

## Introduction

The South Florida Ecosystem Program is an intergovernmental effort to reestablish and maintain the ecosystem of south Florida. One element of the restoration effort is the development of a firm scientific basis for resource decisionmaking. The U.S. Geological Survey (USGS) is one of the agencies that provides scientific information as part of the USGS South Florida Ecosystem Program. The Program, which was begun in fiscal year 1995, provides multidisciplinary hydrologic, cartographic, and geologic data that relates to the mainland of south Florida, the Florida Bay, and the Florida Keys and Reef ecosystems (see fig.). The Program

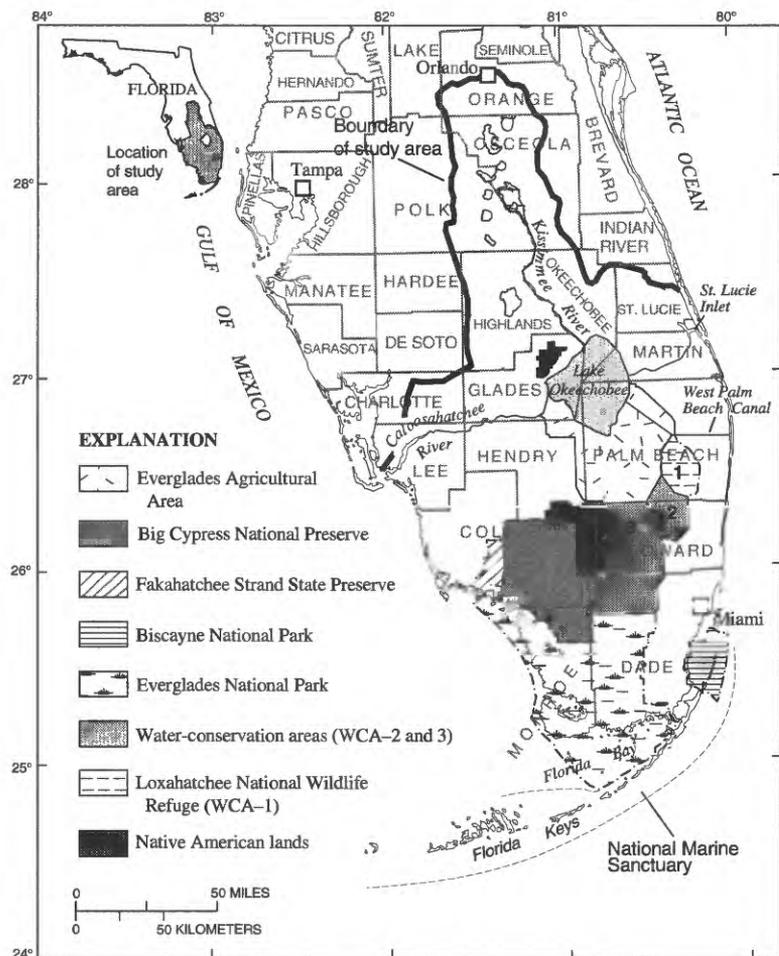
complements ongoing USGS work, such as the National Water-Quality Assessment Program, the Federal-State Cooperative Program, marine and regional geology programs, and topographic mapping and digital cartography.

## Background

Early travelers to south Florida encountered vast wetlands that spanned the State south of Lake Okeechobee. The largest of these was the Everglades—an area of 2.9 million acres of predominantly peat soils and tall sawgrass that is interspersed with tree islands, which are areas of slightly raised elevation covered by shrubs and woody vegetation. The Ever-

glades was part of the Kissimmee-Okeechobee-Everglades watershed, which covered about two-thirds the length of the Florida peninsula. The Kissimmee River flowed into Lake Okeechobee, which is a shallow water body of 470,000 acres. During floods, water spilled over the Lake's natural levee and flowed slowly southward in what was described as the "River of Grass" by Florida author and conservationist Marjory Stoneman Douglas. During the rainy season in normal rainfall years, most of the land was inundated, and during years of heavy rainfall, all but the highest tree islands were flooded. Water levels generally were near land surface during the dry season. When water levels declined well below the land surface as a result of extreme drought, severe fires would burn vegetation and peat. Seasonal flows from the Everglades into Florida Bay and the Gulf of Mexico supported productive coastal wetlands.

The south Florida ecosystem has been greatly altered during the last 100 years. Drainage of the south Florida watershed began in the early 1880's and continued through the 1960's. In response to flooding and hurricanes in 1926, 1928, 1947, 1948, 1960, and 1981, the southern shore of Lake Okeechobee was diked, canals were dug or enlarged to improve drainage, and a complex water-management system that included levees, pumps, and control structures was constructed. Lake Okeechobee and three water-conservation areas (WCA's) were developed for use as reservoirs for flood protection during the wet season and for agricultural irrigation and recharge of ground water in urban well fields during the dry season. About 40 percent of the water that originally flowed from Lake Okeechobee into the Everglades is now diverted to the Gulf of Mexico and the Atlantic Ocean. The northern Everglades were drained and designated the Everglades Agricultural Area. By the early 1990's, about 50 percent of the historic Everglades had been



Parks, preserves, refuges, sanctuaries, Native American lands, the Everglades Agricultural Area, and the South Florida Ecosystem Program study boundary.

drained. The remaining 50 percent is preserved in WCA-1 (Loxahatchee National Wildlife Refuge), WCA-2, WCA-3, and Everglades National Park, which was established in 1947 on 1.4 million acres in the southwestern end of the area (see fig.).

Today, the south Florida ecosystem includes urban areas near the coast, intensively developed agricultural areas in the northern Everglades, rangelands, and wetlands. The northern part is either publicly owned wetlands under the supervision of the U.S. Fish and Wildlife Service and the South Florida Water Management District (SFWMD) or privately owned urban and agricultural areas. Native American lands are located in the central part of the south Florida ecosystem. Most of the southern part of the ecosystem is in public ownership or under public control as parks, preserves, sanctuaries, conservation areas, and refuges (see fig.) and contains most of the remaining Everglades and adjacent south Florida wetlands.

## Resource-Management Issues

Drainage and development of south Florida has had major environmental consequences in the Everglades. Saltwater intrusion into freshwater aquifers has extended as far as 6 miles inland from the coast in some areas. The land surface has subsided as much as 6 feet in some agricultural areas because of lowered water tables, oxidation of drained peat, and subsequent peat fires. Mercury contamination of fish has resulted in a ban on the consumption of fish from the central part of the Park, WCA-2, and WCA-3 and is implicated in the deaths of endangered Florida panthers. Populations of wading birds have decreased by almost 95 percent from 1870 to 1973. In high-nutrient areas, cattails are replacing native sawgrass. Plant and animal communities in the Everglades have been altered by changes in timing and duration of inundation; invasion of exotic plants as a result of drainage and land clearing, nutrient, and (or) contaminant-enrichment of water that flows into Everglades from agricultural and urban areas; and loss of habitat.

Florida Bay and the coral reefs within the National Marine Sanctuary (fig.) have

undergone dramatic changes during the past 10 years. Decreased water flow owing to human activities has increased salinity in Florida Bay. The increases in nutrients and salinity in the Bay and the reefs may have stimulated the growth of algae, thus causing dieoffs of corals and seagrasses. Loss of coral reefs may be further accelerated by seepage of nutrient-laden ground water from the Florida Keys, where sewage is injected into the aquifer for disposal. Declines in seagrasses, which hold bottom sediments in place and provide habitat for fish, have resulted in decreasing water clarity and declining fish populations in Florida Bay.

## Program Objectives

The USGS South Florida Ecosystem Program supplies resource-management agencies with information that will enable them to reestablish the water regime and to manage and maintain the components of the hydrologic system so that natural ecosystem functions can recover.

The U.S. Army Corps of Engineers (COE) and the SFWMD need USGS data and information to improve models of water flows and water quality and to predict the consequences of the restoration efforts in south Florida. Information on such topics as measurement of flows into Florida Bay and the Atlantic Ocean, evapotranspiration measurement and modeling, vegetative resistance to flow, model review, ground-water flow, saltwater intrusion, high-resolution elevation, digital orthophotoquads, and enhanced model linkage is critically needed for the improvement of hydrologic models.

The Everglades National Park and the SFWMD need USGS information about historical environmental conditions and the frequency of fire to understand current (1995) and historical water and fire conditions, to set ecological goals for restoration, to distinguish human influences from the natural background of water fluctuations and trace-element contamination, and to provide yardsticks to measure the success of the restoration. The USGS is providing information on historical environmental conditions by examining geochemical and biological records such as trace elements, spores, pollen, char-

coal, and invertebrate skeletons in sediment cores.

The Florida Department of Environmental Protection (FDEP), the National Marine Fisheries Service (NMFS) and the U.S. Environmental Protection Agency (USEPA) need information on mercury cycling to predict changes in the availability of mercury to fish as a result of restoration. This information includes interactions of mercury with peat, algae, and dissolved organic carbon, as well as historical mercury concentrations in peat.

The National Park Service (NPS), the National Marine Sanctuary (NMS), and State resource managers need a circulation model of Florida Bay to estimate changes in salinities, nutrients and other pollutants in the Bay after restoration activities increase the flow into the Bay. The COE needs USGS monitoring information on sedimentation, circulation, bathymetry, water flow and nutrient loading into Florida Bay, and the effect of that inflow on salinity of the Bay for a predictive circulation model. This information will improve their ability to determine the location, circulation, and effects of nutrients and toxic substances that enter the Bay and their understanding of the relation between freshwater inflow and salinity in the Bay. USGS information on nutrient loads to Florida Bay and the reef track will help the NMS in their efforts to protect the marine sanctuary from nutrient-driven coral dieoffs and decline of the fishery. The FDEP uses USGS information on turbidity and sedimentation for refining their evaluation and monitoring programs in Florida Bay.

Communities in the Florida Keys need information on nutrient seepage from ground water, provided by the USGS, to determine whether it is necessary to modify their sewage-disposal practices.

## Project Descriptions for Fiscal Year 1995

### *Everglades Hydrologic Model Enhancements*

**Freshwater Discharge to the East Coast.** The USGS is measuring and calibrating discharge at 20 highly regulated coastal canals in cooperation with the

SFWMD and the COE. Discharge data from these and six other canals, which are part of the long-term USGS streamflow-gaging-station program, account for the total freshwater discharge to the bays and estuaries between the West Palm Beach Canal (C-51) in the north and C-111 in southern Dade County. These data are needed to quantify water that can be made available for water supply and ecosystem restoration and to calibrate the regional hydrologic models.

### **Freshwater Discharge to Florida**

**Bay.** The USGS, in cooperation with the NPS and the COE, is instrumenting and measuring discharge in primary natural channels that carry freshwater into Florida Bay to obtain stage-discharge relations. These data are used in conjunction with data on salinity to determine how salinity within the Bay is controlled and to calibrate the circulation models being constructed by the COE. Water quality samples are collected at the same time discharge measurements are made. The flow and water-quality data are used in conjunction with other sampling programs to increase the understanding of nutrient transport mechanisms into the Bay.

**Evapotranspiration Measurements and Modeling.** Although evapotranspiration is a major component of the Everglades water budget and hydrologic models, few measurements have been made for the types of land-cover environments that are characteristic of the region. In cooperation with the SFWMD and the NPS, the USGS is making field measurements of evapotranspiration at eight sites in several environmental settings for a process-oriented model. Data from these sites are used to estimate areal evapotranspiration values for use in the hydrologic model that is used by those Federal and State agencies that are involved in planning the restoration of the Everglades.

**Vegetative Resistance to Flow.** Surface-water models in the Everglades are highly sensitive to the surface-roughness coefficient used in the flow equation. USGS laboratory flume experiments provide resistance coefficients that represent characteristic Everglades conditions. These data are used by the SFWMD to

refine the hydrologic models used by those Federal and State agencies involved in planning the restoration of the Everglades.

**Model Review.** Hydrologic models that are being used to simulate flow conditions that existed in south Florida before the construction of canals, levees, and pumping stations require verification. The USGS is analyzing the sensitivities of the models to several parameters by using statistical techniques to define model errors. Results can be used to place confidence limits on the ability of the model to simulate various hydrologic conditions and alternatives. The USGS is working with the SFWMD and the COE on model review.

**Ground-Water Flow Beneath Water-Conservation Area 3B Levee.** Major goals of the Everglades restoration are to raise and maintain higher water levels in WCA-3B than current levels and to construct a flowway between the levee and the adjacent urban area. Ground-water flow through the porous rock beneath the levee has not been measured, but is estimated to be as much as 30 percent of the outflow from the WCA. In cooperation with the SFWMD and the COE, the USGS is using a combination of surface-water measurements and ground-water modeling to provide estimates of leakage beneath the levee and to improve the calibration and predictive ability of regional hydrologic models.

### **Geophysical Mapping of Fresh**

**Ground Water.** Seasonal changes in the interface between fresh and saline ground waters are not well understood. The USGS is using aerial geophysical techniques to map the freshwater/saltwater interface beneath the Everglades north of Florida Bay. Surveys during the wet and dry seasons relate the interface position to hydrologic conditions and provide the basis for supplying ground-water-discharge values to future salinity and ground-water-flow models.

**Elevation Data.** Modeling of sheet-flow and surface-water levels in wetlands is highly sensitive to land-surface-elevation data, which are poorly defined throughout much of the nearly flat terrain of south Florida. By using new Global

Positioning System (GPS) technology, which has been made available by the National Oceanic and Atmospheric Administration (NOAA) and the COE, elevation data with an accuracy of better than 0.5 foot can be obtained in critical areas. These data are used to improve the performance of hydrologic models.

**Image Data.** Color infrared digital orthophotoquads not only serve as a base-map source for the work of the Federal and State agencies engaged in Everglades restoration work, but also are used to map vegetative cover. The USGS provides current digital orthophotoquad format data. The FDEP is contributing to the development of orthophotoquad maps in fiscal year 1995. Additionally, a 1:500,000-scale satellite color image map that is based on rectified satellite imagery is being produced. Interpretation of the color images on the map is facilitated by a key to land cover that was contributed by the National Biological Service. This study is a cooperative effort with the COE, Dade County, and the SFWMD.

**Model Linkage.** Linkage of models that depict flow within several hydrologic components of the Everglades flow system is needed to improve the simulation of the movement of nutrients. The USGS is developing a coupled model to simulate fluid-driven mass and constituent transport in canals, ground water, and sheet flow in wetlands.

## ***Ecosystem History and Processes***

**Ecosystem History in the Everglades and Florida Bay.** Charcoal and biological records, such as pollen, spores, and invertebrate skeletons in sediment cores, give scientists clues to historical hydrologic patterns and conditions. The USGS is comparing modern, historical and prehistoric biotic assemblages in sediments in a wide variety of settings to provide a yardstick for restoration of the ecosystem. Data on hydrologic conditions, salinity distributions, algal blooms, and red tides are useful in helping establish goals for remediation efforts and providing a means for measuring success. This study is a cooperative effort with the COE.

### **Geochemical Processes in Organic-Rich Surficial Sediments.**

Concentrations of dissolved elements, such as carbon, phosphorous, nitrogen, and trace and heavy metals, are controlled by chemical and biochemical reactions that occur in the peat and other organic-rich soils, which underly much of the Everglades. The USGS is examining regional geochemical processes, historical trends, and effects of alternating wet and dry periods. The results are useful to management agencies, such as the COE and the SFWMD, to determine human influences from the natural background of trace contamination.

### **Mercury Accumulation and Cycling.**

Mercury transformation and bioavailability depend on a mix of environmental conditions that are not well understood. The USGS is determining the effect that environmental factors, such as concentration of dissolved-organic carbon, nutrients, and sulfur, as well as hydrologic conditions, have on the transport, sedimentation, volatilization, and methylation of mercury in the Everglades and its ultimate entry into the food chain. USGS research on mercury complements the research of other agencies, such as the FDEP, the NMFS, the USEPA, and the SFWMD, on mercury in water, sediments, and fish. Taken together, the results are useful for predicting the effects of restoration on environmental mercury levels in the Everglades.

### **Florida Bay Water Quality, Bathymetry, and Circulation**

**Remote Sensing of Turbidity and Sedimentation.** Although current monitoring programs provide data on water quality at periodic intervals, they do not address the questions about the frequency and magnitude of turbidity during high-flow conditions or the quantity and fate of the sediment being transported. The USGS is using NOAA satellite imagery, as well as field measurements, to produce time-series data on water reflectance, sediment load, light attenuation, and temperature of waters that enter Florida Bay. This study is a cooperative effort with NOAA.

**Florida Bay Sedimentation.** The bathymetry of Florida Bay has not been systematically mapped in 30 years. New bathymetric data are being collected to help assess sedimentation rates and to provide a foundation for a sediment budget and circulation model for the Bay. The USGS is using new techniques to collect highly accurate data in shallow water and to provide bank-top and tidal flat elevation data that previously were unavailable.

**Sedimentation, Sea-Level Rise, and Circulation.** A 1-foot sea-level rise since 1850 may have increased the depth of Florida Bay to about 5 feet, with an accompanying increase in water exchange with the Atlantic Ocean and the Gulf of Mexico. However, recent data indicate restricted rather than enhanced exchange with these adjacent water bodies. The USGS is integrating existing and planned turbidity and sediment studies to develop a sediment budget and to evaluate the effect of sea-level rise, storms, and sedimentation on circulation and nutrient supply in the Bay.

**Marine Ground-Water Seepage.** The effect of ground-water inflow on the quality of water in Florida Bay is often ignored in assessments and models. The USGS is installing seepage meters in the Bay and the coral reefs to measure pressure and to collect samples of the fluid that seeps through the rock/water interface. Ground-water samples are being analyzed for nutrients, salinity, dissolved oxygen, and fecal coliform bacteria. These data will further the understanding of the water and chemical budgets for the Bay.

**Ground-Water Flow From the Florida Keys.** The fresh and saline ground waters beneath the Florida Keys are known to be contaminated by effluent from domestic sewage-disposal systems. The flow mechanism and pathways that enable this water to reach Florida Bay and coastal waters, however, is poorly understood. The USGS is quantifying ground-water flow by the use of water-level data from observation wells and results of tracer studies. This project is the onshore complement to a planned study of seepage rates and quality in the Bay.

## **Agency Cooperation**

The USGS collaborates with many other Federal and State agencies. The work would not be possible without logistical and other support from the NPS, the COE, and the SFWMD. Activities of the USGS and other agencies in south Florida are coordinated by the South Florida Ecosystem Restoration Task Force and associated working groups, and the Governor's Commission for a Sustainable South Florida. Most of the Federal and State agencies listed below as collaborators are represented on one or both of these coordinating groups.

## **Collaborators**

Bureau of Indian Affairs  
Florida Department of Environmental Protection  
Florida Geological Survey  
Florida Institute of Oceanography  
National Biological Service  
National Marine Fisheries Service  
National Marine Sanctuary  
National Park Service  
National Resource Conservation Service  
Office of the Governor  
South Florida Water Management District  
U.S. Army Corps of Engineers  
U.S. Environmental Protection Agency  
U.S. Department of Justice (U.S. Attorney)  
U.S. Department of Transportation (Federal Highway Administration)  
U.S. Fish and Wildlife Service

—*Benjamin F. McPherson, Aaron L. Higer, Sarah Gerould, and Irwin H. Kantrowitz*

## **For More Information**

Sarah Gerould  
U.S. Geological Survey, MS 107  
Reston Virginia 22092  
(703) 648-6895  
sgerould@wrddmail.er.usgs.gov

Irwin H. Kantrowitz  
U.S. Geological Survey  
227 N. Bronough Street  
Tallahassee, FL 32301  
(904) 942-9500 x3012  
ikantraw@sftlth.er.usgs.gov