive Everglades Restoration Plan. Using the current location of the salinity line as a marker, freshwater can then be released into the Everglades on a need be basis in order to keep the salinity line within a one to two mile boundary.

#### *Creating Coastal Vulnerability Index Maps*

If one of the main objectives of CERP is to improve the ecological values of the Everglades, it is then necessary to identify areas that need restoration and improvement as well as areas that will be vulnerable in the future. The Coastal Vulnerability Index (CVI) should therefore be used to map the relative vulnerability of the south Florida coast to future increased rates of sea level rise. The CVI ranks input variables such as geomorphology, slope, wave height, and mean tidal range in terms of their contribution to coastal changes associated with sea level rise. Using these ranks it then identifies the regions or sections where change is predicted to be the greatest.

## POLICY MEMORANDUM

TO: United States Army Corps of Engineers, South Florida Restoration Office  
and the South Florida Water Management District

FROM: Jennifer Krajewski, Analyst

DATE: March 23, 2008

RE: Climate change alternative for the Everglades National Park

---

### *Introduction*

According to predictions made by the most recent United Nations Intergovernmental Panel on Climate Change, global sea level is estimated to rise 48cm (~19 in) by 2100. If sea level rises at this projected rate, 10% to 50% of the Everglades freshwater marshes could be lost to salt water inundation. Potential future impacts of global climate change threaten the success of the Comprehensive Everglades Restoration Plan (CERP) and therefore, it is crucial for these impacts to be considered when assessing alternatives to restore the Florida Everglades. This memo will propose three ways in which CERP can integrate climate change predictions into the restoration planning and implementation process. First, current predictions of the future rate of sea level rise, salt water intrusion, precipitation, and evapotranspiration should be included in the models used to assess restoration alternatives. Second, salinity levels within the Everglades National Park should be monitored and mapped. Third, the relative vulnerability of the coastline of south Florida to future sea level rise should be assessed using the coastal vulnerability index (CVI) created by the U.S. Geological Survey and the National Park Service Geologic Resources Division.

### *Current climate change predictions for south Florida*

Due to its low elevation and flat landscape, south Florida will be exceptionally vulnerable to inundation from rapid rises in sea level and other possible future climate change impacts. The greatest threats faced by the Florida Everglades that pertain to climate change include: increasing rates of sea level rise, increasing sea surface temperatures, increased hurricane intensity and duration, greater storm surges and flooding, increased erosion, salt water intrusion, and changes in precipitation. If, for example, the rate of sea level rise exceeds the rate of sedimentation, wetlands within the Everglades National Park may be unable to accrete sediment at a rate that equals or exceeds sea level rise and would thus be lost. Rising sea levels in addition to greater storm surges and flooding could also result in increased salinity levels which could lead to the complete loss of the sawgrass prairie from one of the few areas where it remains. If salt water intrudes the aquifer that lies beneath the Everglades, this will also threaten the fresh water supply of Miami and Dade counties.

### *Incorporating climate change into CERP*

Since climate change was not taken into consideration during the alternative formulation process, none of the alternatives described in the Final Integrated Feasibility Report for the Comprehensive Everglades Restoration Plan would be successful if current climate change predictions become a reality. Below are three ways in which the Comprehensive

Everglades Restoration Plan can incorporate climate change predictions into the restoration planning and implementation process.

#### *Improving water and ecosystem models*

The models used to assess the restoration alternatives are commendable and successfully reproduce the hydrologic cycle and how each alternative will impact water quality, trophic structure, and habitat quality. However, the hydrology of these models is based on current conditions, which cannot be assumed for the future. For example, if the rate of sea level rise continues to increase and if precipitation patterns change in south Florida, then the models will be inadequate to predict the success of restoration efforts. Future climate change predictions should be incorporated into the South Florida Water Management Model (SFWMM), the Across-Trophic-Level System Simulation model, the Everglades Water Quality Model, and the Rivers of Grass Evaluation Method.

Since the SFWMM is used as input for the other three models, only the SFWMM may need to be altered. Three climate change scenarios should be run through the SFWMM, low, moderate, and extreme climate change scenarios. The low scenario for example could include a sea level rise rate of 7 inches by 2100 and slight reductions in rainfall. The moderate scenario could include a sea level rise rate of 19 inches by 2100 (current predictions), even less rainfall, and increased rates of evapotranspiration. Lastly, the extreme scenario may include a sea level rise rate of 31 inches by 2100, extreme droughts, and increased rates of evapotranspiration.

#### *Monitoring salinity levels*

The consequences of saltwater intrusion are already being felt within the Everglades National Park, as sawgrass prairies are being replaced by more salt tolerant marsh species. In order to protect the remaining freshwater marsh habitats from saltwater intrusion, plans to monitor salinity levels within the Everglades National Park should be incorporated into the Comprehensive Everglades Restoration Plan. Using the current location of the salinity line as a marker, freshwater can then be released into the Everglades on a need be basis in order to keep the salinity line within a one to two mile boundary. The South Florida Restoration Science Forum has already created a circulation and salinity model for Florida Bay. If feasible, this model could be used as a basis for creating a salinity model for the entire Everglades system.

#### *Creating Coastal Vulnerability Index Maps*

If one of the main objectives of CERP is to improve the ecological values of the Everglades, it is then necessary to identify areas that need restoration and improvement as well as areas that will be vulnerable in the future. The Coastal Vulnerability Index (CVI) should therefore be used to map the relative vulnerability of the south Florida coast to future increased rates of sea level rise. The CVI ranks input variables such as geomorphology, slope, wave height, and mean tidal range in terms of their contribution to coastal changes associated with sea level rise. Using these ranks it then identifies the regions or sections where change is predicted to be the greatest.



### 3.5 Conclusions

The Everglades National Park contains some of the most unique ecosystems of the United States. However, these ecosystems are highly vulnerable to the impacts of global climate change. If one of the goals of the Comprehensive Everglades Restoration Plan is to restore the hydrology and ecological values of the Everglades, it will be unsuccessful unless climate change predictions are taken into consideration in the planning and implementation process. Three ways in which this can be achieved are, by incorporating current climate change predictions in the models, monitoring and mapping the salinity levels within the Everglades National Park, and using the coastal vulnerability index to assess the vulnerability of the coastline of south Florida to future changes in sea level rise. These recommendations are physically, politically, and monetarily feasible. Whether they are implemented will depend on the opinions of Congress and the stakeholders involved.

### **Acknowledgements**

I would like to thank Jeffrey Vincent, my master's project advisor for helping me narrow down my topic and helping me through the process. I would also like to thank Linda Friar and David Hallac at the National Park Service for introducing me to the Everglades and the Comprehensive Everglades Restoration Plan.

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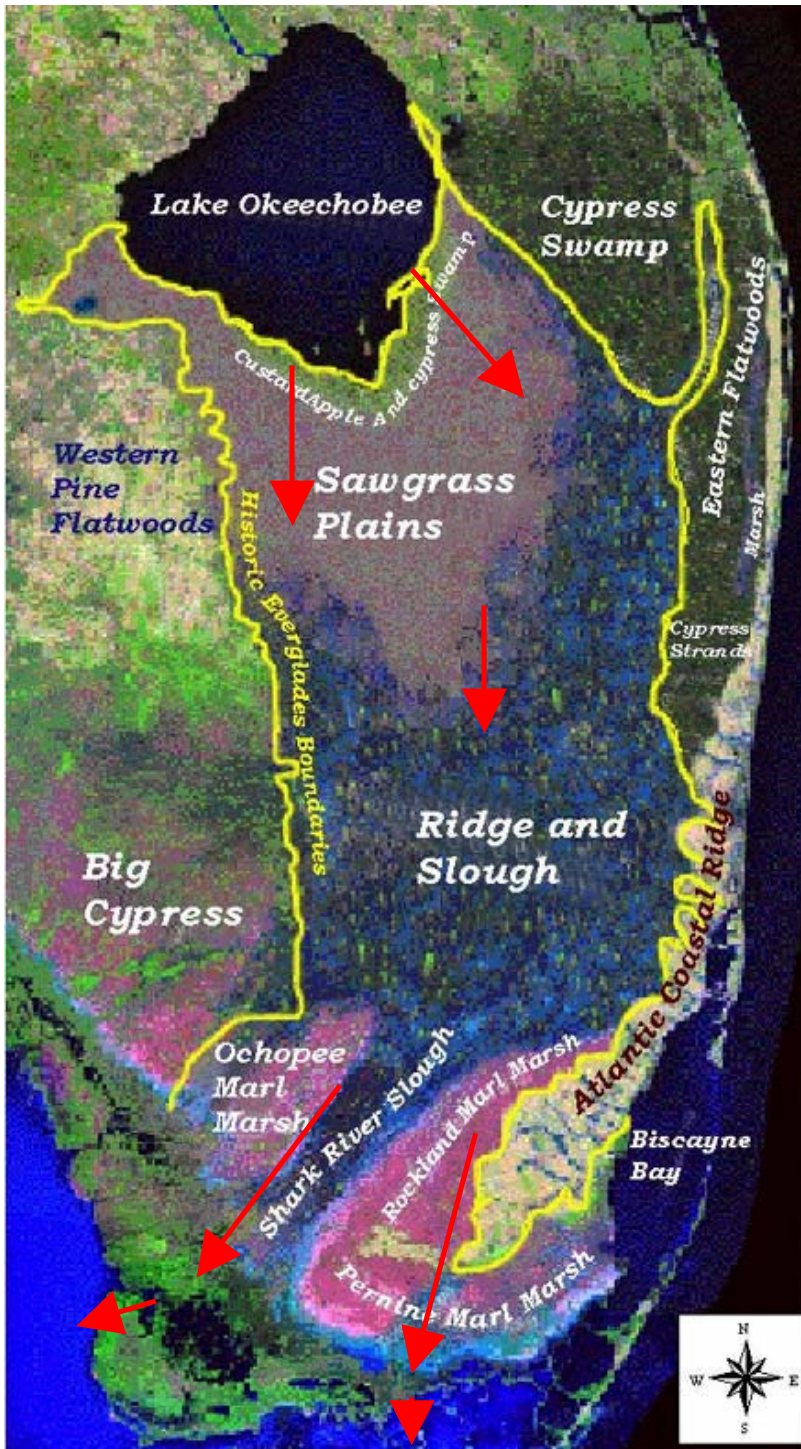
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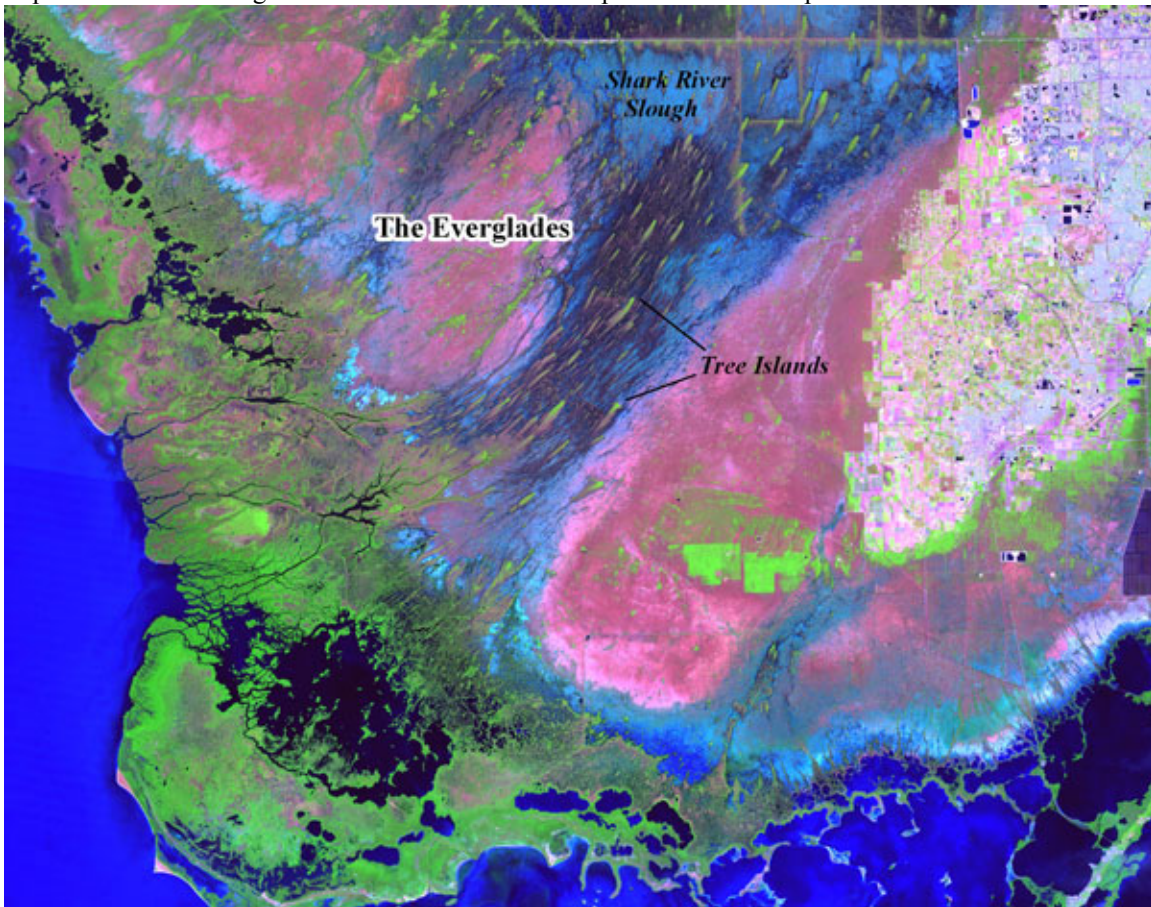
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APPENDIX



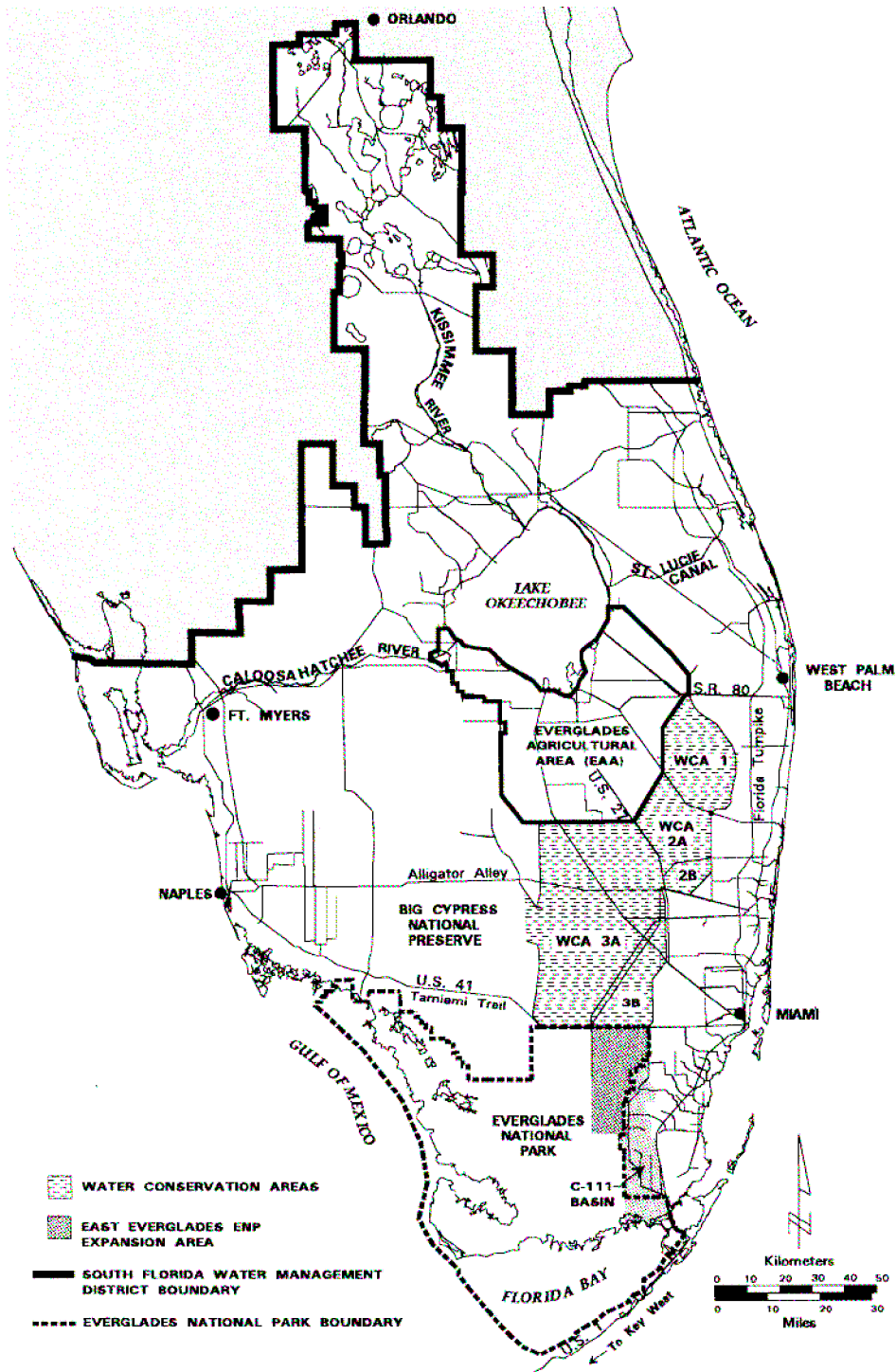
**Figure 1.** A depiction of the historic major landscape types and range of the Everglades prior to human settlement and intervention. This image also illustrates the historic flow of water from the Kissimmee River, to Lake Okeechobee, to the Everglades, and finally to Florida Bay and the Gulf of Mexico. Retrieved February 23, 2008, from Science Coordination Team (SCT), South Florida Ecosystem

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**Figure 2.** A satellite photo of the Everglades showing the Shark River Slough and the tree islands that are contained within the river of grass. The shape of the tree islands illustrates the direction of flow through the slough. Retrieved February 23, 2008 from Schwadron, Margo. (2006). *Everglades Tree Islands Prehistory: Archaeological Evidence for Regional Holocene Variability and Early Human Settlement*. *Antiquity*, 80(310), <http://www.antiquity.ac.uk/ProjGall/schwadron/index.html>.

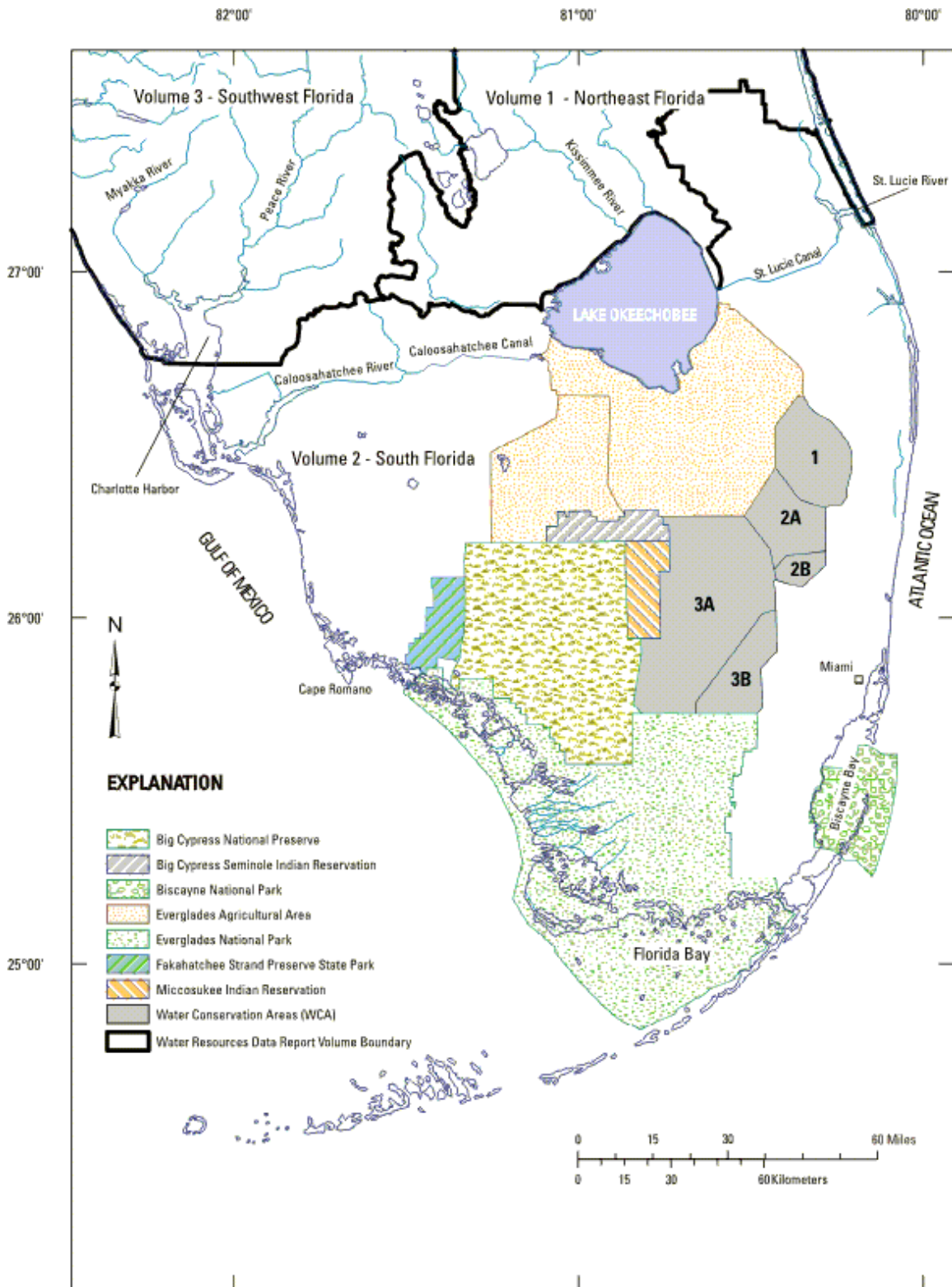




**Figure 3.** A map of the Everglades' watershed starting with the Kissimmee River, Lake Okeechobee, the Everglades, and finally Florida Bay. This image also illustrates the system of hard structures established by the Central and South Florida Project in 1948, including the Everglades Agricultural Area, the three Water Conservation Areas, and the Tamiami Trail or U.S. 41. Retrieved March 23, 2008, from Davis, S.M. and J.C. Ogen, Eds. (1994). *Everglades: The Ecosystem and its Restoration*. Delray Beach, Florida: St. Lucie Press.



**Figure 4.** A Bay-City dredge, circa 1927, excavates sand and limestone to create the Tamiami Trail. Retrieved February 24, 2007 from Collier County Museums. (2001). *Tamiami Trail: History and Photos*. [http://www.colliermuseum.com/history/tamiami\\_pic3.htm](http://www.colliermuseum.com/history/tamiami_pic3.htm).

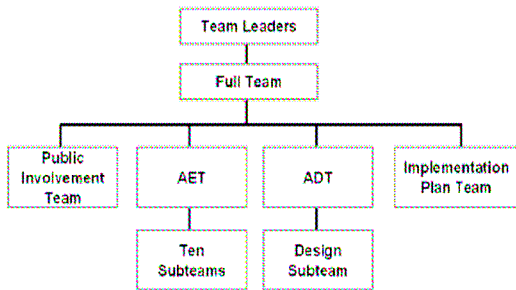


**Figure 5.** A depiction of the Water Conservation Areas 1, 2, and 3 in relation to the Everglades National Park. Retrieved February 24, 2008 from U.S. Geological Survey (2008, February 22). *Ground Water Conditions in South Florida: Background information on South Florida Data collection, Introduction and Summary of Hydrologic Conditions*. [http://www.sflorida.er.usgs.gov/edl\\_data/text/back\\_intro.html](http://www.sflorida.er.usgs.gov/edl_data/text/back_intro.html).

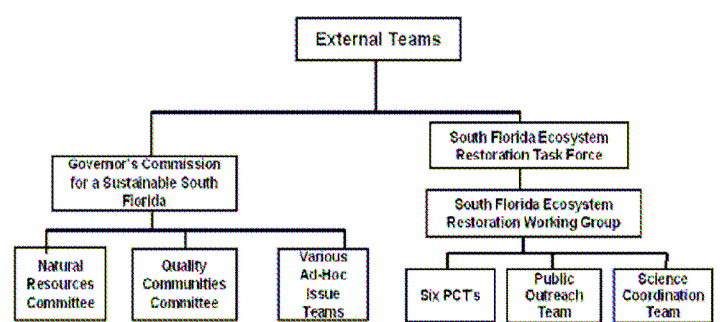


**Figure 6.** Photographs comparing a well preserved ridge and slough landscape to one that is degraded. The photograph on the left represents a well preserved ridge and slough mosaic landscape. The ridges appear to be in alignment with water flow. The photograph to the right represents a degraded ridge and slough landscape where the sawgrass appears more patch-like and the sloughs less open. Both photographs were taken in June of 2001 at Water Conservation Area 3A. Photographs retrieved from: Science Coordination Team (SCT), South Florida Ecosystem Restoration Working Group. (2003). *The Role of Flow in the Everglades Ridge and Slough Landscape*. Retrieved February 23, 2008, from <http://www.sfrestore.org/sct/docs/SCT%20Flow%20Paper%20-%20Final.pdf>.

### Internal Restudy Team



### External Restudy Team



**Figure 7.** The two flow-charts seen above represent the Internal and External Restudy Teams for the C&SF Project Comprehensive Review Study or Restudy that was carried out in the late 1990's. The Army Corps of Engineers and the South Florida Water Management District were the main groups responsible for the Restudy but overall 62 groups participated. Members of each group formed teams, the external restudy team and the internal restudy team. The internal team was made up of federal agencies, state agencies, local governments, and tribal governments. The external team consisted of policymakers, political representatives, and local citizen groups. Retrieved February 22, 2008, from Orth, Kenneth D. & Agnes R. McLean. (1999). *Restoring the Everglades: Lessons in Team Planning*. Army Corps of Engineers & South Florida Water Management District. Retrieved February 22, 2008, from [http://www.evergladesplan.org/docs/orth\\_nwc\\_restudy\\_paper.pdf](http://www.evergladesplan.org/docs/orth_nwc_restudy_paper.pdf).

**PERFORMANCE OF THE COMPREHENSIVE PLAN  
COMPARED TO THE NO-ACTION ALTERNATIVE**

Area	Future Without Plan	Future With Plan	
Lake Okeechobee	Y	G	
Caloosahatchee Estuary	R	G	
St Lucie Estuary	R	G	
Lake Worth Lagoon	Y	Y	
Holey Land & Rotenberger WMA	Y	G	
Loxahatchee National Wildlife Refuge	Y	G	
Water Conservation Area 2A	↑ R ↓	G/Y	
Water Conservation Area 2B		R	
Northwestern Water Conservation Area 3A		G	
Northeastern Water Conservation Area 3A		Y	
Eastern Water Conservation Area 3A		Y	
Central & Southern Water Conservation Area 3A		G/Y	
Water Conservation Area 3B		Y	
Everglades National Park – Shark River Slough		R	G
Everglades National Park – Rockland Marl Marsh		R	Y
Florida Bay		R	G
Biscayne Bay	Y	G	
Model Lands	R	G	
Big Cypress National Preserve	Y	G	
Lake Okeechobee Service Area	R	G	
Urban Lower East Coast	R	G	

Green (G) - predicted hydrologic performance will result in recovery and long-term sustainability of ecological or water supply objectives.

Yellow (Y) -marginal or uncertain ability to achieve long-term sustainability of ecological or water supply objectives.

Red (R) -ecological or water supply objectives will not be met.

**Figure 8.** The table above compares the future of the south Florida ecosystem without a comprehensive restoration plan and with a comprehensive restoration plan. Without a comprehensive restoration plan, the future of south Florida and the Everglades National Park does not appear sustainable. Increased population and water demand pressures will reduce the amount of water discharged into the Everglades National Park thus endangering its ecosystem and the ecosystems of the Florida and Biscayne bays. Retrieved February 22, 2008 from, United States Army Corps of Engineers & South Florida Water Management District (USACE & SFWMD). (1999, April). *Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environmental Impact Statement*. Disc 1. Final Integrated Feasibility Report and PEIS CD-ROM.

Major Features	Alternatives						
	Starting Point	1	2	3	4	5	6
North L.O. Storage	100K ac-ft	200K ac-ft	200K ac-ft	200K ac-ft	200K ac-ft	200K ac-ft	200K ac-ft
C-44 Basin Storage	20K ac-ft	20K ac-ft	40K ac-ft	40K ac-ft	40K ac-ft	40K ac-ft	40K ac-ft
C-43 Basin Storage	80K ac-ft	160K ac-ft	160K ac-ft 220 mgd ASR	160K ac-ft 220 mgd ASR	160K ac-ft 220 mgd ASR	160K ac-ft 220 mgd ASR	160K ac-ft 220 mgd ASR
EAA Storage Area	240K ac-ft	240K ac-ft	240K ac-ft	360K ac-ft	360K ac-ft	360K ac-ft	360K ac-ft
Additional L-8 Improvements					25 mgd ASR	25 mgd ASR	50 mgd ASR 48K ac-ft
Site 1 Impoundment	10K ac-ft	10K ac-ft	10K ac-ft	10K ac-ft 25 mgd ASR	10K ac-ft 75 mgd ASR	10K ac-ft 75 mgd ASR	14.8K ac-ft 150 mgd ASR
Western C-11 & North New River Diversion	6.4K ac-ft	6.4K ac-ft	6.4K ac-ft	6.4K ac-ft	6.4K ac-ft	6.4K ac-ft	6.4K ac-ft
C-9 Impoundment and Diversion	10K ac-ft	10K ac-ft	10K ac-ft	10K ac-ft	10K ac-ft	10K ac-ft	10K ac-ft
Central Lake Belt Storage	80K ac-ft	80K ac-ft	80K ac-ft	100K ac-ft	135.2K ac-ft	135.2K ac-ft	187.2K ac-ft
Bird Drive Basin Impoundment	11.5K ac-ft	11.5K ac-ft	11.5K ac-ft	11.5K ac-ft	11.5K ac-ft	11.5K ac-ft	11.5K ac-ft
L-31N Seepage Management	100% Levee 100% Groundwater	100% Levee	100% Levee 100% Wet Season Groundwater	100% Levee 100% Wet Season Groundwater	100% Levee 100% Wet Season Groundwater	100% Levee 100% Wet Season Groundwater	100% Levee 100% Wet Season Groundwater
Taylor Creek/Nubbin Slough Storage and Treatment			50K ac-ft Reservoir 20K ac-ft STA	50K ac-ft Reservoir 20K ac-ft STA	50K ac-ft Reservoir 20K ac-ft STA	50K ac-ft Reservoir 20K ac-ft STA	50K ac-ft Reservoir 20K ac-ft STA
Lake Okeechobee ASR				1K mgd ASR	1K mgd ASR	1K mgd ASR	1K mgd ASR
C-51 Regional Ground Water ASR				340 mgd ASR	540 mgd ASR	540 mgd ASR	340 mgd ASR
C-23/24/Northfork and Southfork Storage Reservoirs					166K ac-ft	190K ac-ft	192K ac-ft
North New River Regional Ground Water ASR				250 mgd ASR			
Hillsboro Canal Basin Regional Groundwater ASR				370 mgd ASR	220 mgd ASR	220 mgd ASR	
WCA-3 and ENP (Remove Canals and Levees)				9 miles of Canal	146 mi of Canal 82 mi of Levee	127 mi of Canal 54 mi of Levee	127 mi of Canal 56 mi of Levee
Palm Beach County Agriculture Reserve Reservoir					10K ac-ft	10K ac-ft 75 mgd ASR	19.9K ac-ft 75 mgd ASR
North Lake Belt Storage					70K ac-ft	70K ac-ft	90K ac-ft
Lower East Coast Water Conservation						6% Reduction in 2050 Utility Demands	6% Reduction in 2050 Utility Demands
South Dade County Reuse						131 mgd Capacity	131 mgd Capacity
C-51/Southern L-8 Reservoir							120K ac-ft Capacity
West Dade Reuse							100 mgd Capacity

Ac-ft - Acre-Feet, K- unit of 1,000's, STA - Stormwater Treatment Area, mi - miles, mgd - million Gallons per Day

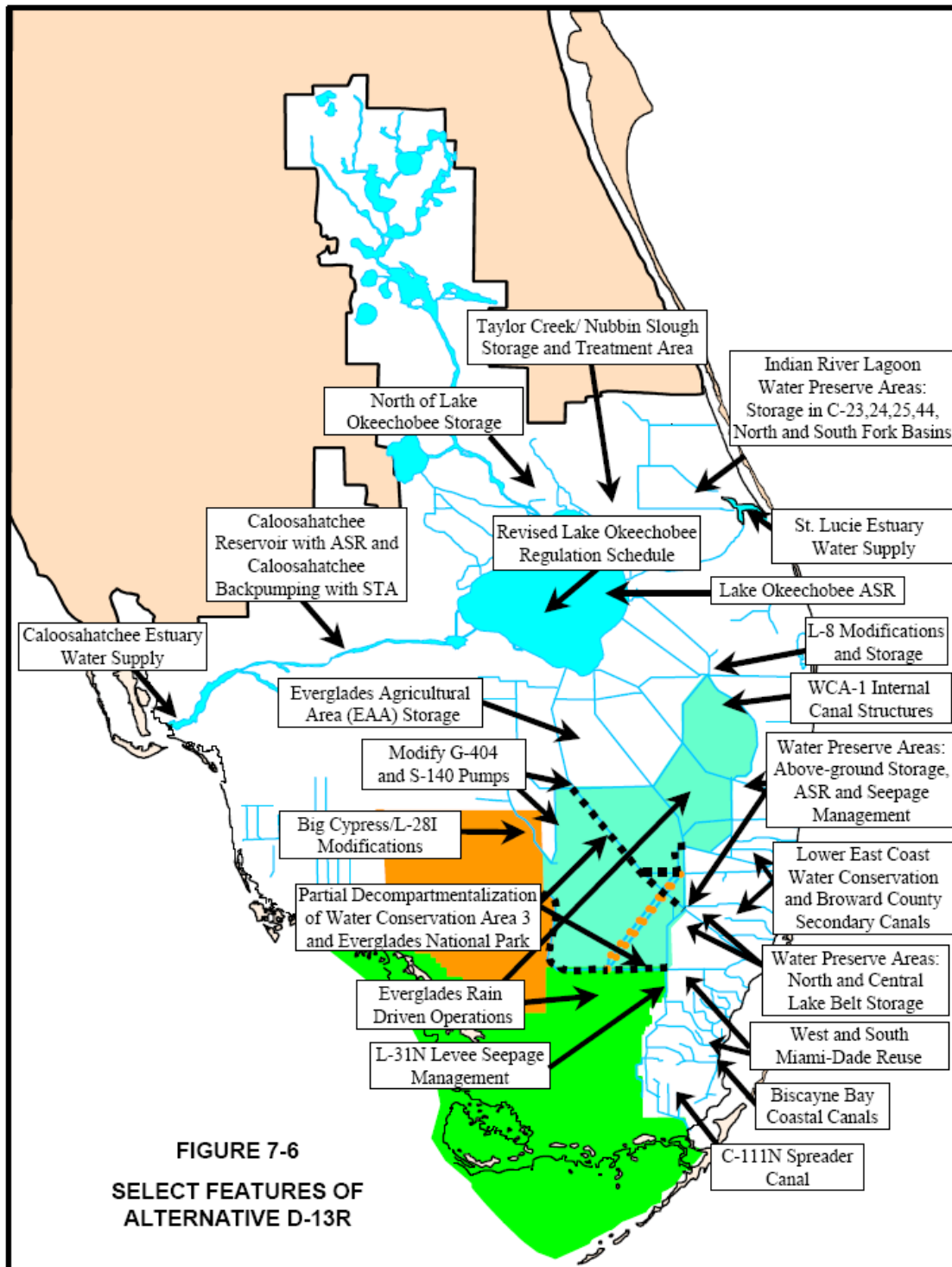
**Figure 9.** The table above describes the major differences between Alternatives 1-6 of the Comprehensive Everglades Restoration Plan. Each new alternative modifies the previous alternative or adds to it. Retrieved February 24, 2008, from, United States Army Corps of Engineers & South Florida Water Management District (USACE & SFWMD). (1999, April). *Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environmental Impact Statement*. Disc 1. Final Integrated Feasibility Report and PEIS CD-ROM.

**COMPONENTS DIFFERENT IN ALTERNATIVES A - D**

Component Title		Alternatives			
		A (Alt 3 Rev)	B (Alt 4 Rev)	C (Alt 5 Rev)	D (Alt 6)
I	Improve Conveyance between Water Conservation Area-3B and ENP	✓	Merged with QQ		
N	Water Conservation Area-2 B Levee Seepage Management	✓	Merged with YY		
P	North New River Diversion and Treatment	✓	Merged with YY		
AA	Additional S-345 Structures	✓		✓	✓
HH	Modify S-343 A&B Operations	✓		✓	✓
MM	Hillsboro Canal Basin Regional Groundwater ASR	✓	✓	✓	
pp	Backpumping of the C-7 Basin to the Central Lake Belt Storage System via the C-6 Canal	✓			
QQ	Decomartmentalize Water Conservation Area-3		✓	✓	✓
RR	Flow to Central Water Conservation Area 3A		✓	✓	✓
SS	Relocate Miami Canal Water Supply Deliveries to NNR		✓	✓	✓
VV	Palm Beach County Agriculture Reserve Reservoir		✓	✓	✓
WW	C-11 IN Spreader Canal		✓	✓	✓
XX	North Lake Belt Storage		✓	✓	✓
YY	Divert Water Conservation Area-2 flows to Central Lake Belt Storage		✓	✓	✓
ZZ	Divert Water Conservation Area-3A/3B flow to Central Lake Belt or South Dade			✓	✓
AAA	Lower East Coast Water Conservation			✓	✓
BBB	South Dade County Reuse			✓	✓
CCC	Big Cypress L-26I Modifications			✓	✓
EEE	Flow to eastern Water Conservation Area-3B			✓	✓
FFF	Biscayne Bay Coastal Canals			✓	✓
GGG	C-51/Southern L-8 Reservoir				✓
HHH	West Dade Reuse				✓

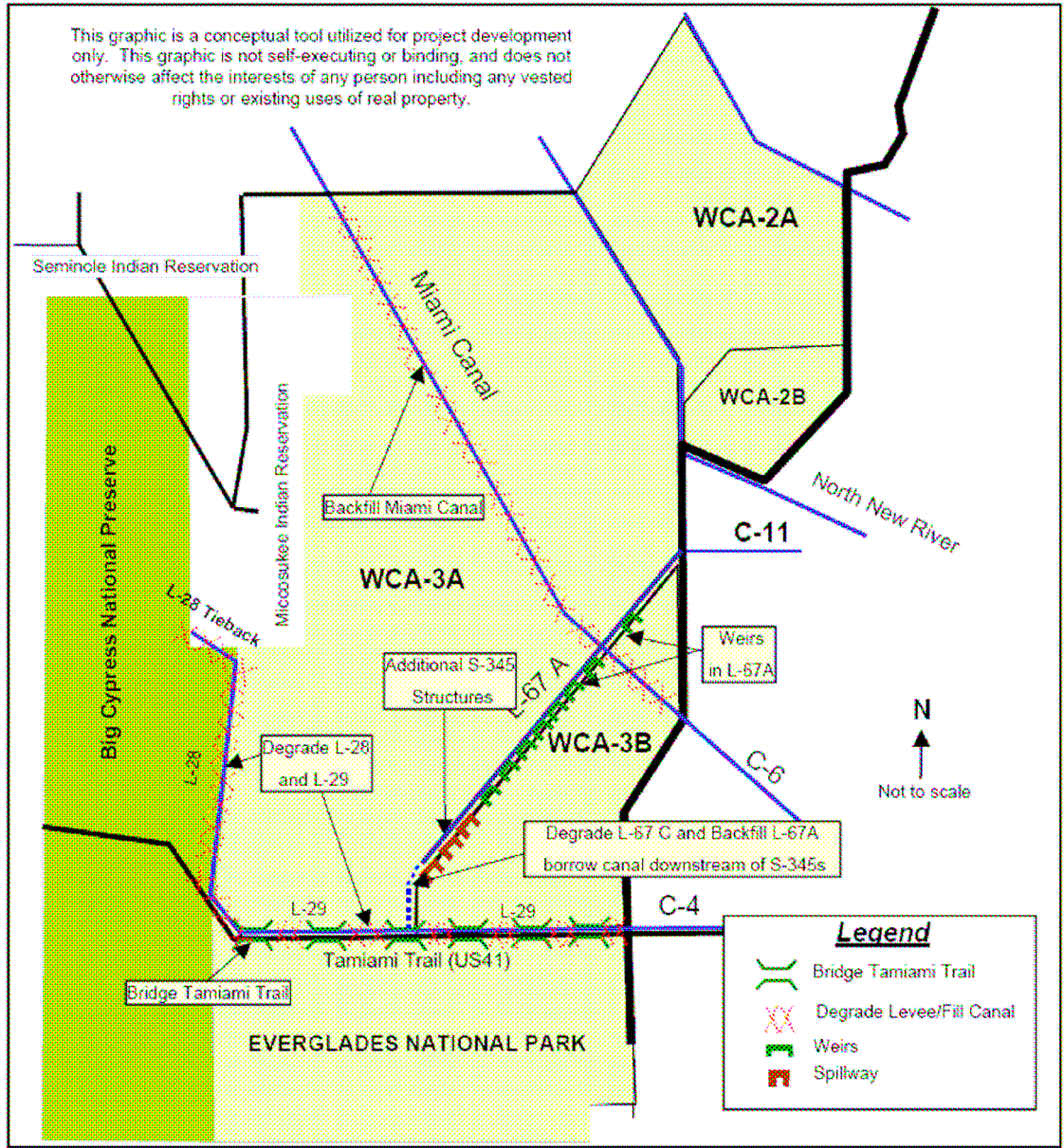
✓ - indicates that the component is included in the respective alternative  
 Components J, Z, JJ, NN and TT are not included in alternatives A-D

**Figure 10.** The table above describes the major differences between Alternatives A-D of the Comprehensive Everglades Restoration Plan. United States Army Corps of Engineers & South Florida Water Management District (USACE & SFWMD). (1999, April). *Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environmental Impact Statement*. Disc 1. Final Integrated Feasibility Report and PEIS CD-ROM.



**Figure 11.** The image above illustrates several of the components of the final Comprehensive Everglades Restoration Plan. United States Army Corps of Engineers & South Florida Water Management District (USACE & SFWMD). (1999, April). *Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environmental Impact Statement*. Disc 1. Final Integrated Feasibility Report and PEIS CD-ROM.



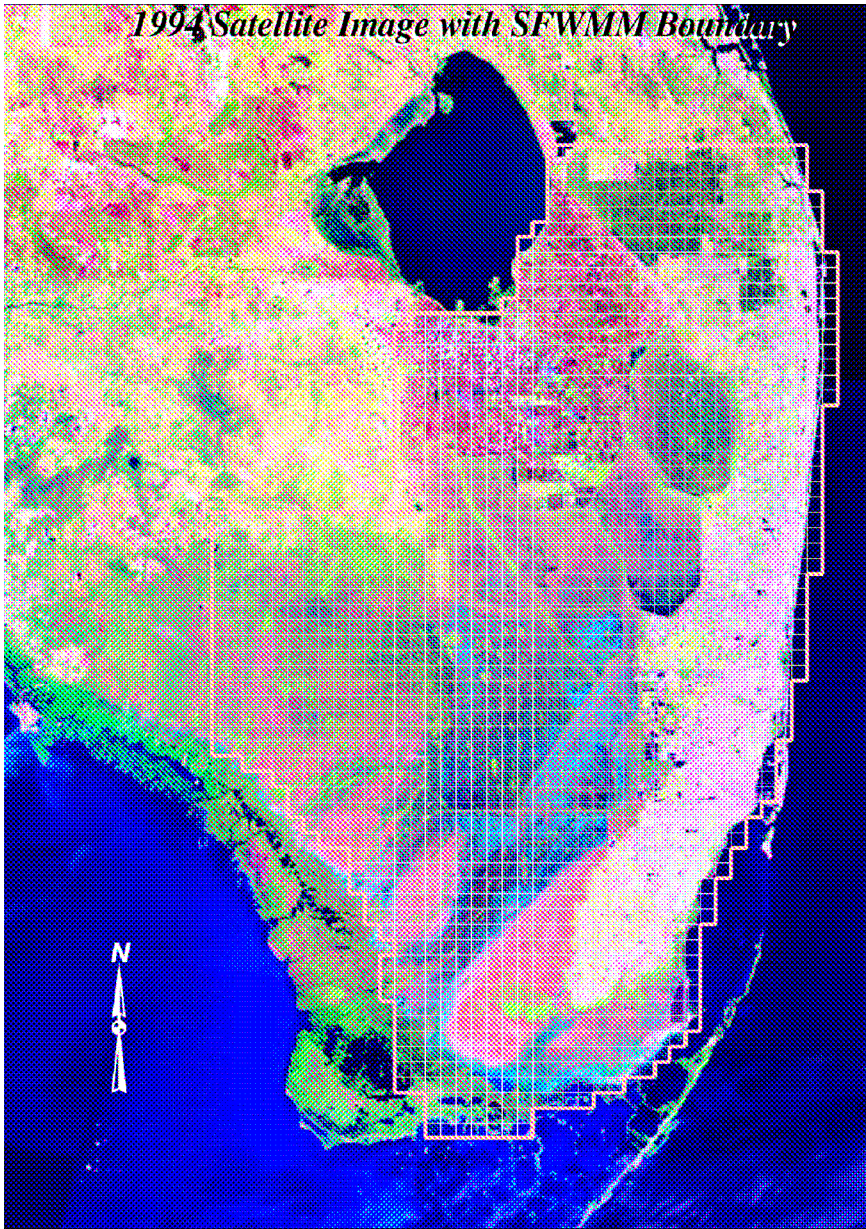


**Figure 12.** A depiction of one component of Alternative D13R, the rebuilding of the Tamiami Trail. The final Comprehensive Everglades Restoration Plan calls for 20 miles of the Tamiami Trail to be rebuilt with bridges and culverts to allow water to flow more naturally from Water Conservation Area 3 to the Everglades. United States Army Corps of Engineers & South Florida Water Management District (USACE & SFWMD). (1999, April). *Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environmental Impact Statement*. Disc 1. Final Integrated Feasibility Report and PEIS CD-ROM.

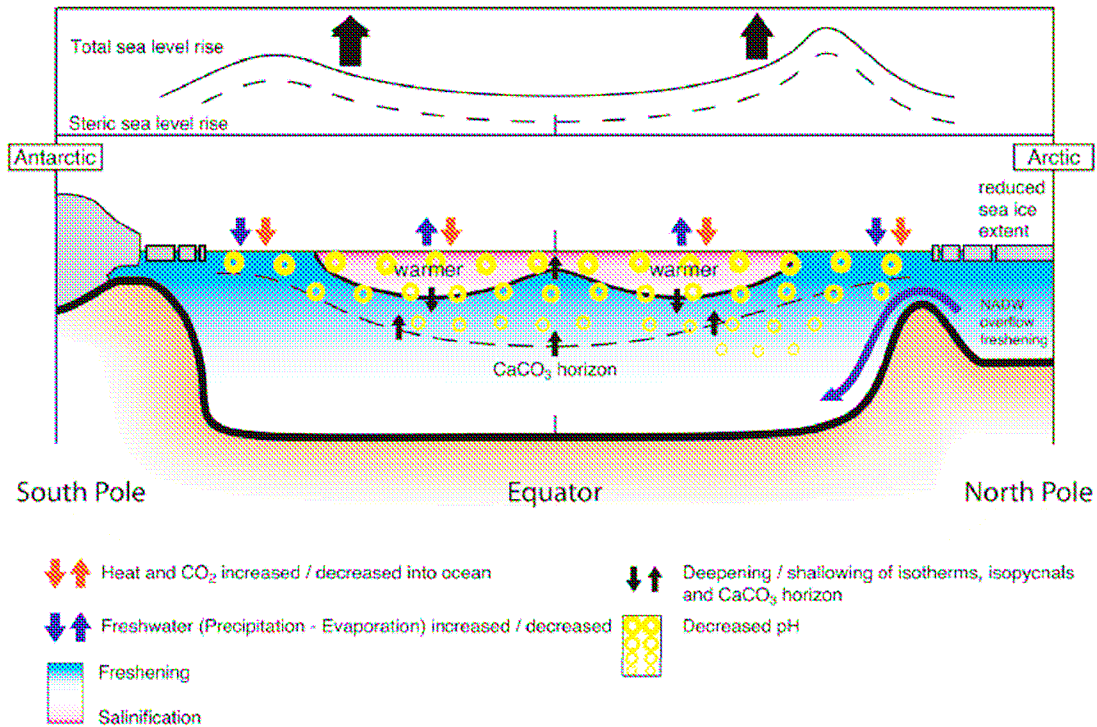
**PERFORMANCE OF THE WITHOUT PLAN CONDITION AND  
ALTERNATIVES  
RELATIVE TO PERFORMANCE MEASURES  
LETTER GRADE**

Sub-region	Alternatives				
	Without Plan	A	B	C	D
Lake Okeechobee	C	B	B	A	A
Caloosahatchee Estuary	F	A	A	A	A
St Lucie Estuary	F	C	C	C	B+
Lake Worth Lagoon	F	D	B	C	C
Holey Land & Rotenberger Wildlife Management Areas	C	B	B	B	B
Loxahatchee National Wildlife Refuge	C	A	A	A	A
Water Conservation Areas 2 & 3	D	C	D	D	D
Shark River Slough	F	F	D	D	D
Rockland Marl Marsh	D	C	C	B	B
Model Lands	F	F	C	B	B
Florida Bay	F	C	C	C	C
Biscayne Bay	C	F	F	C	B
Southern Big Cypress	B	B	B	B	A
Southeastern Big Cypress	B	A	B	A	A
Connectivity	D	D	A	B	B
Sheet Flow	F	B	B	B	B+
Fragmentation	F	F	A	B	B
Lake Okeechobee Service Area	F	B	C	B	A
Dade Agricultural Area	F	A	A	A	B
Lower East Coast Service Area	D	B	B	A	A
Water Quality	D	C	C	C	C

**Figure 13.** The table above lists the results of the grading evaluation of the without plan, A, B, C, and D alternatives. Each alternative and the without plan alternative was evaluated and analyzed using the South Florida Water Management Model (SFWMM), the Across-Trophic-Level System Simulation (ATLSS) model, the Everglades Water Quality Model, and the Rivers of Grass Evaluation Method. Each alternative was then graded based on water supply, water quality, and ecological objectives. United States Army Corps of Engineers & South Florida Water Management District (USACE & SFWMD). (1999, April). *Central and Southern Florida Project Comprehensive Review Study: Final Integrated Feasibility Report and Programmatic Environmental Impact Statement*. Disc 1. Final Integrated Feasibility Report and PEIS CD-ROM.



**Figure 14.** This image illustrates output from the South Florida Water Management Model (SFWMM). The SFWMM is an integrated surface-groundwater model which can be used to evaluate the hydrologic cycle of South Florida. In this image, the water management area of the Everglades is broken up into 2 mile by 2 mile cells. South Florida Water Management District. (2008). *South Florida Water Management Model (SFWMM)*. Retrieved March 18, 2008, from [https://my.sfwmd.gov/pls/portal/docs/PAGE/PAGE\\_GRP\\_SFWMHESM/PORTLET\\_POSITIONANALYSIS/OPLN/ADP/FRAME1/SFWMM.HTM](https://my.sfwmd.gov/pls/portal/docs/PAGE/PAGE_GRP_SFWMHESM/PORTLET_POSITIONANALYSIS/OPLN/ADP/FRAME1/SFWMM.HTM).



**Figure 15.** This diagram describes the currently observed changes in ocean temperature, salinity, sea level, sea ice, and biogeochemical cycles. From this diagram it appears the waters surrounding the Everglades National Park have become warmer, the amount of freshwater and pH has decreased, the amount of CO<sub>2</sub> absorption has increased, as well as the salinity level and sea level. Retrieved March 2, 2008 from Bindoff, N.L., J. Willebrand, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley & A. Unnikrishnan. (2007). Chapter 5, Observations: Oceanic Climate Change and Sea Level. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Eds. Cambridge, United Kingdom and New York, NY: Cambridge University Press.