The South Florida Environment—

A Region Under Stress

By Benjamin F. McPherson *and* Robert Halley

U.S. Geological Survey Circular 1134

National Water-Quality Assessment Program

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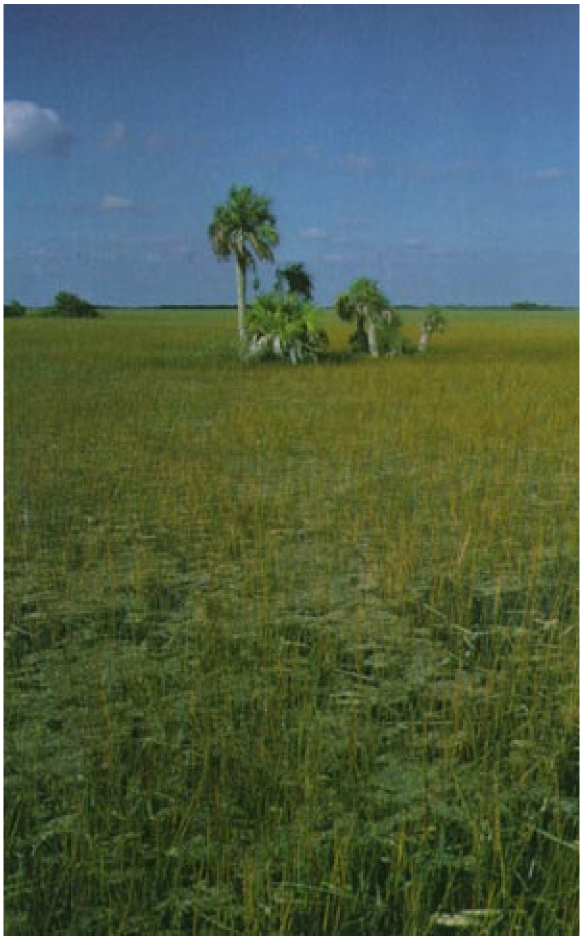

The Florida Everglades

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Conversion Factors

Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
gallon per day (gal/d)	0.003785	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallon per day (Mgal/d)	0.04381	cubic meter per second
pound	0.4536	kilogram
ton, short	0.9072	megagram

Temperature Conversion

Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = 5/9 \times (°F - 32)$$

Vertical Datum

Sea Level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations

µg/kg..... microgram per kilogram
mg/L..... milligram per liter
µ..... micron
ppt..... parts per thousand

Acronyms

C&SF..... Central and Southern Floridan Project for Flood Control and other Purposes
EAA..... Everglades Agricultural Area
NAWQA..... National Water-Quality Assessment
PCB..... Polychlorinated biphenyls
SFWMD..... South Florida Water Management District
SFWMM..... South Florida Water Management Model
USGS..... U.S. Geological Survey
WCA..... Water-conservation area

The South Florida Environment—

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Abstract

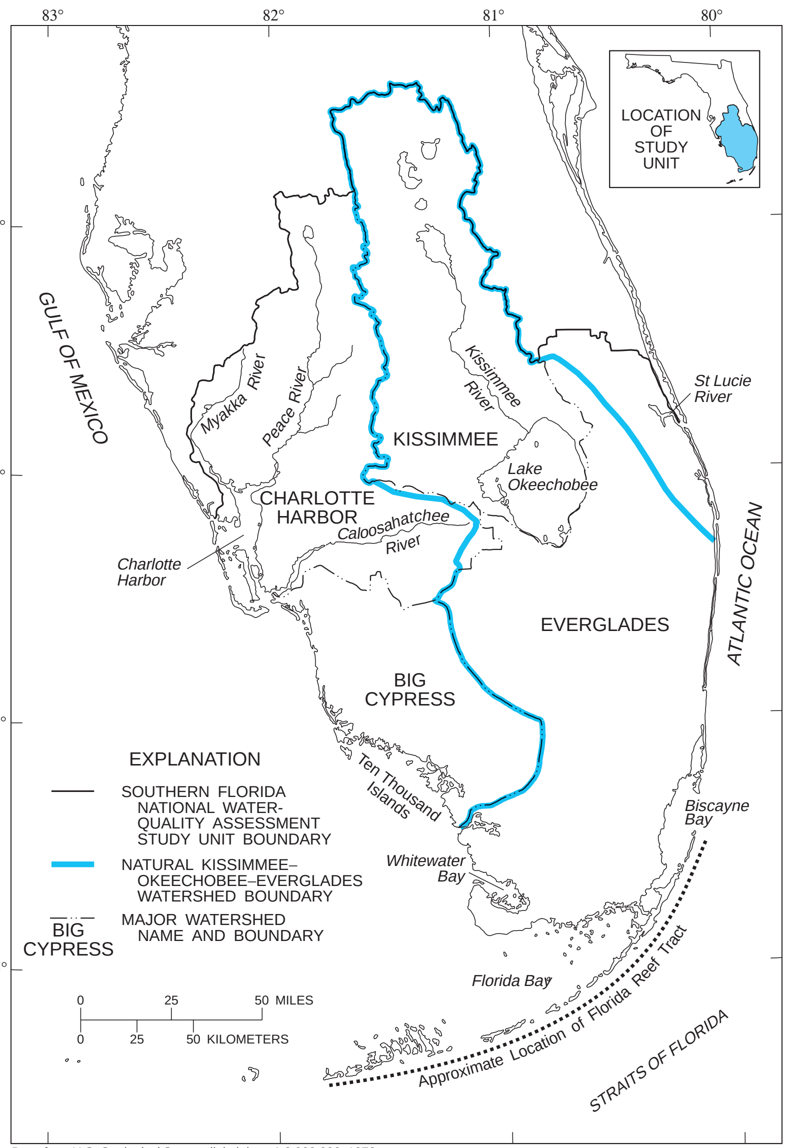
When Europeans first arrived in North America, south Florida was a lush, subtropical wilderness of pine forest, hardwood hammocks, swamps, marshes, estuaries, and bays. Wetlands dominated the landscape. The region contained one of the largest wetlands in the continental United States, the Everglades, which itself was part of a larger watershed that extended for more than half the length of the Florida Peninsula.

During the last 100 years, the Everglades and its watershed have been greatly altered by man, primarily through drainage and development; however, parts of the natural system remain in public lands and waters that are protected at the southern end of the peninsula. In the remaining natural system, drainage and development have had severe environmental effects, such as large losses of soil through agriculturally induced subsidence, degradation of water quality, nutrient enrichment, contamination by pesticides and mercury, fragmentation of the landscape, loss of wetlands and wetland functions, widespread invasion by exotic species, impairment of estuarine and coastal resources, and significant declines in populations of native plant and animal species. Additionally, the large and increasing human population and the active agricultural development in the region are in intensive competition with the natural system for freshwater resources.

Recently, a consensus has developed among Federal and State agencies and environmental groups that the south Florida ecosystem, and the Everglades in particular, should be protected and restored, to the extent possible, to its predevelopment condition. A first and primary step in this undertaking would be the restoration of the predevelopment hydrologic conditions to the remaining natural system. As part of an interagency effort, the U.S. Geological Survey (USGS) is providing scientific information that will contribute to the protection and restoration effort in south Florida. This information will be generated through such programs as the National Water-Quality Assessment and the South Florida Initiative. This report serves as an environmental review and framework for developing USGS programs in the region and stresses the critical role of water in natural and human systems and its importance as a link between those systems within south Florida.

Introduction

At the time of settlement by Europeans (mid-1800's), the south Florida region was a lush, subtropical wilderness of pine forest, hardwood hammocks, swamps, marshes, estuaries, and bays (Davis, 1943). Wetlands dominated the landscape. The region contained one of the largest wetlands in the continental United States, the Everglades. The Everglades was part of a larger watershed: the Kissimmee–Okeechobee–Everglades that extended for more than half the length of the Florida Peninsula. The Everglades and the Big Cypress Swamp stretched as a continuous wetland across the southern part of the peninsula south of Lake Okeechobee. These wetlands and the entire watershed *(fig. 1)* provided the freshwater that sustained the high productivity and abundant fisheries of the coastal waters (McIvor and others, 1994).



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 1. Regional ecosystem and watersheds in the study unit boundary, south Florida.

The wetlands of south Florida were regarded as being inhospitable and without intrinsic value. In the early 1900's, draining the wetlands was considered to be essential for commerce and safety. Loss of lives as a result of hurricane flooding in the 1920's accelerated drainage projects, primarily in the Everglades. Today, much of south Florida's wetlands are intensively managed, with more than 1,400 mi of primary canals and more than 100 water control structures. Because of drainage and development, the south Florida ecosystem has experienced a variety of environmental problems such as loss of soil, nutrient enrichment, contamination by pesticides, mercury buildup in the biota, fragmentation of landscape, loss of wetlands and wetland functions, widespread invasion by exotic species, increased algal blooming in coastal waters, seagrass die off, and declines in fishing resources.

Water is life for the human and natural systems in south Florida. Clean, abundant water was a fundamental characteristic of the original south Florida system. Increased human population and activity in south Florida have brought, not only an increased need for water, but also a decrease in water supply and a deterioration in water quality.

Changes in the hydrologic system are thought by many to be the root cause of the dramatic declines in fish and wildlife populations and habitat across the south Florida ecosystem.

Today in south Florida, competition for water is intense and divided between a large, rapidly growing population along the coast and agriculture north and south of Lake Okeechobee *(fig. 2)*, on the one hand, and the remaining natural ecosystem mostly within State and Federal parks, reserves, sanctuaries, and preserves *(fig. 3)*, on the other. Satisfying the water-resource demands of these competing interests is a complicated and difficult task. The quantity of water required for urban and agricultural uses may, at times, exceed supply. Plants and animals also have critical requirements with respect to the quantity of water, because they are dependent on the timing and duration of wet and dry periods. Water-quality requirements also vary markedly. The Everglades natural biota require water that is extremely low in phosphorus concentration, yet agricultural activities produce waters that contain high levels of phosphorus. Such conditions result in direct competition because the natural biota are "downstream" from the agricultural areas.

Recently, a consensus has begun to emerge among Federal and State agencies and environmental groups that south Florida and the Everglades should be restored, to the extent possible, to patterns similar to those of the original system. For concerned parties to discuss productively, let alone implement, such recommendations requires a substantial increase in available scientific data and understanding of the hydrology, geology, and ecology of south Florida and the Everglades specifically (Holloway, 1994).

The investigations needed to support restoration have been outlined recently by the Science Sub–Group of the South Florida Ecosystem Task Force. These investigations include characterizing the predrainage system and comparing it with the present system, particularly hydrologically; determining the key characteristics of the former natural hydrologic system that supported the rich diversity and abundance of wildlife that has been lost; designing structural and operational modifications of the Central and Southern

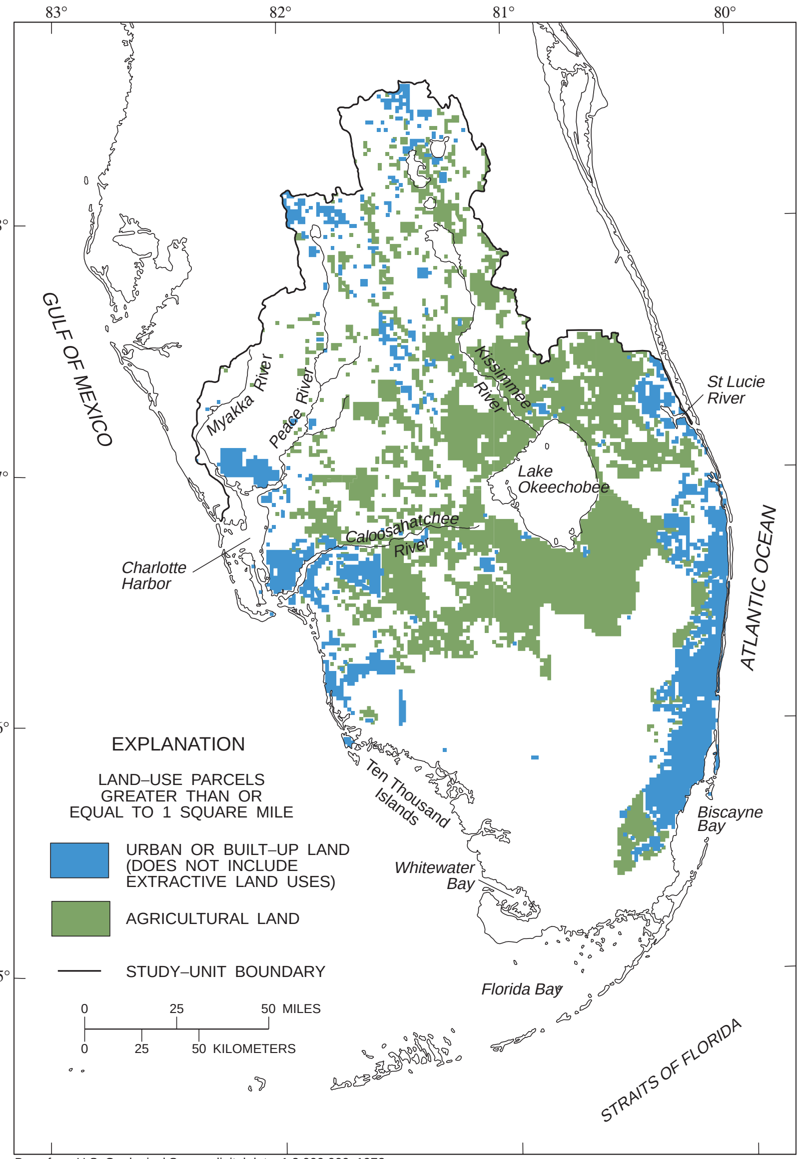


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Figure 2. Urban and agricultural lands in south Florida. (Modified from South Florida Water Management District and Southwest Florida Water Management District digital data, 1988-90.) *Land use and land cover categories based on South Florida Water Management District classification codes. Equivalent categories are shown for the area within the Southwest Florida Water Management District.*

Florida Project for Flood Control and other Purposes (C&SF) that would recreate the key characteristics of the natural hydrologic system; assessing the hydrologic and ecological results of these modifications through pre- and post-modification monitoring; and modifying the design to make improvements (Science Sub–Group, written commun., 1994).

The U.S. Geological Survey is providing some of the scientific information necessary for protection and restoration in south Florida through several Survey programs that include the South Florida Initiative and the National Water–Quality Assessment (NAWQA) Program. The USGS is coordinating these efforts with other Federal agencies through the South Florida Ecosystem Interagency Working Group and the Science Sub–Group and through regularly scheduled liaison meetings of the Southern Florida NAWQA study unit. The South Florida Initiative is a collaborative effort by the U.S. Geological Survey and other Federal and State agencies to provide scientific insight into conflicting land-use demands and water-supply issues in the south Florida regional ecosystem. The NAWQA Program is described in the adjacent box.

This report provides an overview of the environmental setting in south Florida and serves as a review and framework for developing USGS programs in the region. In the report, we describe the predevelopment and the current (present-day) environmental conditions in south Florida, with emphasis on the quantity and quality of water. The geographical area covers the southern half of the State, and includes the Southern Florida NAWQA study unit and adjacent coastal waters. The Southern Florida NAWQA study unit covers about 19,500 mi^2 and is the watershed of the larger regional ecosystem *(fig. 1)*. We define the regional ecosystem to include coastal waters between Charlotte Harbor on the Gulf of Mexico and the St. Lucie River on the Atlantic Ocean and the lands that drain into these waters *(fig. 1)*.

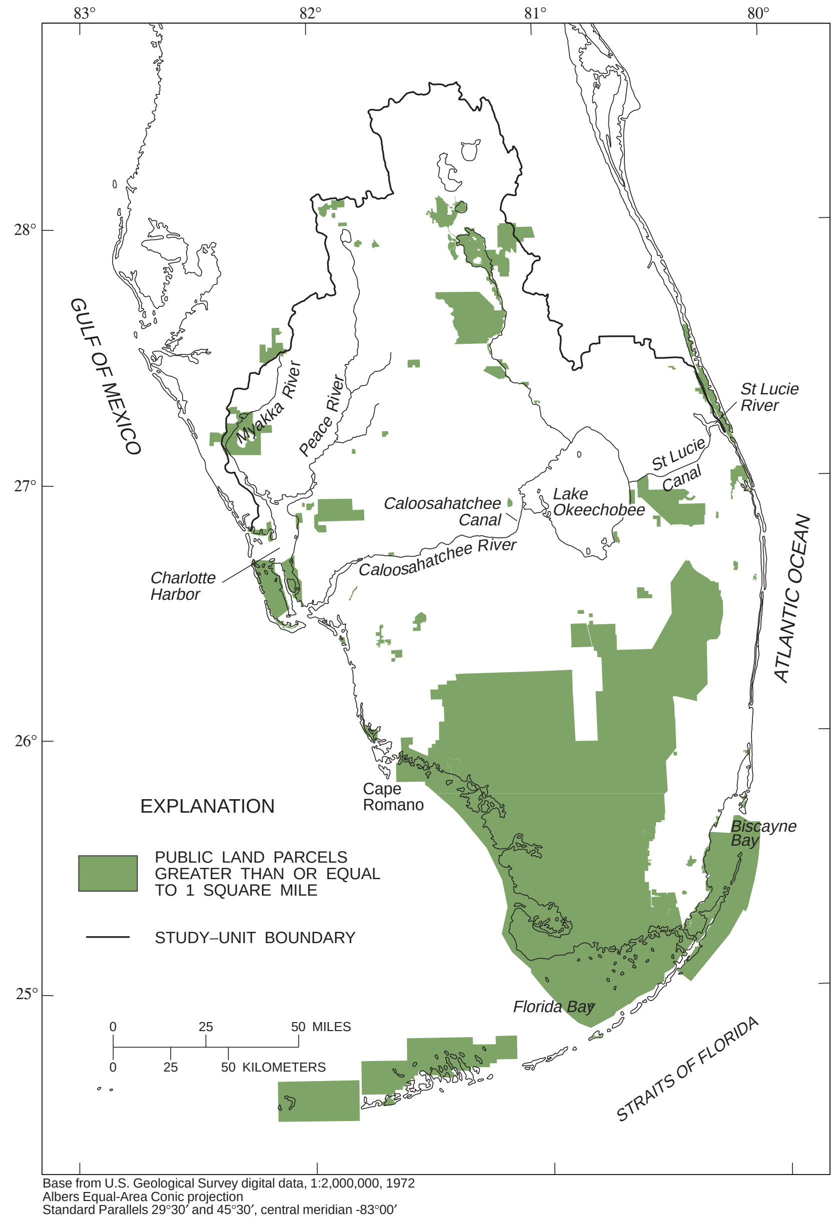

Figure 3. Lands in south Florida under public ownership or control. (Modified from South Florida Water Management District and Southwest Florida Water Management District digital data, 1994.)

NAWQA

National Water-Quality Assessment Program

In 1991, the USGS began to implement a full-scale NAWQA Program. The three major objectives of the NAWQA Program are to provide a consistent description of current water-quality conditions for a large part of the Nation's water resources, to define long-term trends (or lack of trends) in water quality, and to identify, describe, and explain the major factors that affect observed water-quality conditions and trends. These objectives are being met (1) by conducting retrospective analyses of existing data, (2) by establishing a long-term nationwide monitoring network designed to assess existing water-quality conditions and provide a data base for trend analyses, and (3) by conducting process-oriented studies designed to provide a better understanding of the relation between land- and water-use activities and water-quality conditions. The NAWQA Program is providing an improved scientific basis for evaluating the effectiveness of water-quality management programs and practices.

The NAWQA Program is being implemented through investigations of hydrologic systems in 60 study units that include parts of most major river basins and aquifer systems in the United States. Study units range in size from 1,200 to about 65,000 mi2 and incorporate 60 to 70 percent of the Nation's water use and population served by public water supply. The south Florida study unit includes most of the southern half of the Florida Peninsula and contains a major urban complex of more than 5 million people. The study unit in this report was included in the NAWQA Program in 1993.

Acknowledgments

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Environmental Setting—the Natural System

The south Florida ecosystem formed during the last several thousand years after the world-wide climatic changes and sea-level rise at the end of the Pleistocene age. The ecosystem consists primarily of wetlands and shallow-water habitats set in a subtropical environment.

Physiography

The south Florida ecosystem includes coastal waters between Charlotte Harbor on the Gulf of Mexico and the St. Lucie River on the Atlantic Ocean and all or part of the following physiographic provinces: the Lake Wales Ridge, the Flatwoods, the Atlantic Coastal Ridge, the Big Cypress Swamp, the Everglades, the Mangrove and Coastal Glades, and the Florida Keys *(fig. 4)*. The coastal waters consist of a system of interconnected estuaries, bays, lagoons, and coral reefs that include Charlotte Harbor, Ten Thousand Islands, Whitewater Bay, Florida Bay, Biscayne Bay, and the Florida Reef Tract *(fig. 1)*.

The highest altitude in the region is on Lake Wales Ridge, where sand hills range from 70 to 300 ft above sea level *(fig. 5)*. Adjacent to the ridge, the relatively lower Flatwoods range in altitude from about sea level to 100 ft in the north.

The Atlantic Coastal Ridge extends along the eastern coast as a low ridge of sand over limestone that ranges in altitude from about 10 to 50 ft above sea level. The ridge averages about 5 mi wide and is breached in places by shallow sloughs or transverse glades.

The Everglades, which is located west of the Atlantic Coastal Ridge, is slightly lower in altitude than the ridge or the Flatwoods and extends southward from Lake Okeechobee to the Mangrove and Coastal Glades near Florida Bay. The Everglades has an almost imperceptible slope to the south, which averages less than 2 in. per mile. Altitudes range from 14 ft near Lake Okeechobee to sea level at Florida Bay. Under predeveloped conditions, the Everglades was seasonally inundated, and water drained slowly to the south through what was referred to as the “River of Grass” by Florida author and conservationist Marjory Stoneman Douglas.

The Big Cypress Swamp to the west of the Everglades is on slightly higher land. Water inundation and peat deposition in the swamp are less extensive than in the Everglades. The land surface of the swamp is flat except for numerous low-mounded limestone outcrops and small, circular, elongated depressions in the limestone. Water in the swamp drains slowly to the south and southwest through a number of cypress strands into the coastal mangrove forest.

The Mangrove and Coastal Glades consists of a broad band of swamps and marshes south of the Everglades and the Big Cypress Swamp. The land is at or near sea level and is often flooded by tides or by freshwater runoff. Salinities range from freshwater to hypersaline, depending on the amount rainfall and runoff, and on tide levels. The gradual slope of the land continues offshore across the broad west Florida platform into the Gulf of Mexico. Much of the southern Florida Gulf Coast receives low wave energy which is favorable to the development of tidal marshes, seagrass beds, and mangrove forests.

The Florida Keys are a series of low limestone islands that extend 140 mi southwest of the mainland. Altitudes in the islands rarely exceed 5 ft above sea level. A narrow shelf is present along the Atlantic Coast, where the seafloor drops sharply into the Straits of Florida.

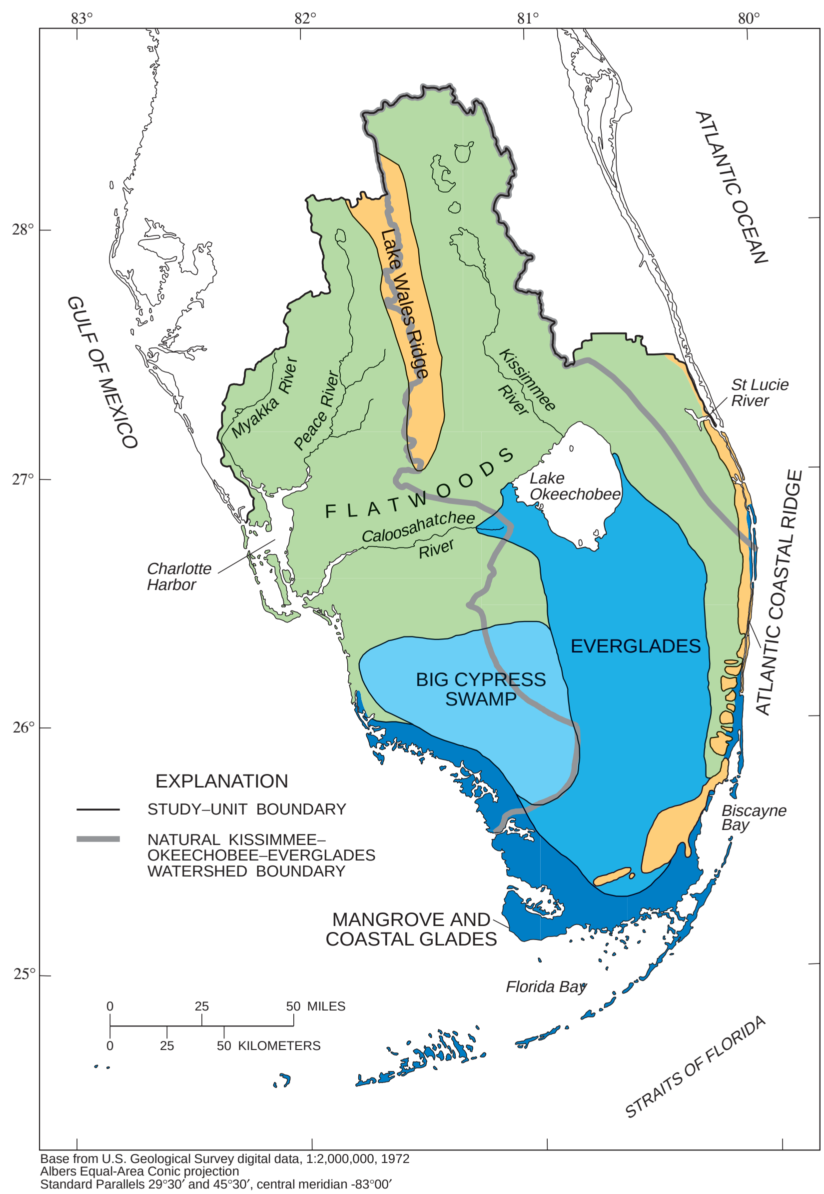


Figure 4. Physiographic provinces of south Florida. (Modified from Davis, 1943; and Parker and others, 1955.)

The Atlantic Coast is bathed in the clear, tropical waters of the Florida Current which is favorable to the development of coral reefs several miles offshore of the keys.

Climate

Annual average rainfall in south Florida ranges from about 40 to 65 in. *(fig. 6)*. The east coast usually receives the greatest amount of rainfall, whereas the Florida Keys and the areas near Lake Okeechobee and Charlotte Harbor usually receive the least. More than half the rain falls in the wet season from June through September *(fig. 7)* and is associated with thundershowers, squalls, and tropical cyclones. Afternoon thundershowers are frequent over land, where moisture-laden air from sea breezes and wetlands warms, and rises, and the moisture condenses to form clouds (Pardue and others, 1992). The wet season often has a bimodal rainfall pattern with two maxima, one in early and one in late summer (Thomas, 1974; Duever and others, 1994). Rainfall during the remainder of the year is usually the result of large frontal systems and is broadly distributed rather than localized. April and May typically have the lowest rainfall. Annual and seasonal rainfalls, however, vary from year to year, as shown in *figure 8* and the table below.

Duever and others, (1994) analyzed severe droughts at several stations from 1910 through 1980 and reported that, whereas some droughts were fairly widespread, others were more localized, even over distances of only 30 mi. The variability in rainfall is often characterized by multiyear wet and dry cycles *(fig. 8)*. These cycles are apparent in the average annual rainfall in the South Florida Water

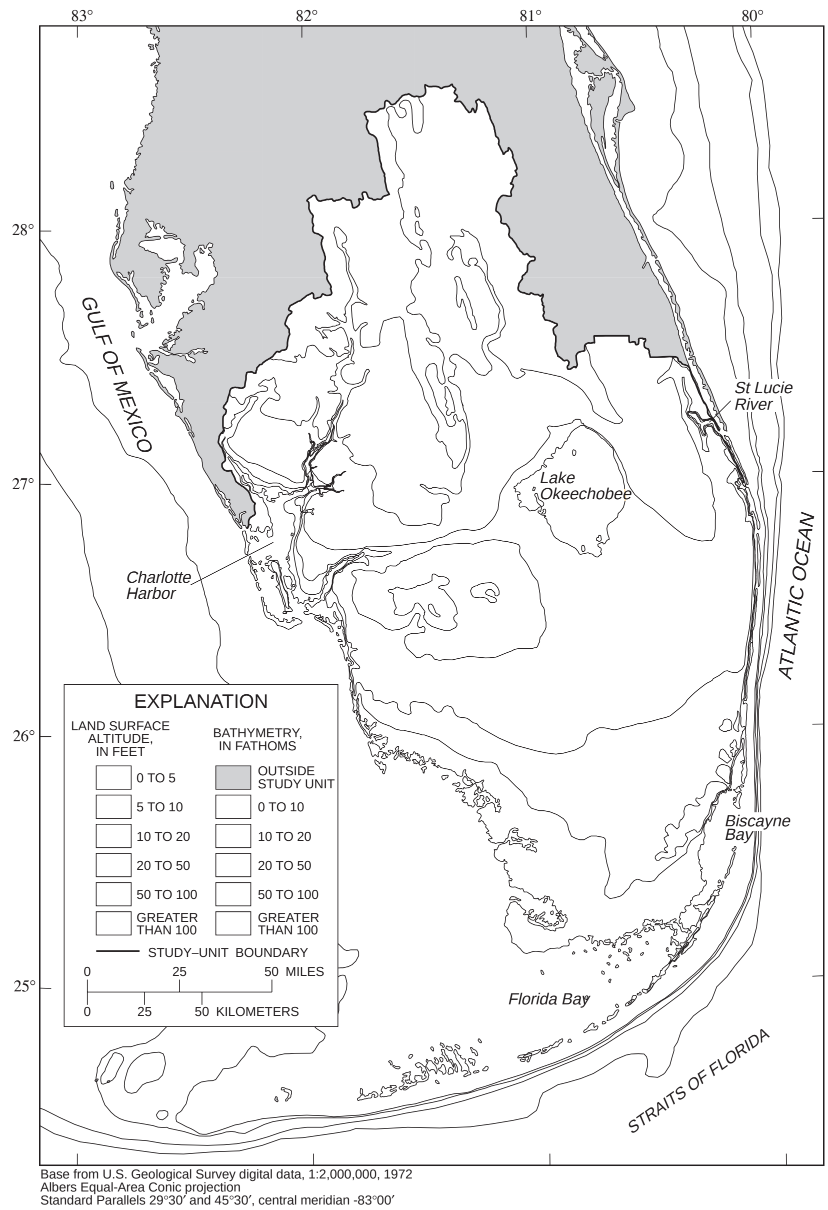


Figure 5. Generalized topography and bathymetry in south Florida. (Topography generalized from U.S. Geological Survey 1:24,000 quadrangles provided in digital form by South Florida Water Management District, 1992. Bathymetry modified from Fernald, 1981.)

Mean, maximum, and minimum inches of rainfall for the lower east coast of Florida, 1915-85 (South Florida Water Management District, 1993)

Period	Mean	Maximum	Minimum
Annual	51.9	77.5	36.7
Wet season	34.5	53.5	23.4
Dry season	17.4	30.9	7.3

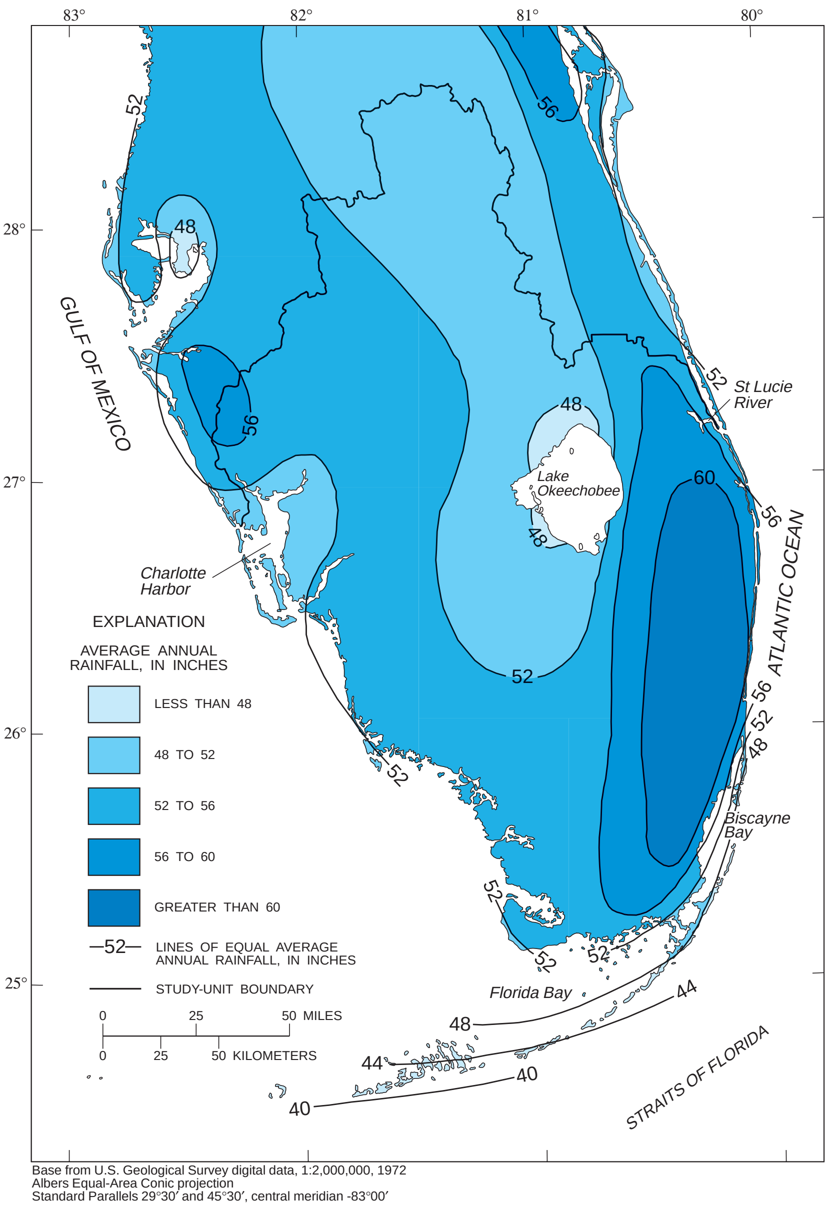


Figure 6. Average annual rainfall in south Florida, 1951–80. (Water Resources Atlas of Florida, 1984.)

Management District (SFWMD) network where average annual rainfall decreased by 1.3 in/yr from 1900 through 1920, increased by 1.3 in/yr from 1921 through 1970, and decreased by 3 in/yr from 1971 through 1991 (Robert Hammeric, South Florida Water Management District, oral commun., 1994). Analysis of the longest period of rainfall record in south Florida (Fort Myers) indicates, however, that the trend for total annual rainfall and variability in mean annual rainfall for 10-year intervals, has not changed at that location since the late 1800's (Duever and others, 1994).

Tropical cyclones (hurricanes and tropical storms) produce the most severe weather conditions in south Florida. The high tides and heavy rains associated with these storms can produce coastal and inland flooding, and strong winds can cause extensive damage. Rainfall often exceeds 5 in. Tropical cyclones have repeatedly passed through the region, most frequently in late summer or early fall. Between 1871–81, 138 tropical cyclones, passed near or over the region (Neumann and others, 1981; Duever and others, 1994); some evidence indicates that hurricane strikes have declined during this span (Robert Hammeric, South Florida Water Management District, oral communication, 1994). These storms varied greatly in size, amount of rainfall, and windspeed and, thus, in their effects on the region. Generally, cyclones have had their greatest effects near the coast and on coral reefs where storm surges have eroded and buried natural communities (Tabb and Jones, 1962; Ball and others, 1967). Noncoastal areas are primarily affected by heavy rains that cause flooding and by strong winds that damage plant communities (Craighead and Gilbert, 1962; Alexander, 1967; Loope and others, 1994). Despite the immediate damage, natural communities in south Florida have evolved with these storms and have adapted to them (Pimm and others, 1994).

Evapotranspiration in south Florida has been estimated to be from 70 to 90 percent of the rainfall in undisturbed wetlands (Kenner, 1966; Dohrenword, 1977). Evaporation from open water is greatest in late spring when temperatures and windspeeds are high and relative humidity is low, and is least in winter when temperatures, windspeeds, and humidity are low *(fig. 7)*. Evapotranspiration is greatest during the summer wet season when water is available for surface evaporation and vegetative transpiration (Duever and others, 1994).

The climate in south Florida is subtropical and humid. Average temperatures are in the mid-70's °F annually, ranging from about 60 °F in midwinter to about 80 °F in summer (Florida Department of National Resources, 1974). Temperatures in coastal areas are moderated by the Gulf of Mexico and the Atlantic Ocean *(fig. 9)*. The summer heat is tempered by sea breezes near the coast and by frequent afternoon and evening thundershowers. The southern one-third of central Florida and the lower two-thirds of the coastline have nearly freeze-free climates *(fig. 10)*. Although freezes do occur, their pattern and severity is erratic from year to year (Duever and others, 1994). The low frequency of freezes has allowed a number of tropical species to colonize and survive in the area.

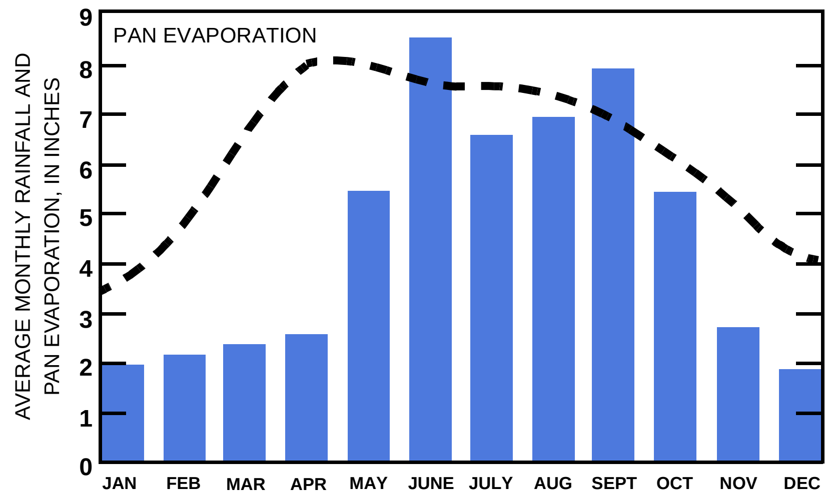


Figure 7. Average monthly rainfall (South Florida Water Management District, 1993*) for the lower east coast (1915-1985) and average pan evaporation* (Duever and others, 1994) *at selected locations in south Florida in 1988.*

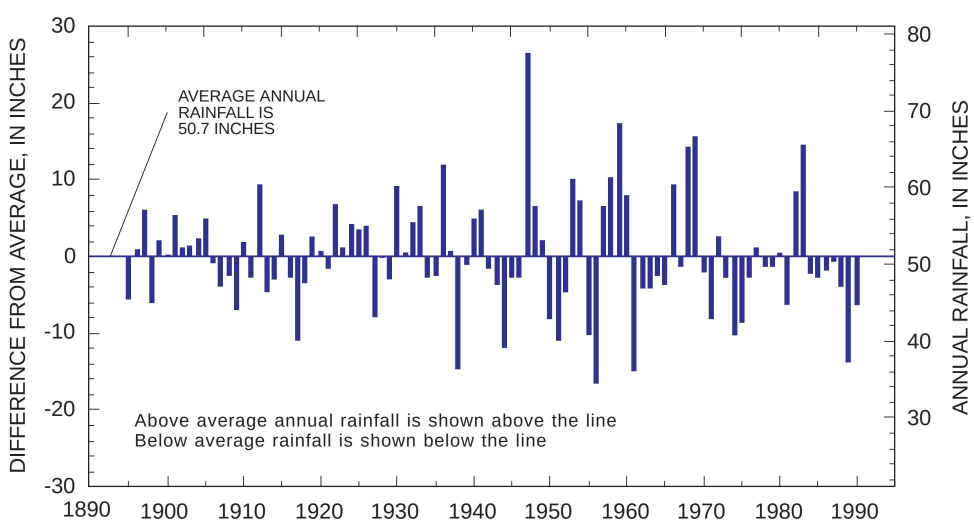
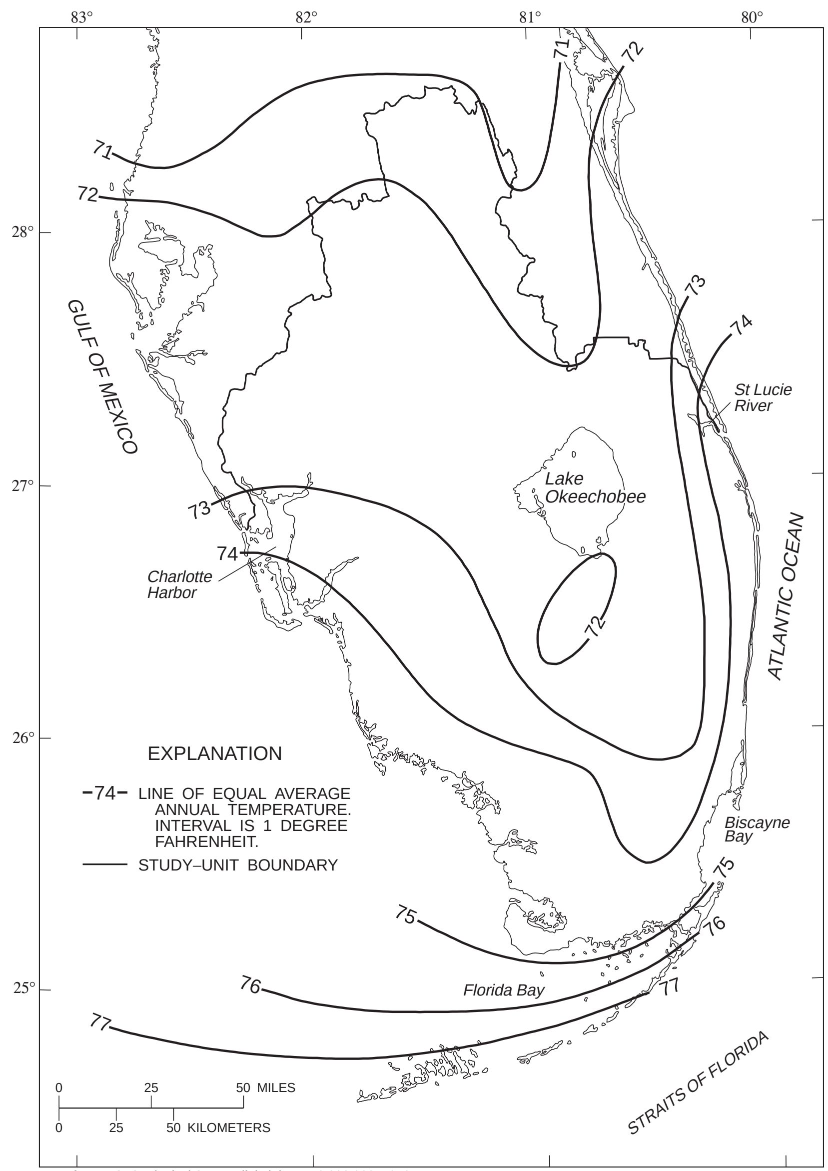
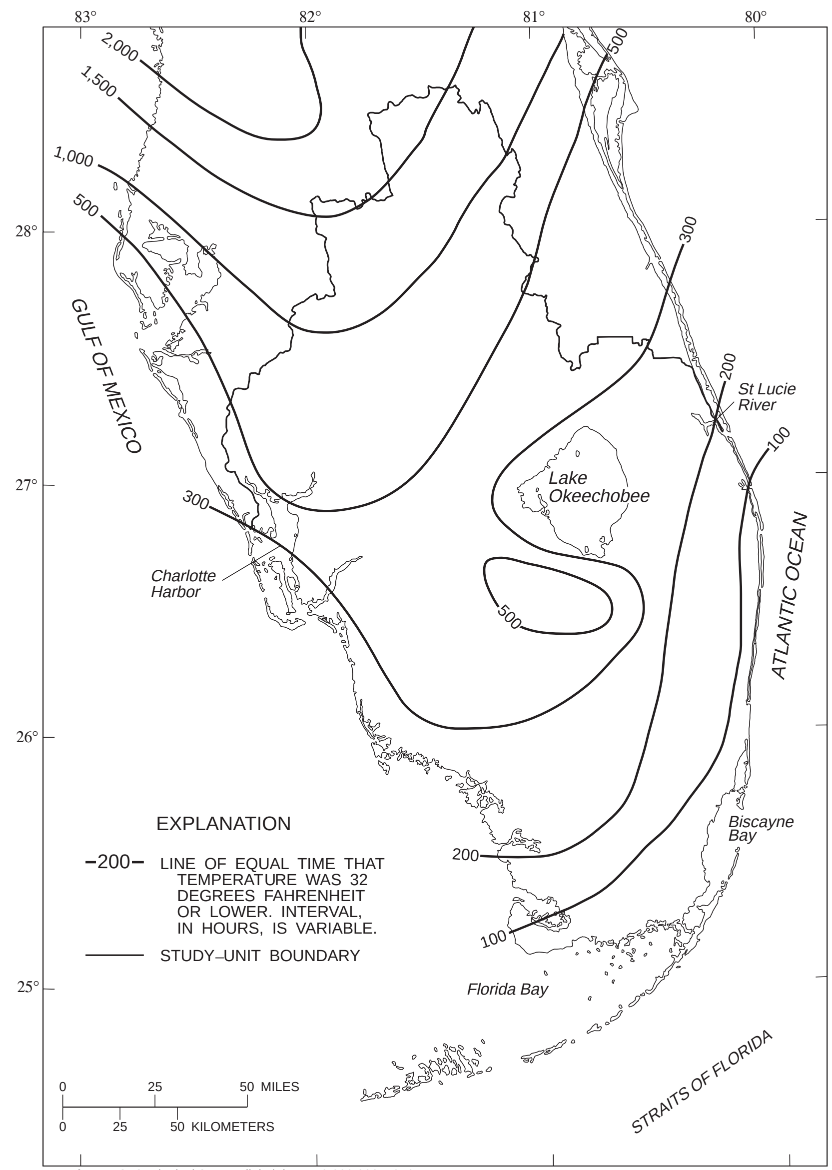


Figure 8. Rainfall above and below the average annual rainfall for 20 stations in south Florida, 1895-1990. (Data from the National Climatic Center.)



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 9. Average annual temperature in south Florida. (Thomas, 1974.)



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
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Figure 10. Total numbers of hours where temperatures fell to 32 degrees Fahrenheit or lower between November 1937 and March 1967. (Winsberg, 1990.)

Geology

The surficial geology of south Florida *(fig. 11)* is a result of marine and freshwater processes that have alternated with the rise and fall of sea level. At high sea level, limestone was deposited and beaches and dunes were created. The Atlantic Coastal Ridge *(fig. 4)*, for example, resulted from marine deposition that occurred during an interglacial age (about 125,000 years before present) when sea level was as much as 25 ft above the present level (Scott and Allmon, 1992; Gleason and Stone, 1994). At low sea level, the limestone was dissolved and eroded by drainage of acidic freshwater to create the riddled solution features that are characteristic of the region.

With the recession of glaciers in northern North America at the end of the Pleistocene Epoch, sea level rise began and has continued to the present day. The rising sea level retarded runoff and downward leakage in south Florida and, with abundant rainfall, helped establish the broad expansion of wetlands in the region (Gleason and Stone, 1994). The rise in sea level slowed about 3,200 years ago, and this slow rise favored the expansion of coastal and freshwater wetlands (Wanless and others, 1994). The Atlantic Coastal Ridge helped retain freshwater in the Everglades Basin and this, in turn, allowed thick layers of peat to (up to 18 ft) to accumulate within the northern parts of the Basin (Gleason and Stone, 1994). Parts of the present-day Everglades area had become short-term flooded calcitic mud marshes by about 6,500 years ago. Peat deposition began in the Everglades area about 5,000 years ago, which indicates that conditions favorable to long-term flooding had begun (Gleason and Stone, 1994). By the time Europeans came to south Florida, Everglades peat lands covered nearly 2 million acres.

South Florida is underlain by a huge volume of shallow marine carbonate sediments *(fig. 12)*. The deeper sediments, which exceed 20,000 ft, are almost pure limestone, dolomite and anhydrite, and were deposited from Cretaceous through early Tertiary time as a carbonate platform (Klitgord and others, 1988). During much of this time, south Florida was isolated from the mainland by the deep water of the Suwannee Strait (Chen, 1965).

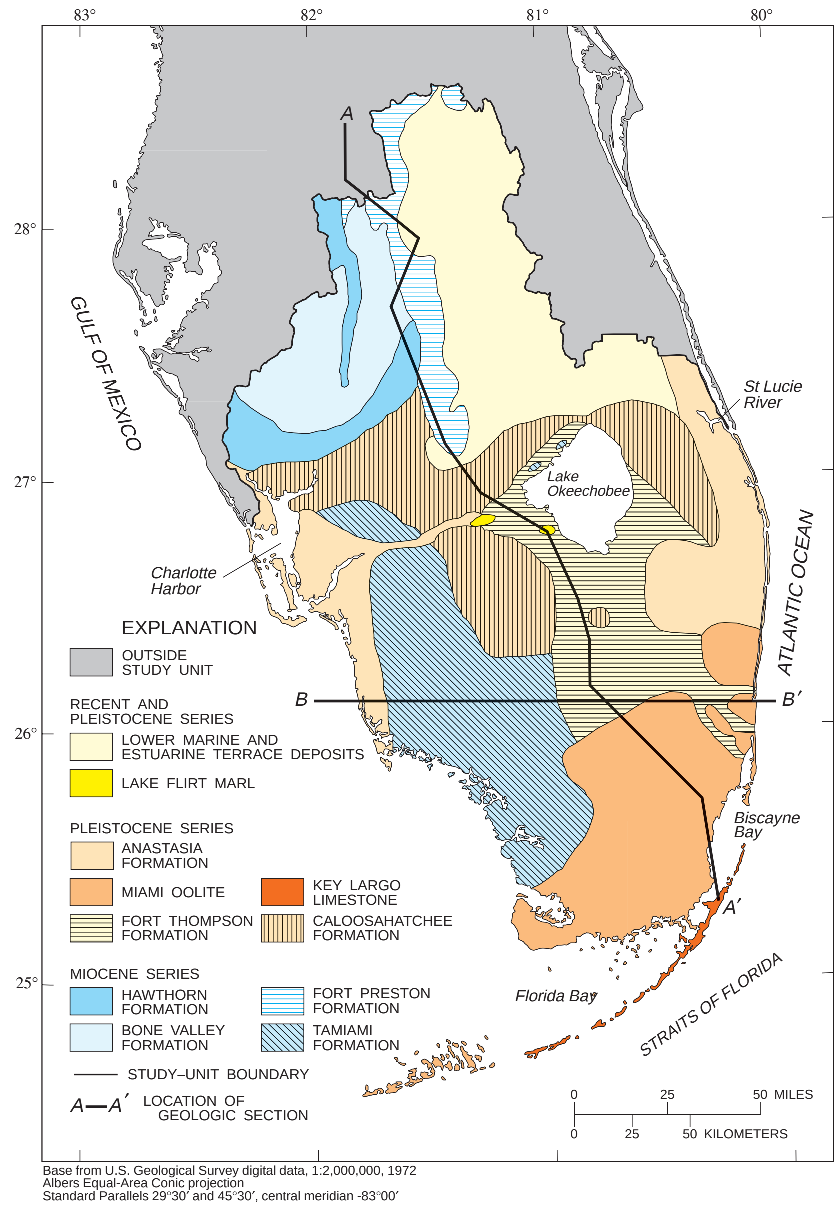


Figure 11. Generalized surficial geology of south Florida. (Puri and Vernon, 1964.)

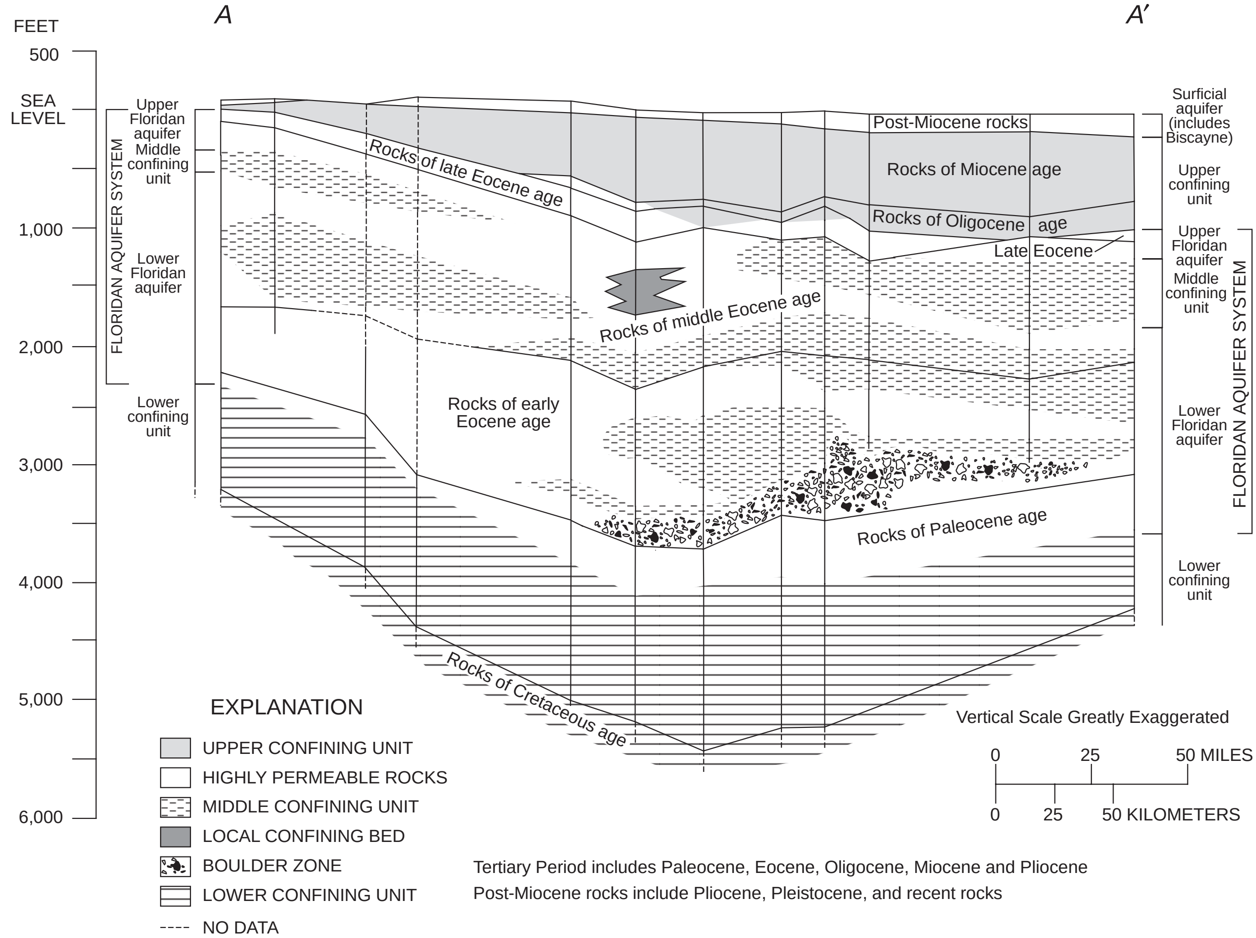


Figure 12. Generalized geohydrologic section A-A' of south Florida. (Miller, 1986.) (Trace of section shown in figure 11.)

Later, as the strait filled, south Florida was connected to the mainland and clastic sediments were transported to the south to form the younger Tertiary deposits *(fig. 12)* that consist of shallow marine sandy limestone, marls, and sands (Pinet and Popenoe, 1985).

The marine carbonate sediments in south Florida contain three major aquifer systems—the Floridan, the intermediate, and the surficial *(fig. 13)*. The confined Floridan aquifer system is at or near the land surface in central Florida but dips deeply beneath the surface to the south. The semi-confined intermediate aquifer system overlies the Floridan and serves as a confined unit for the Floridan. The surficial aquifer system includes the highly permeable Biscayne aquifer. The Biscayne aquifer is more than 200 ft thick under parts of the Atlantic Coastal Ridge and wedges out about 40 mi to the west in the Everglades. The shallow aquifer of southwest Florida is about 130 ft thick along the Gulf Coast and wedges out in the eastern Big Cypress Swamp *(fig. 13*; Klein, 1972). The surficial aquifers are recharged by abundant rainfall.

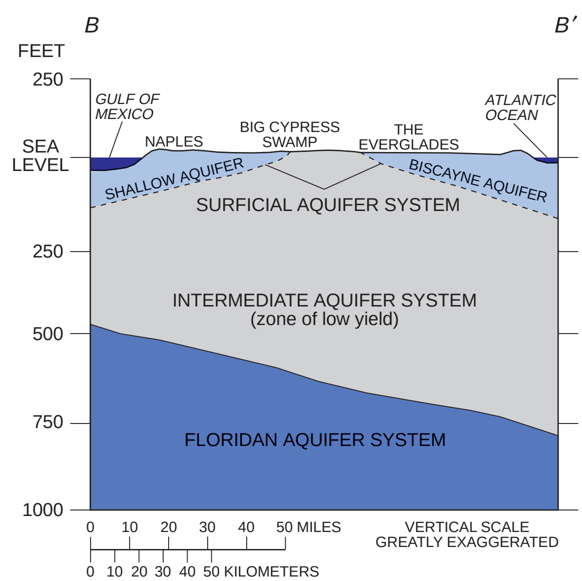
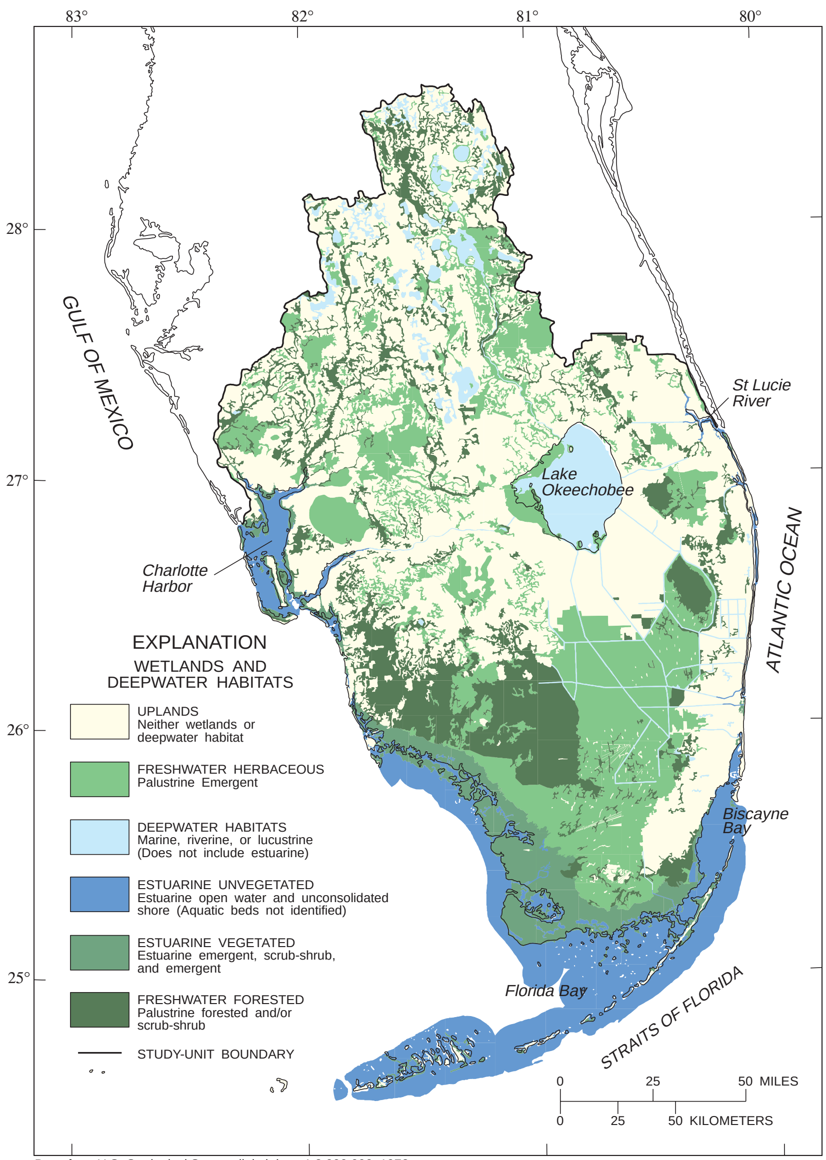


Figure 13. Generalized subsurface section B–B' showing aquifers of south Florida. (Klein and others, 1975.) (Trace of section shown in figure 11.)

Hydrology

Wetlands are the predominant landscape feature of south Florida *(fig. 14)*. The prevalence of wetlands is a result of abundant rainfall and a low, flat terrain. Rainfall becomes ponded in wetlands where it is evapotranspired, infiltrates shallow aquifers, or moves slowly by sheetflow toward tidal waters.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 14. Wetlands and deepwater habitats of south Florida. (U.S. Department of the Interior, Fish and Wildlife Service, National Wetlands Inventory, 1979-81.)

Peat develops in wetlands that are flooded for extensive periods during the year, and calcitic muds develop in wetlands where hydroperiods (time land is flooded) are shorter and limestone is near the surface *(fig. 15)*. During the wet season, and for several weeks afterwards, much of the land surface in south Florida is inundated.

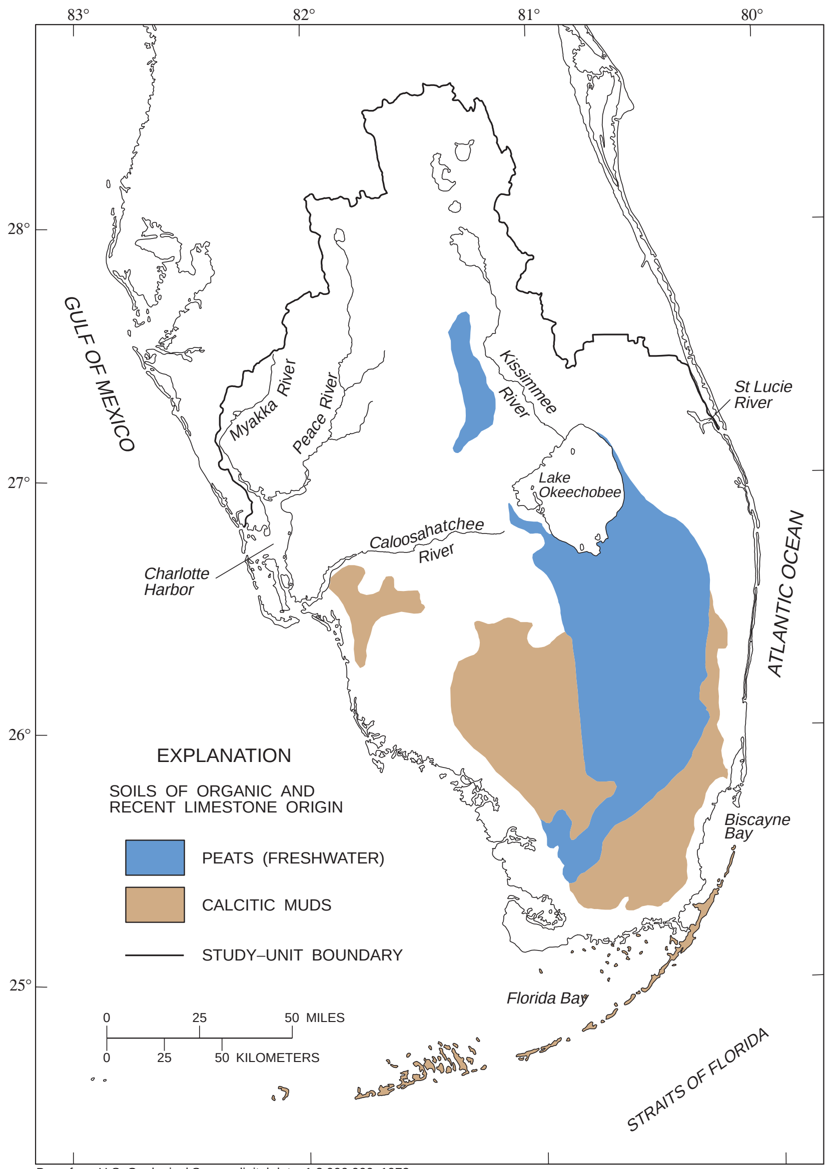
Before development, wetlands were more extensive, and water levels fluctuated over a wider range; water management has tended to reduce peaks and minimums in water levels and to lessen flooding and drought *(fig. 16)*. Hydrologic models developed by the South Florida Water Management District for south Florida indicate that, in predevelopment times, surface water covered larger areas for longer periods of time than it does today. The models also indicate that the quantity and timing of surface and ground-water flow were significantly different than they are today (Fennema and others, 1994).

The type of wetland drainage varies from north to south in the region. In the northern part of the region, wetlands are drained by several large rivers, which include the Kissimmee, the Caloosahatchee, the Myakka, and the Peace Rivers. The Kissimmee River meanders through a broad floodplain and discharges into Lake Okeechobee. The Caloosahatchee, the Myakka, and the

Peace Rivers discharge into Charlotte Harbor and into the Gulf of Mexico. In the southern part of the region, streams are smaller, and freshwater discharge to coastal waters is more dispersed.

With the exception of the Peace River, which drains a phosphate-rich area in central Florida and discharges large amounts of phosphorus to coastal waters, nutrient concentrations of water that drains south Florida's wetlands are typically low, and loading of nutrients to coastal waters is dispersed over broad areas by sheetflow. The freshwater typically flows through extensive mangrove forests into numerous tidal creeks, estuaries, and bays where it mixes with saltwater and becomes brackish. Mangrove trees contribute detrital materials that enrich the brackish water with nutrients that support a highly productive estuarine system.

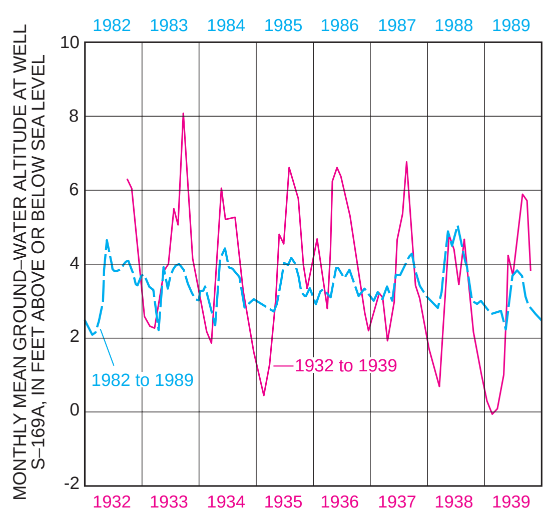
Along the southwestern Gulf Coast, the gentle slope of the West Florida Shelf provides a broad, shallow zone where brackish water mixes with marine water of the open Gulf of Mexico. This shallow zone extends south to the Florida Keys. Several miles south and east of the Keys, the Florida Current flows north in the deep Straits of Florida. Water of the Florida Current is warm, clear, and salinity is constant.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 15. Soils of organic and recent limestone origin in south Florida (above). (Fernald, 1981.)

Figure 16. Long-term hydrograph showing water-level fluctuations at well S–169A in southern Dade County, 1932-39 and 1982-89 (right). (Data from U.S. Geological Survey.)

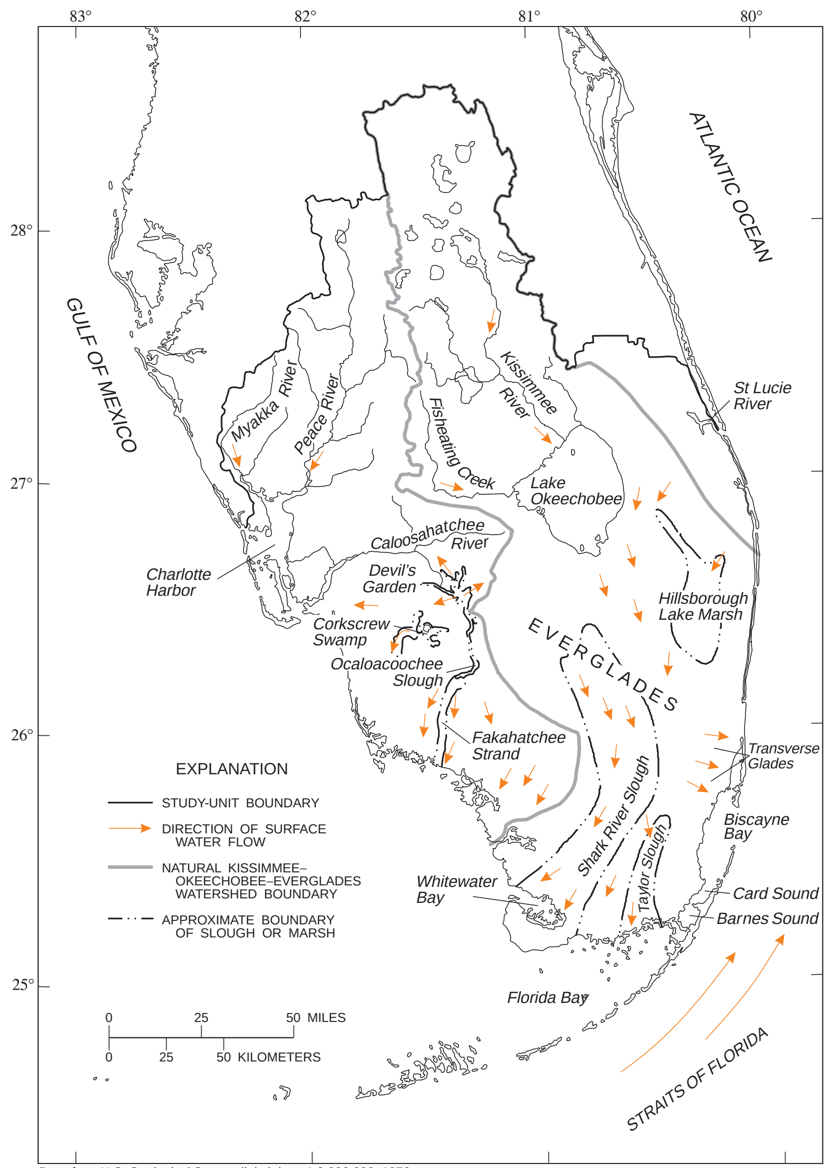


Watersheds and Coastal Waters

Kissimmee–Okeechobee–Everglades Watershed

The Kissimmee-Okeechobee-Everglades watershed, an area of about 9,000 mi^2, once extended as a single hydrologic unit from present-day Orlando to Florida Bay, about 250 mi to the south *(fig. 17)*. In the northern half of the watershed, the Kissimmee River and other tributaries drained slowly through large areas of wetlands into Lake Okeechobee, a shallow water body of about 730 mi^2. The lake periodically spilled water south into the Everglades (Davis, 1943; Parker, 1974), a vast wetland of about 4,500 mi^2. Under high water-level conditions, water in the Everglades moved slowly to the south by sheetflow, thus forming the area known as the River of Grass. Water discharged from the Everglades into Florida Bay and the Gulf of Mexico, and under high-flow conditions, also into the Atlantic Ocean through small rivers or transverse glades in the Atlantic Coastal Ridge or as seepage and spring flow into Biscayne Bay.

The Everglades was a complex mosaic of wetland plant communities and landscapes with a central core of peatland that extended from Lake Okeechobee to mangrove forest that border Florida Bay (Davis and others, 1994). The peatland was covered by a swamp forest of custard apple *(Annona glabra)* and willow *(Salix caroliniana)* along the southern shore of Lake Okeechobee and by a vast plain of monotypic sawgrass *(Cladium jamaicense)* to the south and east of the swamp forest. Farther southeast, the sawgrass was broken by sloughs and small islands of brush. Tree islands and sloughs became increasingly numerous to the south where the vegetation formed a mosaic of sawgrass strands interwoven with lily-pad-covered sloughs, wet prairies, and tree islands in Shark River Slough *(fig. 18)*. A similar mosaic of sawgrass, slough, wet prairie, and tree islands was on peatland in the northeastern Everglades in the Hillsborough Lake Slough. The peatland was bounded by peripheral wet prairies, southern marl marsh, and, cypress *(Taxodium distichum)* forest. The peripheral wet prairies were sand-bottomed wetlands of mixed grasses, sedges, and other macrophytes that



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
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Figure 17. Hydrologic features and the natural direction of surface-water and coastal-water flows under predevelopment conditions in south Florida.

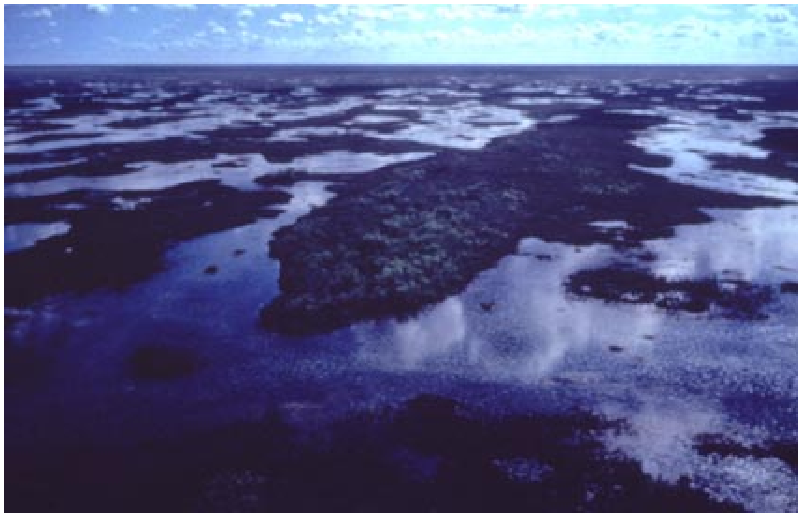
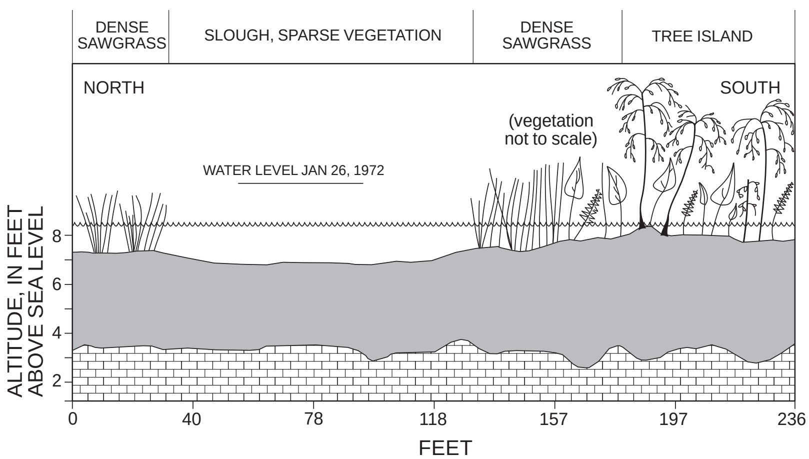


Figure 18. Aerial photograph of Everglades wetlands in the Shark River Slough (above)*, and a generalized section of the slough* (below). (McPherson, 1973a.)



intermingled with higher altitude pine flatwoods and extended as transverse glades through parts of the Atlantic Coastal Ridge. To the south, the peatland and prairie vegetation blended into marl and rock-bottomed marshes of herbaceous plants, short sawgrass, and bay head tree islands and tropical hammocks.

Water levels and flows in the Everglades fluctuated seasonally in response to rainfall and runoff. Much of the land was inundated during the year, and during heavy rains, all but the highest tree islands were flooded. During flood periods, water moved with enough force to cause tree islands to develop an alignment pattern that was parallel to the lines of surface-water flow (Parker, 1974). During the dry season, water levels generally were close to the land surface, but extreme droughts during some years lowered water levels substantially below the land surface, and severe fires swept over the land, burning vegetation and peat (Craighead, 1971).

Animal populations in the Everglades have adapted to and are dependent upon the seasonal hydrologic fluctuations (McPherson and others, 1976). Fishes and macroinvertebrates, which form the central link in the food chain, require flooded conditions for their growth and survival. As water levels decline during the dry season, fishes and other aquatic animals concentrate in deeper parts of the marsh and sloughs where they become prey for several groups of predators, especially wading birds *(fig. 19)* whose nesting season is especially timed to coincide with the high availability of food in the remaining pond water (Kushland, 1991). The animal populations in the adjacent tidal waters also are dependent upon the seasonal flows of freshwater that create the salinity conditions that support productive estuarine and marine fish populations (Lindall, 1973).

The Everglades has been dynamic during the approximately 5,500 years of its existence (Davis and others, 1994). Numerous shifts have occurred between marl- and peat-forming marshes and between sawgrass marshes and water-lily sloughs (Gleason and Stone, 1994). Fire, climate, sea level, topography, hydroperiods, alligator activity, and recently, man, have had long-term effects on the vegetation (Craighead, 1971; Parker, 1974; Gunderson and Snyder, 1994).

Figure 19. Wading birds in south Florida.

"When I first came to Florida, about 50 yrs ago, I found the country an almost untouched wilderness filled with beautiful wild life. Wild life fairly swarmed, especially the birds. Vast numbers of roseate spoonbills, snowy herons, American egrets, and the great white heron....winged their way far out over the pineland as they visited swamps in search of food. And food was abundant. In the Gulf of Mexico....there were schools of mullet, packed like sardines in a box and reaching away up and down the coast as far as the eye could carry."

Charles Torrey Simpson, 1920

Big Cypress Watershed

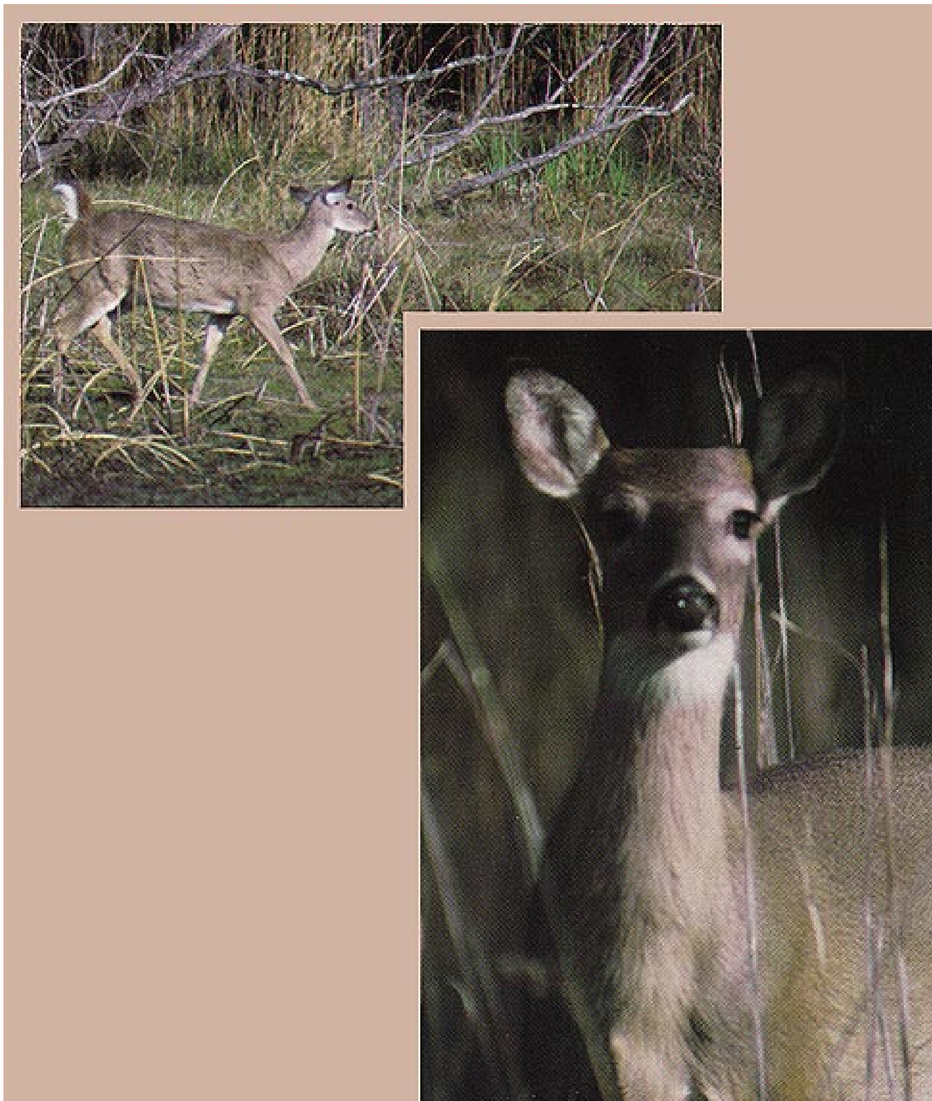
The Big Cypress Watershed covers about 2,470 mi^2 of southern Florida west of the Everglades and south of the Caloosahatchee River *(fig. 1)*. The northern part of the watershed is poorly drained sandy flatlands. Much of this area is dotted with small, shallow circular ponds, which generally are less than a foot deep and several hundred feet in diameter. Altitudes in the watershed are highest on the Immokolee Rise (25–42 ft), a sandy ridge that was formed at higher sea levels and which now contains the divide that separates the Caloosahatchee River drainage from that of the Big Cypress. In the northwestern part of the watershed, water drains westward into Estero Bay. On the Immokolee Rise and to the south, the sandy flatlands are dissected by several drainage ways that include the Okaloacoochee Slough, the Devil's Garden, and the Corkscrew Swamp *(fig. 17)*. The Okaloacoochee Slough extends southward about 50 mi from the vicinity of the Caloosahatchee River into the Big Cypress Swamp. Its average width is a little more than 2 mi. The Okaloacoochee Slough drains northward and southward from about the latitude of the Devil's Garden, a prong of the Slough that extends to the northeast. The Devil's Garden normally drains westward to the Okaloacoochee Slough, but in times of high water, it may overflow in all directions. The southern end of the Okaloacoochee Slough drains into the Fakahatchee Strand in the Big Cypress Swamp.

Corkscrew Swamp, which begins near Lake Trafford and extends southwesterly, contains one of the last virgin cypress forests in north America. Some trees tower 130 ft and have a girth of 25 ft. Part of Corkscrew Swamp is a National Audubon Society Sanctuary.

The Big Cypress Swamp lies south of the sandy flatlands and west of the Everglades. The swamp is characterized by an abundance of small, stunted cypress trees and by cypress trees of moderate size associated with depressions in the bedrock. Pine and hammock forests occur on land slightly higher than cypress forest land. Numerous ponds and cypress domes are in deeper water areas *(fig. 20)*. Water levels fluctuate seasonally, and during prolonged droughts, water levels fall below even the deep ponds *(fig. 20)*. Natural drainage is by slow, overland flow to the south. Well defined streams do not exist except along the southwestern coast where the swamp merges with the estuarine mangrove forest. The soil in the swamp is usually a thin (less than 2 ft) layer of marl, sand, or a mixture of the two or is absent where limestone is at the surface. Muck and peat, however, accumulate to depths of 3 ft or more in depressions in the bedrock (Davis, 1943).

Charlotte Harbor Watershed

The Charlotte Harbor watershed is an area of about 4,685 mi^2 that drains into the 270 mi^2 Charlotte Harbor Estuary *(fig. 1)*. Three major rivers flow into the estuary—the Peace, the Myakka, and the Caloosahatchee. The Peace River, draining an area of 2,350 mi^2, flows southward for about 75 mi from a group of lakes at its headwaters to Charlotte Harbor. Land-surface altitudes range from about 200 ft above sea level at the headwaters of the



Peace River to sea level at the mouth (Hammett, 1990). The Myakka River, draining an area of 602 mi^2, flows about 50 mi in a southerly direction to Charlotte Harbor. The Caloosahatchee River drains an area of 1,378 mi^2. The river was originally a shallow, meandering stream with headwaters near Lake Hicpochee. In its natural state, upstream parts of the river could go dry during the dry season, and saltwater could move upstream to within about 10 mi of the lake (Fan and Burgess, 1983).

Estuaries and Bays

A series of interconnected bays—Biscayne and Florida Bays, Card and Barnes Sounds–lie between the mainland and the Florida Keys *(fig. 17)*. The bays are semitropical environments that support a variety of biological communities that are dependent on the distribution of sediment, salinity, temperature, and tidal flow. The bays and estuaries are protected in a shallow depression formed between the Keys and the mainland. On the Keys side, bedrock consists of coralline Key Largo Limestone (Hoffmeister and Multer, 1968). This generally low ridge of limestone that forms the upper Florida Keys is as much as 18 ft above sea level at Windley Key and extends from Soldier Key in the north to Big Pine Key in the southwest. On the mainland side of the bays, the bedrock is the Miami Limestone which is dominated by two lithologies–an oolitic facies forming the Atlantic Coastal Ridge and a nonoolitic bryozoan facies beneath the Everglades to the west (Hoffmeister and Multer, 1968).

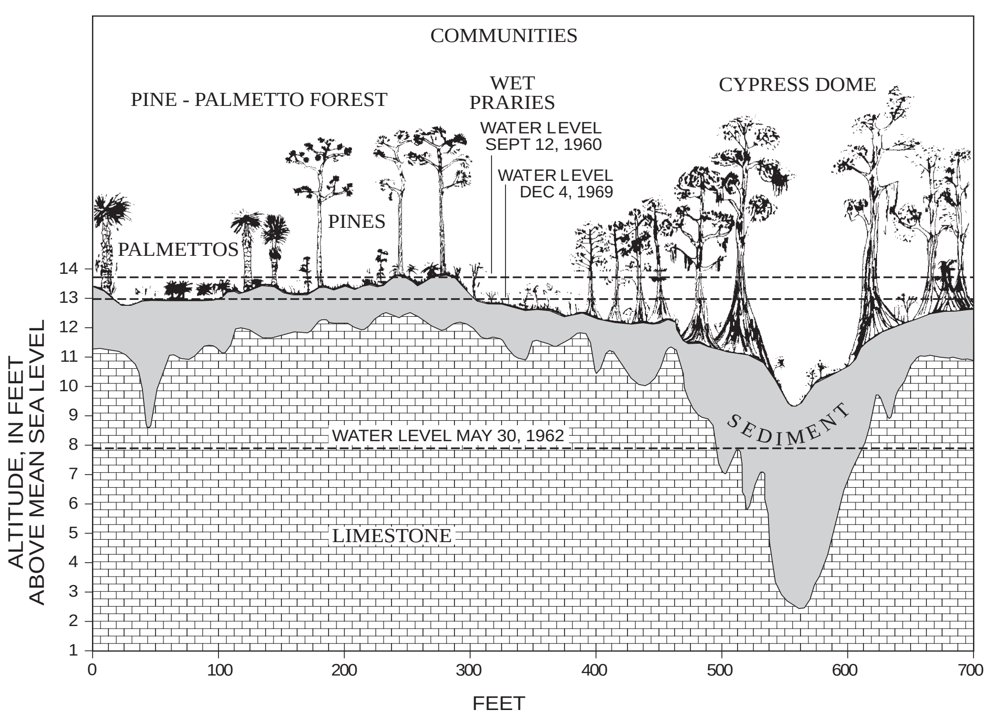


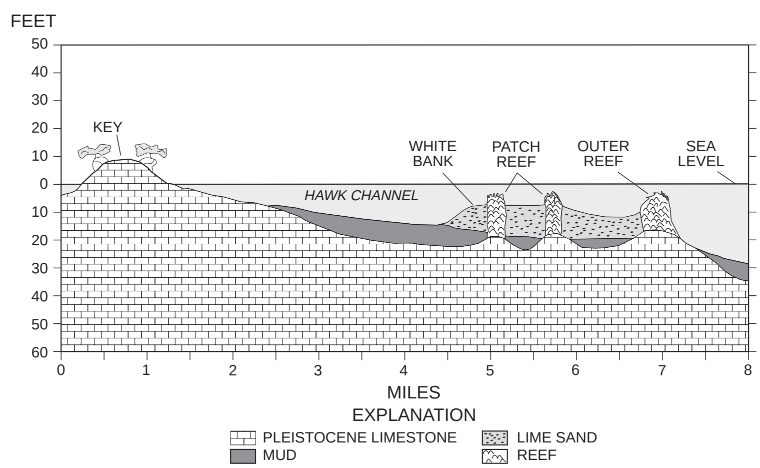
Figure 20. Cypress pine forests in the Big Cypress Swamp (above), *and a generalized section of a cypress dome* (at left). (McPherson, 1974.)

Florida Bay is a triangular area of about 850 mi^2 *(fig. 1)* whose western side opens directly to the Gulf of Mexico *(fig. 21)*. Except for tidal channels between the Keys, it is almost completely enclosed to the south and east. The rock under Florida Bay is porous limestone, which is similar to the bryozoan facies of the Miami Limestone in the eastern Everglades to the north. As much as 16 ft of marine sediments, mud, peat, and sand has accumulated on the limestone and formed a latticework of mud banks in Florida Bay. The banks enclose more than 40 shallow depressions, locally termed “lakes” that are between 4 and 6 ft deep (Enos and Perkins, 1978). Mangroves grow where the banks come near the surface and create small islands (Enos, 1989). The irregular lattice pattern was created by a complex process of erosion and deposition during the slow inundation of an Everglades-like marsh by a rising sea (Davies and Cohen, 1989). Mangroves that grow inland along storm berms, rills, and sloughs joined with mangroves on elevated shorelines to form a perpendicular meshwork that trapped marine sediments, thus forming the lattice pattern of banks and depressions (Wanless and Tagett, 1989). Thin layers of freshwater mud and peat that fill depressions in the limestone indicate that Florida Bay was similar to the Everglades when sea level was lower (Davies and Cohen, 1989).

Numerous interconnected bays and estuaries also lie along the western coast between Florida Bay and Charlotte Harbor, including the Ten Thousand Islands. In the Ten Thousand Islands area, oyster bars and mangrove islands create an intricate pattern of protected backwaters. Longshore currents from the north have deposited silica sand to form offshore bars that are parallel to the coastline. On top of these sandbars, dense mats of oysters grow perpendicular to the tidal flow and thus gain a feeding advantage. Mangroves grow on these intertidal bars and with time deposit tough, fibrous layers of peat. Eventually, further growth of the oyster bars may so restrict tidal flow that oyster growth declines. The mangroves, however, will continue to cover the bars and to connect adjacent islands. Later, sediments will fill the lagoons between the bars. Even so, mangrove land building appears to be balanced by the gradual drowning of offshore islands by a rising sea (Scholl, 1964; Scholl and others, 1969; Parkinson, 1989).

Figure 21. Western Florida Bay at Cape Sable.

Figure 21—Continued. Coral reef in south Florida (at left) *and generalized section from the Florida Keys to the reef* (below). (Shinn, 1993.)



Florida Reef Tract

Corals and coral reefs *(fig. 21)* are most abundant and best developed offshore of the Florida Keys seaward of Hawk Channel. These reefs which started growing about 6,000 years ago (Shinn and others, 1988), form a tract that is almost 150 mi long and about 4 mi wide extending to the edge of the Florida Straits *(fig. 1)*. The reef tract is not uniform, but consists of a series of ridges and channels parallel to the Keys. Two zones of discontinuous, but parallel, ridges are evident—the inner ridge, White Bank, composed of skeletal sand and scattered patch reefs; and the outer ridge, a discontinuous shelf margin of reefs and hard banks, composed of coral rubble and skeletal sand that form the seaward edge of the reef tract (Ginsburg and James, 1974). The corals that formed the Key Largo Limestone and built the upper Florida Keys are living today on the reefs. The best examples of living reefs exist off Key Largo where the islands retard exchange with Florida Bay and the offshore water is dominated by the waters of the Florida Current (Ginsburg and Shinn, 1964; Hoffmeister, 1974; Lidz and Shinn, 1991).

Small patch reefs and large grass beds, as well as large areas of bare sand, are scattered on White Bank. Most of the common life forms of the outer reef occur on the patch reefs with the interesting exception of elkhorn coral, which is absent in patch reefs and in the Key Largo Limestone, but is a prominent reef-building coral of the outer reefs (Shinn, 1963). Also, the dominance of marine species differs between the outer reefs and the patch reefs, as does the growing shape of some corals. Sea fans and whips seem more common on the patch reefs than on the outer reef. The percentage of grass-feeding fishes is higher on patch reefs than on the outer reefs. These fishes utilize the patch reefs as a daytime resting place and then move onto nearby grass beds to feed at night. Patch reefs often have a halo of white sand around their perimeter; this is usually caused by the browsing of the black-spined sea urchins on the adjacent seagrasses (Ogden and others, 1973).

The greatest variety of corals and coral-reef animals live on the outer reefs (Jaap, 1984). Dustin (1985) listed more than 40 species of stony corals from the Florida Reef Tract. The outer reefs have the most stable temperature and salinity and the clearest water because of the proximity of the Florida Current. Most reef-building corals require clear water for photosynthetic algae living in their soft tissues. The corals, in turn, benefit from the oxygen and nutrients produced by the algae (Muscatine, 1990). The Florida Current, which moves northward parallel to the reef tract, provides a rich source of plankton, an important food source for many fishes and invertebrates of the outer reefs. The fish population on the outer reefs, which is one of the most varied in the world, contains more than 500 recorded species (Starck, 1968). The varied morphologies of reef corals provide a haven for fish, crustaceans, mollusks, worms, and sea urchins. Also, the dead coral limestone offer attachment surfaces to a multitude of marine algae and invertebrates. Nearly 1,400 species of marine plants and animals were recorded for a small area of the Florida Reef Tract (Voss and others, 1969).

These coral reefs are, perhaps, the most diverse and colorful marine habitats within the continental United States. Although they have developed near the northern limit for coral reefs (Mayor, 1914) and are subjected to winter water temperatures that can be fatal to corals (Vaughan, 1918), the reefs of Florida rival those of many other areas of the Caribbean in diversity and beauty. Like coral reefs elsewhere, they are among the most highly productive marine ecosystems (Erez, 1990). They thrive in regions typically low in nutrients because they have evolved mechanisms for conserving and efficiently recycling food. This ability of reefs to thrive in a nutrient-poor setting led Odum (1971) to describe a coral reef as “an oasis in a desert ocean.”

Coral Reefs and Sea Level

In south Florida, most luxuriant reef growth has long been observed to be located near the shelf edge seaward of the largest Florida Keys. Ginsburg and Shinn (1964, 1994) noted that this distribution, as well as similar relations between reefs and islands in the Bahamas, indicate that reefs grow best where islands protect them from extremely shallow bay waters. Reefs are absent in Florida Bay because the water is too cold in the winter, too hot in the summer, and too variable in salinity to support the growth of reef-building coral (Tabb and others, 1962; Holmquist and others, 1989; Robblee and others, 1989). Similarly, reef growth is limited where bay water passes between the Keys to the shelf (Shinn and others, 1988; Ginsburg and Shinn, 1994).

During a rising sea level, circulation increases between shelves and coastal bays on low-relief carbonate platforms because water depths increase and larger areas of the platforms are flooded, thus increasing the volume of the tidal wedge. On platform tops, water may become increasingly warm, saline, or, in the case of the Bahama Platform, cold in the winter (Roberts and others, 1982). Reefs that become established along the margins of platforms may thrive for thousands of years until the platform is flooded and bays develop water conditions that limit the growth of coral. During thousands of years of sea-level rise, shelf margin reefs may be “shot in the back” by their own bays and lagoons as circulation increases between the platform interior and shelf edge (Neumann and McIntyre, 1985).

Sea level is continuing to rise in south Florida *(fig. 22)*, and the measured rise at Key West has been almost 6 in. since 1913 (Emery and Aubrey, 1991) and about 1-ft since 1850 (Maul and Martin, 1993). Although the result of sea-level rise is not fully understood, a 1-ft increase is thought to have significantly changed the circulation dynamics of Florida Bay. Florida Bay, on average, is about 5 ft deep, so the natural increase represents a 25-percent increase in depth and, presumably, a significant increase in water exchange between the bay and reef tract. Water depth also is determined, in part, by sedimentation rates in the bay that are, to date, undetermined. The relation between current sea-level rise and the health of reefs is a topic that requires more study before specific forecasts of these processes can be applied to the Florida Keys. If sea level continues to rise for geologically significant periods, however, then the long-term fate of the coral reefs of Florida is toward continued decline.

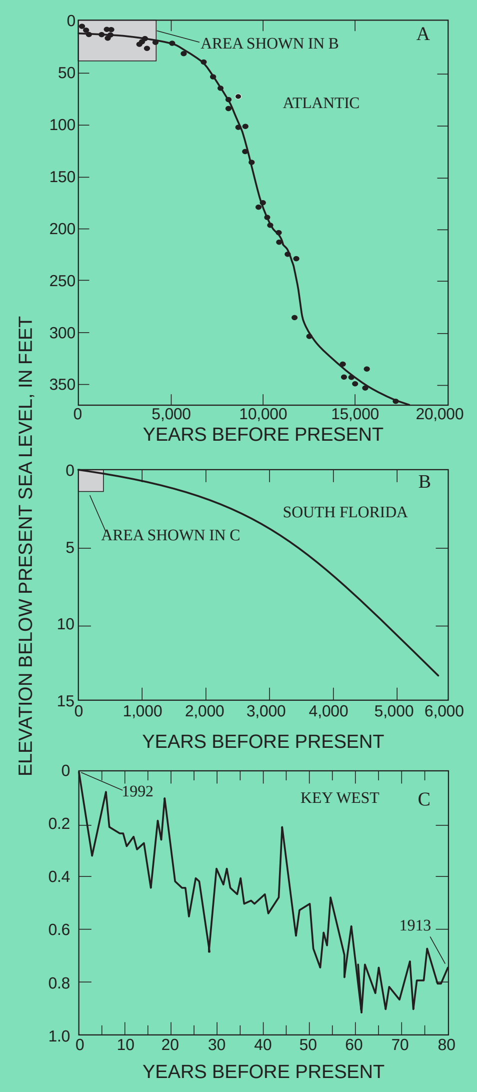


Figure 22. Sea-level fluctuations on three time scales. (Sea level is relative to 1992 in graph C.)

[Fairbanks, 1989 (graph A); Scholl and others, 1969 (graph B); Maul and Martin, 1993 (graph C).]

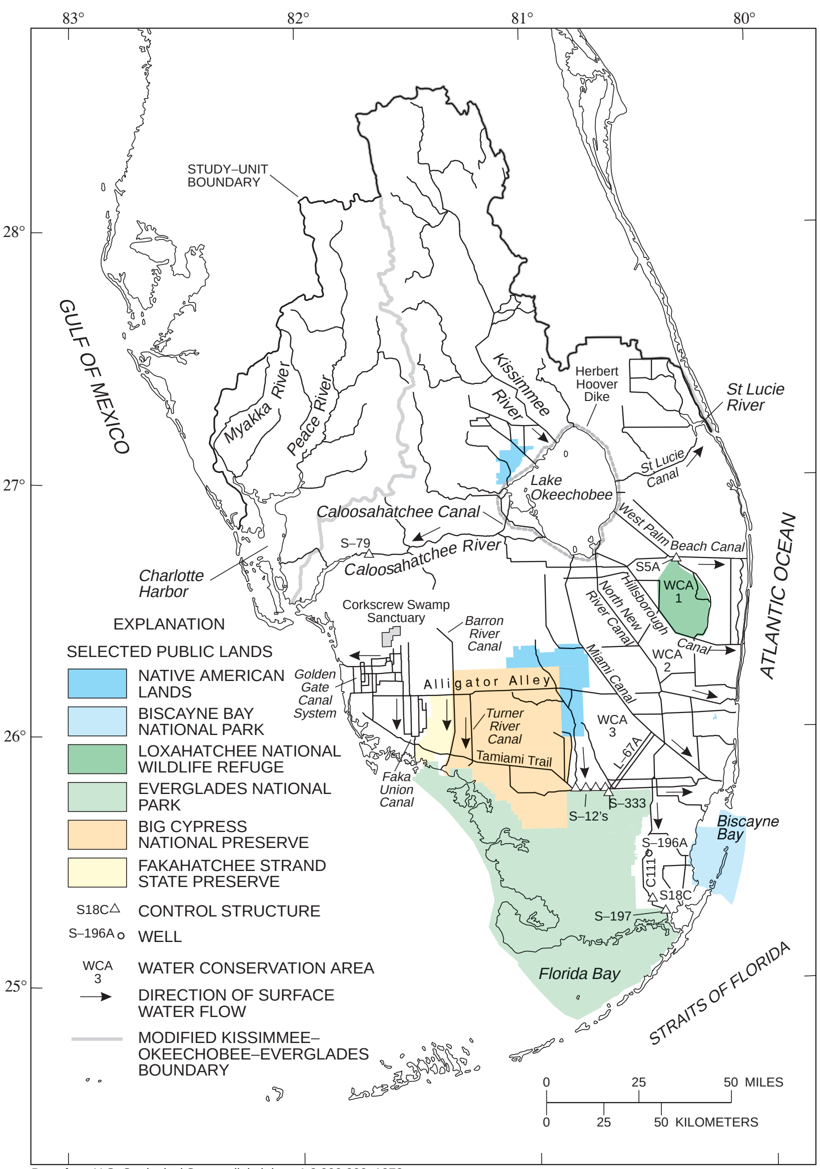
Environmental Setting—the Altered System

The south Florida ecosystem has been greatly altered by man *(fig. 23)*. Although the hydrology, water quality, and ecology of much of the region has been changed by drainage and development, parts of the old ecosystem remain, primarily on protected lands and in protected waters at the southern end of the peninsula.

Drainage and Development

Drainage of the Everglades watershed began in the early 1880's and continued into the 1960's. The first drainage canals were dug in the upper Kissimmee River and between Lake Okeechobee and the Caloosahatchee River. Beginning with the Miami River in 1903, canals were cut through the Atlantic Coastal Ridge and into the northern Everglades. By the late 1920's five canals had been dug between Lake Okeechobee and the Atlantic Ocean–one that passed north of the Everglades and connected the lake with the St. Lucie River, and four that passed through the Everglades *(figs. 23, 24)*. Drainage has enabled agriculture to develop south of Lake Okeechobee. In the late 1920's, a low, muck levee was constructed along the southern and southwestern shore of the lake to prevent flooding; but during the hurricanes of 1926 and 1928, the levee was breached, which resulted in the destruction of property and lives. In response to these catastrophes, the Federal Government initiated flood-control measures, which included the construction of a levee around the southern shore of the lake and the enlargement of the Caloosahatchee and the St. Lucie Canals.

Drainage and development irreversibly altered the natural Everglades watershed and had severe environmental consequences. Early drainage lowered water tables up to 6 ft below predevelopment levels and resulted in conditions favorable for severe fires that damaged and eliminated vegetation (Alexander and Crook, 1973; 1975). Peat burned and oxidized, and the land subsided as much as 6 ft below predevelopment levels. Saltwater from the ocean intruded inland via canals and filtered into the previously freshwaters of the aquifer (Parker and others, 1955; Klein and others, 1975).



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
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Figure 23. Major canals, control structures, direction of water flow, and other hydrologic features in south Florida.

In 1948, Congress authorized the Central and Southern Florida Project for Flood Control and other Purposes to provide flood protection for urban and agricultural development and an adequate water supply for development. A water-management plan was adopted that included Lake Okeechobee and three water conservation areas (WCA's) and that provided flood protection and water supply through a complex series of canals, levees, pumps, and control structures. The northern Everglades was identified as an area that was suitable for agricultural development on the basis of soil thickness and geologic formations. As a result, 800,000 acres was designated agricultural land and termed the "Everglades Agricultural Area" (EAA). Subsequently, most of this land was drained and farmed. The WCA's were constructed in the central Everglades and consisted of levees and canals that enclosed areas that total about 900,000 acres *(fig. 23)*. These areas, which were completed by 1962, provided flood protection during the wet season by storing water and discharging excess water to the ocean and supplied water during the dry season for irrigation and municipal uses (Klein and others, 1975).

Congress authorized the channelization of the Kissimmee River for flood control in 1954. Canal construction began in 1961 and was

Figure 24. Miami Canal in Water Conservation Area 3.

completed 10 years later. The 90-mi-long meandering river was replaced by a 52-mi-long canal, and seasonal flooding of much of the river's flood plain, which averaged about 2 mi in width, was eliminated. Flow into Lake Okeechobee was controlled by six locks and dams along the rivers (Carter, 1974).

Construction of the Kissimmee River Canal (C-38) considerably altered the hydrology, water quality, and wetlands in the Kissimmee Basin. The dams in the canal created pond areas that were permanently flooded, whereas farther upstream from each dam, wetlands were drained and replaced by terrestrial vegetation. As a result, about 40,000 to 50,000 acres of flood plain marsh disappeared, resulting in a significant loss of habitat for wading birds and other aquatic animals (South Florida Water Management District, 1989) and in a loss of the natural nutrient-filtering effects of these wetlands. Drainage also eliminated the river's natural oxbows and stimulated agricultural development in flood plain and adjacent wetlands, all of which have contributed to the increased nutrient loading to Lake Okeechobee (Lamonds, 1975; Federico, 1982). The environmental impacts of channelization were quickly recognized, and calls for restoration of the river began even during canal construction. Plans are underway to restore the river and its flood plain by increasing water storage in the upper Kissimmee Basin and by physical modifications to the lower basin. This will include backfilling 22 mi of C-38, recarving 9 mi of river channel, removing two water-control structures, and removing flood-plain levees. Construction will require approximately 15 years (South Florida Water Management District, written commun., 1993).

A large percentage of the water that originally flowed from the Kissimmee River and Lake Okeechobee into the Everglades is now diverted directly to the Gulf of Mexico by the Caloosahatchee Canal and to the Atlantic Ocean by the St. Lucie Canal. The remaining outflow from the lake is released in canals that pass through the EAA (South Florida Water Management District, 1989). Water is pumped from the EAA into the WCA's, but the timing and spatial distribution of this water delivery is altered from natural flows, and the amount

of water discharged is greatly reduced. As a result, water levels in the Everglades generally are shallower and have shorter hydroperiods than those of predevelopment time, and the timing and distribution of flows have changed (Parker, 1974; Fennema and others, 1994). In the northern parts of the WCA's, water levels are drawn down rapidly by canals, and in the southern parts, water ponds as flow is impeded by levees (Dineen, 1972). The ponding effect began in the mid-1960's in WCA–3 and resulted in extensive flooding of tree islands. During droughts, water is released from Lake Okeechobee to the EAA and the WCA's. Most of this water, however, never reaches the interior marshes, because it is confined to canals and their nearby marshes.

Drainage of the Big Cypress Swamp began in the 1920's with the construction of the Barron River Canal *(fig. 23)*. Subsequently, the Turner River Canal was dug 5 mi to the east. Even though these canals have not been effective in lowering water levels, both intercept substantial quantities of water from the Okaloacoochee Slough and divert them directly to the estuaries. A major drainage system, the Golden Gate Canals, was started in the Big Cypress in the early 1960's. As a result of this system, water levels in the western part of the swamp have been lowered an average of 2 ft, and seasonal flooding has been reduced.

Public Lands

Today, a fragmented part of the old, predevelopment landscape exists in south Florida at the southern end of the peninsula. Most of this area is wetlands *(fig. 14)* and is in public ownership or under public control *(fig. 3)*. These lands include Everglades National Park, Big Cypress National Preserve, Loxahatchee National Wildlife Refuge, the water-conservation areas, the Fakahatchee Strand State Preserve, and other State lands.

Parts of the Everglades were set aside for preservation and protection of wildlife by the Federal Government in the mid-1900's. The Everglades National Park was established in 1947 on marshland south of the WCA's and now covers about 1.4 million acres. The Loxahatchee National Wildlife Refuge was established in 1951 in WCA–1 and covers 145,000 acres. The refuge, park, and the other WCA's contain most of the remaining natural Everglades.

Everglades National Park depends on seasonal flows of good-quality freshwater from outside its boundaries from such sources as the headwaters of the Shark River and the Taylor Sloughs. However, flows into the park from these sloughs have been greatly altered. Federal legislation was passed in 1968 to assure that a minimum monthly water delivery be made to the park. With the minimum flows, however, the wetlands and the aquatic animals in the park still suffered from lack of water in dry periods. Also, the legislation did not protect the park from receiving too much water in extremely wet years. Water delivery to the park is now based on rainfall measurements to the north of the park and mimics natural seasonal flow, but does not provide the prolonged flows and hydroperiods of the predevelopment Everglades when flows were attenuated from one wet season into the next dry season (Davis and others, 1994). Also, water releases to the park are, for the most part, outside the natural flow path in the Shark River Slough. In addition to alterations in flow, deterioration of water quality in the northern Everglades through nutrient enrichment also threatens the integrity of the park (Amador and others, 1992).

Observation tower (looking south) at Everglades National Park; Shark River Slough on the horizon

Agriculture

Despite the obvious benefit of a year-round growing season, most of south Florida was originally not suited to farming because of annual flooding. Agricultural activity increased in the 1920's as more and more peat soil in the northern Everglades was drained. Drainage also opened land for farming between the Everglades and the Atlantic Coastal Ridge *(fig. 4)* and in parts of the Western Flatlands. Increasing availability of farm machinery, fertilizers, and pesticides allowed for intensive farming and farming of marginal lands. On rock land, for example, machinery was used to break up the original rock surface and produce a coarse soil suitable for farming (Nicholas, 1973).

Today, farming is concentrated primarily in the northern Everglades, the Western Flatlands, and the rocky glades west of the Atlantic Coastal Ridge *(figs. 2 and 4)*. Sugarcane *(fig. 25)*, vegetables, and citrus are the most important crops. Vegetables from the region provide a large part of the Nation's winter supply. More than $750 million is earned annually from production of sugarcane, vegetables, sod, and rice, and has provided more than 20,000 full-time equivalent jobs (Snyder and Davidson, 1994).

Much of the farming in south Florida depends on the rich muck land for the production of sugarcane, snap beans, celery, cabbage, sweet corn, as well as other crops. However, oxidation is progressively removing this important rich organic soil. As water levels are regulated for agricultural development, muck is alternately covered by water and exposed to the air. During low-water periods of drying, the muck oxidizes and the probability of fire increases. Subsidence rates in the EAA have averaged about 1 in/yr. An elevated water table reduces oxidation, and in recent years, management to maintain elevated water levels in the soil has probably reduced the average rate of soil subsidence (Barry Glaz, Department of Agriculture, written commun., 1994). Forced abandonment of farms is predicted in the intensively farmed muck land because of soil subsidence. Other farms will be abandoned or sold to urban and residential development as land taxes and land values increase (Alexander and Crook, 1973).

Figure 25. Sugarcane fields south of Lake Okeechobee.

Pesticides are widely used in south Florida to control insects, fungi, weeds, and other undesirable organisms. These compounds vary in their toxicity, persistency, and transport. Some of the more persistent pesticides, such as DDT, chlordane, dieldrin, and aldrin, have been banned for use in the State, but their residues still occur in the environment. Although pesticides are usually applied to specific areas and directed at specific organisms, these compounds often become widely distributed and pose potential hazards to nontarget biota.

The major pesticides used for agricultural crops in south Florida and their estimated application rate are listed in *table 1*. Herbicides having the highest application rates, including atrazine, bromocil, simazine, 2-4-D, and diuron, are among the most frequently detected pesticides in Florida's surface waters (Shahane, 1994). Insecticides currently applied in south Florida, such as ethion and endosulfan, are sometimes detected in Florida's surface waters. By far the greatest frequency of insecticide detection is from chlorinated hydrocarbon insecticides that are no longer used in the State, such as DDD, DDE, DDT, dieldrin, and heptachlor. These insecticides also are the most frequently detected pesticides in bottom sediments (Shahane, 1994).

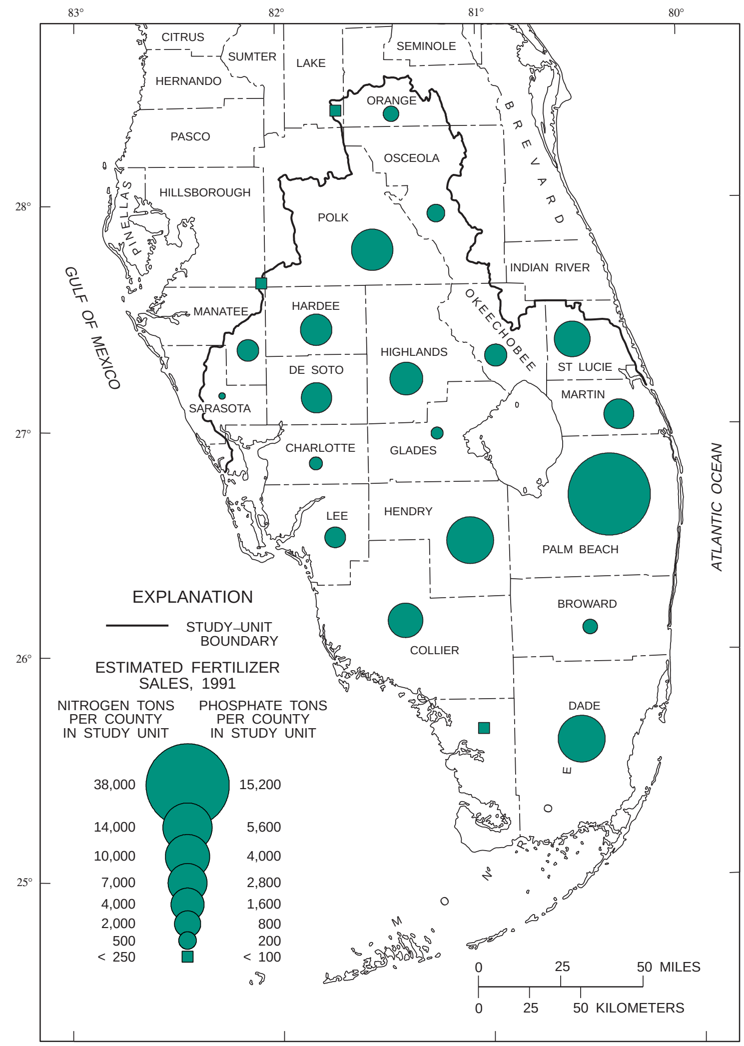
Fertilizers are widely used in south Florida to maintain high levels of agricultural productivity. Fertilizers sold in the study unit from July 1, 1990, through June 30, 1991, contained about 140,000 tons of inorganic nitrogen and 56,000 tons of phosphate (U.S. Environmental Protection Agency, written commun., 1991). The rates of fertilizer application for this period, which were based on county sales, are shown in *figure 26*. The average rates of fertilizer application for the study unit were 7 tons/mi^2 for nitrogen and 3 tons/mi^2 for phosphate. The highest rates of application (19 tons/mi^2 for nitrogen and 8 tons/mi^2 for phosphate) were in Palm Beach County.

Cattle ranching and dairy farming are important agricultural activities in south Florida *(fig. 27)*. The total number of cattle in the study unit in 1994 was almost 1 million (U.S. Department of Agriculture, written commun., 1994). Cattle ranching and farming is most intensive near and to the north of Lake Okeechobee, where densities can exceed 200 head of cattle per square mile *(fig. 28)*. High densities of cattle are a potential source of nutrients that can degrade the surface and ground waters of the region.

Table 1. Major pesticides used on agricultural crops in the south Florida study unit, listed in order of estimated total pounds of active ingredient applied annually (1989–91)

[Based on data compiled by Resources of the Future, 1990; 1992]

Insecticides		***Herbicides***		***Fungicides***	
Oil	13,300,000	Atrazine	1,250,000	Sulfur	2,300,000
Ethion	810,000	Asulam	880,000	Copper	1,900,000
Phorate	320,000	Bromacil	730,000	Maneb	600,000
Methomyl	270,000	Simazine	490,000	Chlorothalonil	600,000
Aldicarb	240,000	2-4-D	260,000	Fosetyl-Al	170,000
Endosulfan	230,000	Diuron	260,000	Mancozeb	120,000
Chlorpyrifos	200,000	Dicamba	240,000	Metalaxyl	120,000
Fenbutatin oxide	191,000	Dalapon	210,000	Benomyl	65,000
Ethoprop	170,000	Paraquat	170,000	Ziram	45,000
Methamidophos	170,000	Metribuzin	140,000	Captan	7,000
Dicofol	150,000	Norflurazon	130,000		



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 26. Estimated fertilizer sales, in tons of phosphate and nitrogen, in counties within the study unit, south Florida. (USEPA, 1990.) (1991 data calculated by Jerald Fletcher, West Virginia University, using a method described in the USEPA publication.)

Figure 27. Cattle in a drainage ditch near Lake Okeechobee.

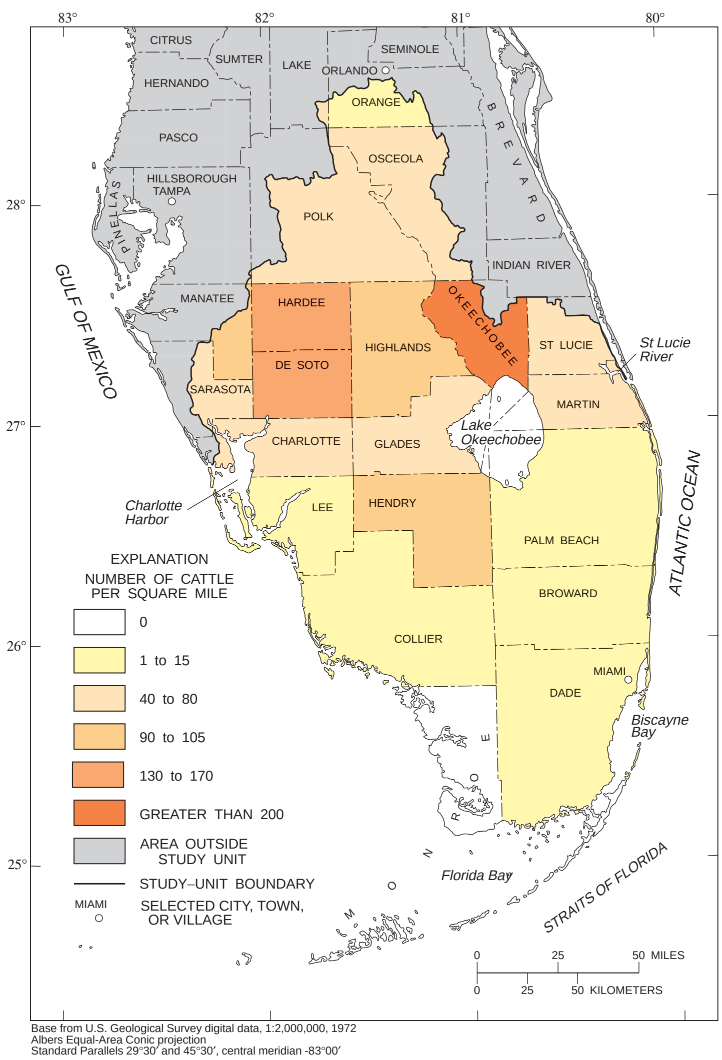


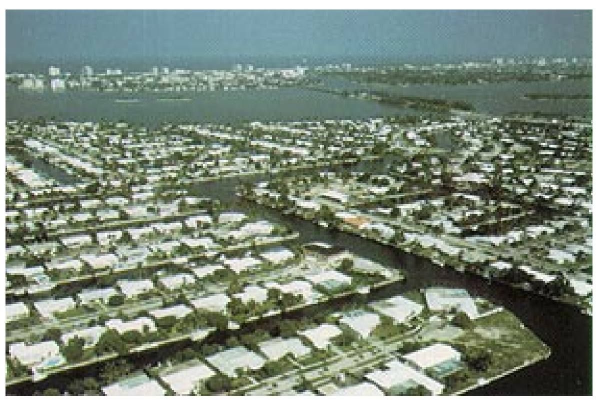
Figure 28. Estimated number of cattle per square mile, per county, in south Florida, 1992. (U.S. Department of Agriculture, National Agricultural Statistics Service, June 1994.)

Urbanization

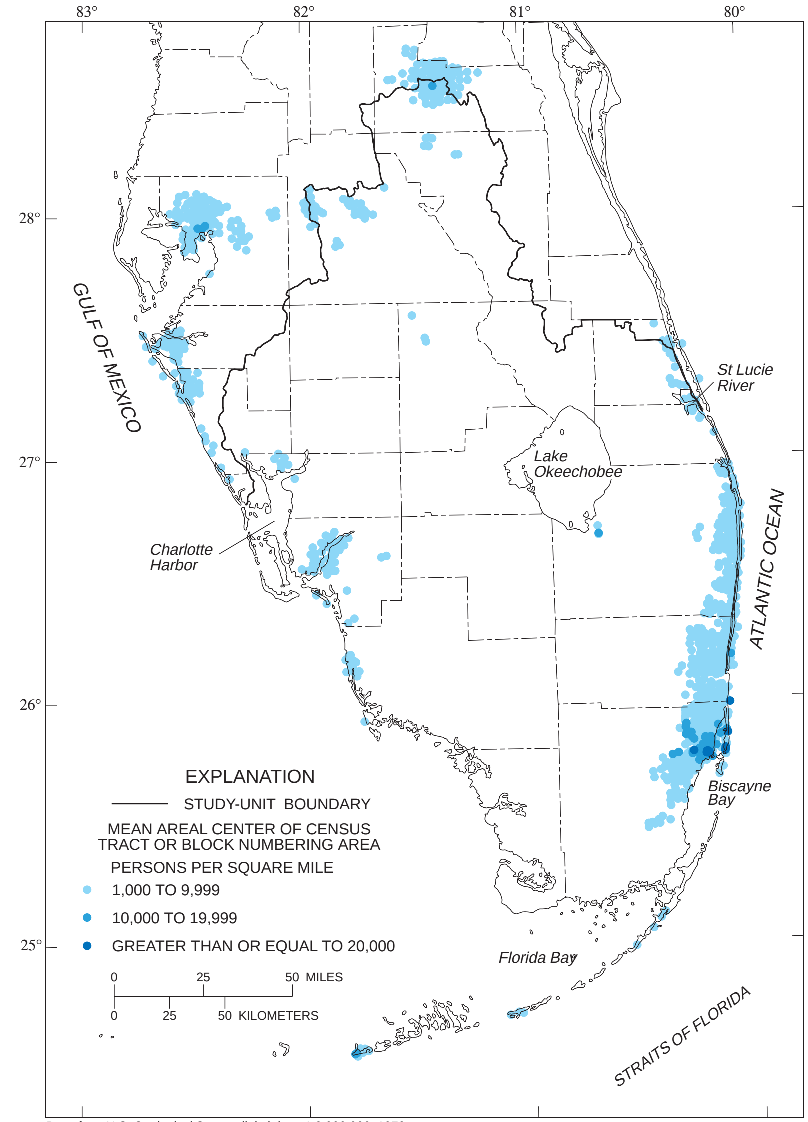
Urbanization in south Florida began along the Atlantic Coastal Ridge where the land is high and close to the marine transport that was essential to the original coastal settlements. Extension of a railroad to Miami at the turn of the century sparked phenomenal growth. Through the years, flood-control and water-management practices have made some land west of the ridge available for development. Today, more than 4 million people live in an urban complex along or near the eastern coast *(fig. 29)*. A second urban complex of more than 0.5 million people has developed along the Gulf Coast between Charlotte Harbor and Cape Romano. The Everglades and the Big Cypress Swamp presented a formidable barrier to development between the two coasts.

The major effects of urbanization on water resources are reduction of infiltration, increase of flood potential, and degradation of the quality of water bodies receiving water. Trash and litter deposited on streets and parking lots, erosion of exposed ground as a result of construction, lawn and landscape fertilization, pet wastes, automobile emissions, atmospheric deposition from industrial and thermoelectric powerplants, and seepage from landfills, septic tanks, and disposal wells have been identified as sources of urban stormwater loads. These sources of generally distributed substances are grouped together under the classification of “nonpoint” to distinguish them from the more readily identifiable industrial- and domestic-sewage plant effluents, called “point sources” (fig. 30).

Consequences of drainage for urban and agricultural development have included seawater intrusion into coastal parts of the shallow aquifers. During the prolonged droughts of the 1930’s and 1940’s, seawater moved inland along canal channels and infiltrated aquifers. At the end of the 1945 dry season, seawater intrusion had affected large segments of the Biscayne aquifer, and several of Miami’s municipal supply wells yielded salty water. Water levels in southern Dade County and in what is now the eastern part of Everglades National Park were as low as 2 ft below sea level (Parker and others, 1955).

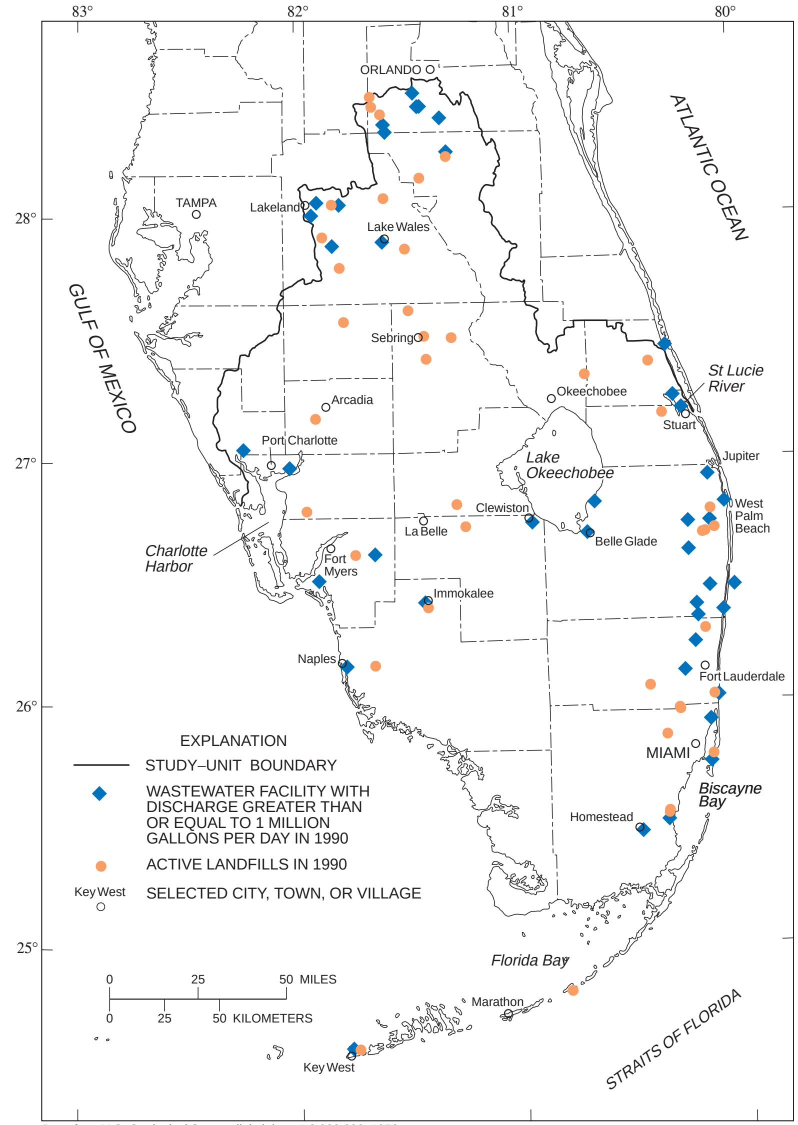


Uncontrolled drainage in southeastern Florida was halted in 1946 by the installation of control structures (barriers) near the outlets of most drainage canals. These structures mitigated the recurring problems of seawater intrusion and excessively low water levels. During the rainy season, the controls are opened to release water for flood prevention in the urban and agricultural areas, and during the dry season, they are closed to prevent overdrainage and to retard seawater intrusion. Canal flows have been controlled since 1946, and regional water management in southeastern Florida was begun in 1962 with storage of water in Conservation Area 3. Water control in the 1950’s and management in the 1960’s reduced canal outflows from the Everglades (Leach and others, 1972) but resulted in increased water losses from the coastal ridge area where flood prevention was necessary in the rapidly expanding urban areas.



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 29. Population density in south Florida, 1990. (Derived from U.S. Department of Commerce, Bureau of Census, 1990 Census of Population and Housing Public Law 94-171.)



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 30. Location of major wastewater facilities and landfills in south Florida. (Florida Department of Environmental Protection, 1990-94.)

Water Use

Most public water supplies in south Florida are withdrawn from shallow aquifers, generally from wells less than 250 ft deep. The most productive and widespread of these aquifers are the Biscayne aquifer in the southeast and the shallow aquifer in the southwest. The Biscayne aquifer has been designated as a "sole-source water supply" by the U.S. Environmental Protection Agency. Important also, but of lower yield, are the coastal aquifer, which extends northward from West Palm Beach, and the local aquifers that are scattered through the remaining area, particularly those that supply water to the western coast urban region.

The Floridan aquifer system is a source of water primarily north of Lake Okeechobee. South of the lake, this aquifer is deeper and more brackish. Although it is capable of large yields of saline water by artesian flow, it is not generally used as a source of water supply, but rather used for wastewater injection.

Freshwater withdrawals within the Southern Florida NAWQA study unit were about 4,110 Mgal/d in 1990. Most of this water was used for public supply (22 percent) and agriculture (67 percent). Public water supply for most of the 5.8 million people that live in the study unit is from ground-water sources *(table 2)*. Ground water supplied 94 percent (872 Mgal/d) of the water used for public supply in 1990. Water withdrawn for agricultural purposes is nearly divided between ground-water and surface-water sources. In 1990, ground water accounted for 45 percent (1,230 Mgal/d) and surface water accounted for 55 percent (1,505 Mgal/d) (Richard L. Marella, U.S. Geological Survey, written commun., 1994).

Water Budget

The movement and storage of water in south Florida is represented in a schematic diagram in *figure 31*, and the average annual flows from 1980 through 1989 in the area are summarized in *figure 32*. The Kissimmee River annually discharged about 0.8 million acre-ft to Lake Okeechobee. In turn, the lake annually discharged about 0.4, 0.2, and 0.5 million acre-ft south into the EAA, east into the St. Lucie Canal, and west into the Caloosahatchee Canal, respectively.

Table 2. Population characteristics, by hydrologic cataloging unit, in the south Florida study unit, 1990

[From Richard L. Marella, U.S. Geological Survey, written commun., 1994]

Name of unit	Catalog unit number	Total population	Served by public supply			Self-supplied population
			Total water	Ground water	Surface water	
Kissimmee River	03090101	482,871	272,810	272,810	0	210,061
Northern Okeechobee inflow	03090102	24,466	17,035	0	17,035	7,431
Western Okeechobee inflow	03090103	5,036	0	0	0	5,036
Lake Okeechobee	03090201	4,152	0	0	0	4,152
Everglades	03090202	4,268,450	3,941,135	3,845,228	95,907	327,315
Florida Bay–Florida Keys	03090203	77,212	77,212	77,212	0	0
Big Cypress Swamp	03090204	233,601	211,917	193,172	18,745	21,684
Caloosahatchee River	03090205	250,712	190,103	163,043	27,060	60,609
Peace River	03100101	361,709	311,330	261,330	50,000	50,379
Myakka River	03100102	29,552	27,565	7,600	19,965	1,987
Charlotte Harbor	03100103	31,144	23,188	23,188	0	7,956
Total		5,768,905	5,072,295	4,843,583	228,712	696,610

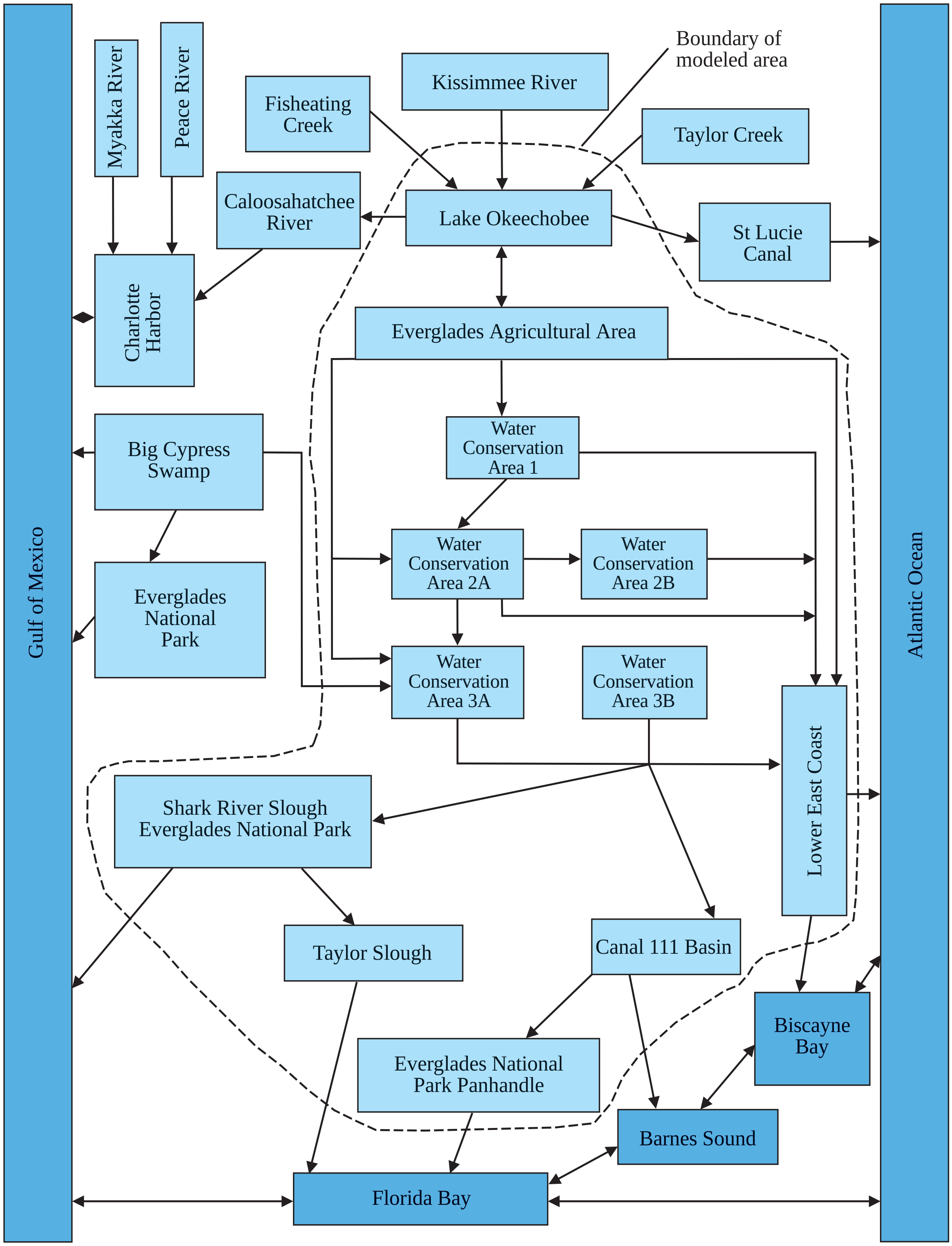
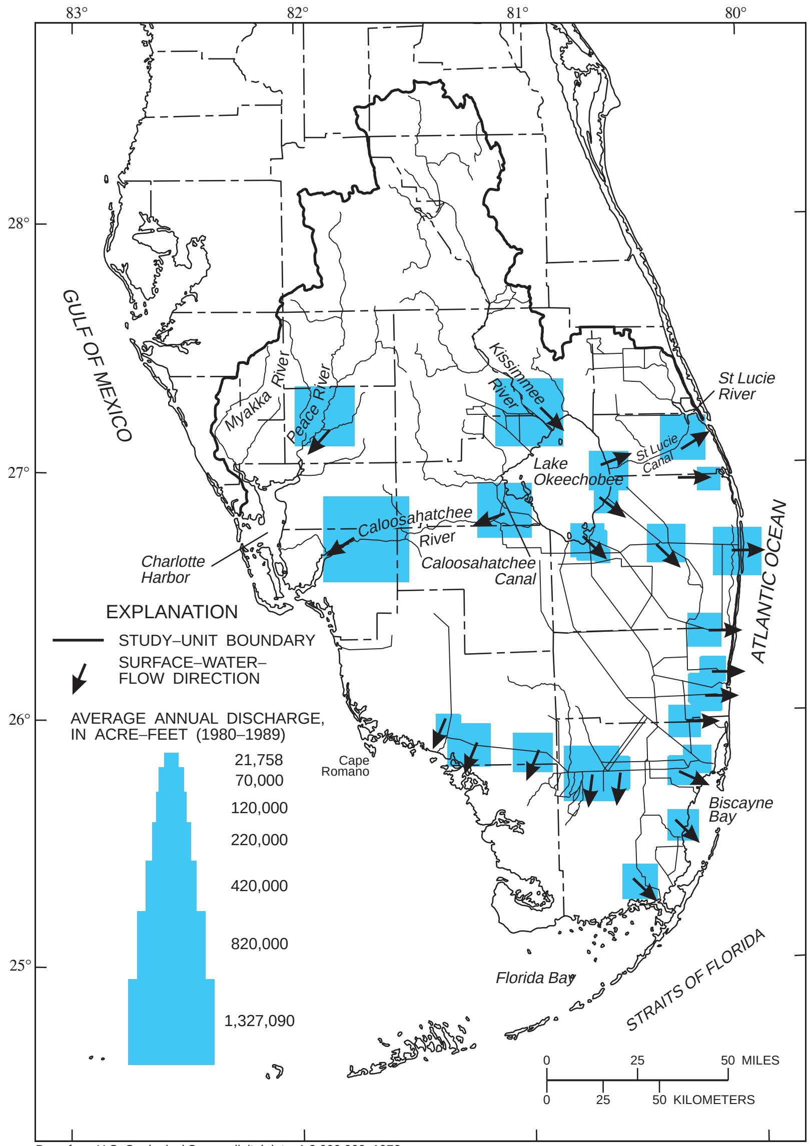


Figure 31. Water storage and movement in south Florida (arrows indicate dominate flow direction). (Modified from South Florida Water Management District, 1993.)



Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 32. Average annual discharge from major canals in south Florida.

The word, *swamp*, as we understand it, has no application whatever to the Everglades ... it is a country of pure water ... [that] is moving in one direction or another depending on the natural topography of the county; ... the air is wholesome, pure, free from disease ... Near the coast, the mangroves and the mosquitoes thrive; but deep in the Everglades, in the winter time at least, you can sleep comfortably without a net. No stagnant pools exist for the larvae to thrive in.

Hugh L. Willoughby, 1898

The average annual discharge to coastal waters was about 1.3, 0.3, and 1.4 million acre-ft, respectively, from the Caloosahatchee and St. Lucie Canals, and into the Atlantic Ocean from 11 canals south of the St. Lucie Canal. The average discharge under the Tamiami Trail to the southern Everglades and the Big Cypress Swamp was about 1.2 million acre-ft.

The movement and storage of water in southeastern Florida from 1980 through 1989 was evaluated by the South Florida Water Management District (1993) by using a water-budget approach. Budgets were developed for the region and for subbasins in the region, which includes Lake Okeechobee, the three water conservation areas, the Everglades Agricultural Area, the eastern part of Everglades National Park, and the developed Atlantic Coastal Ridge *(fig. 33)*. Hydrologic components used in developing the water budgets were those estimated directly from measurement data, which included rainfall, canal flows, and consumptive pumpage, and those estimated by using a computer

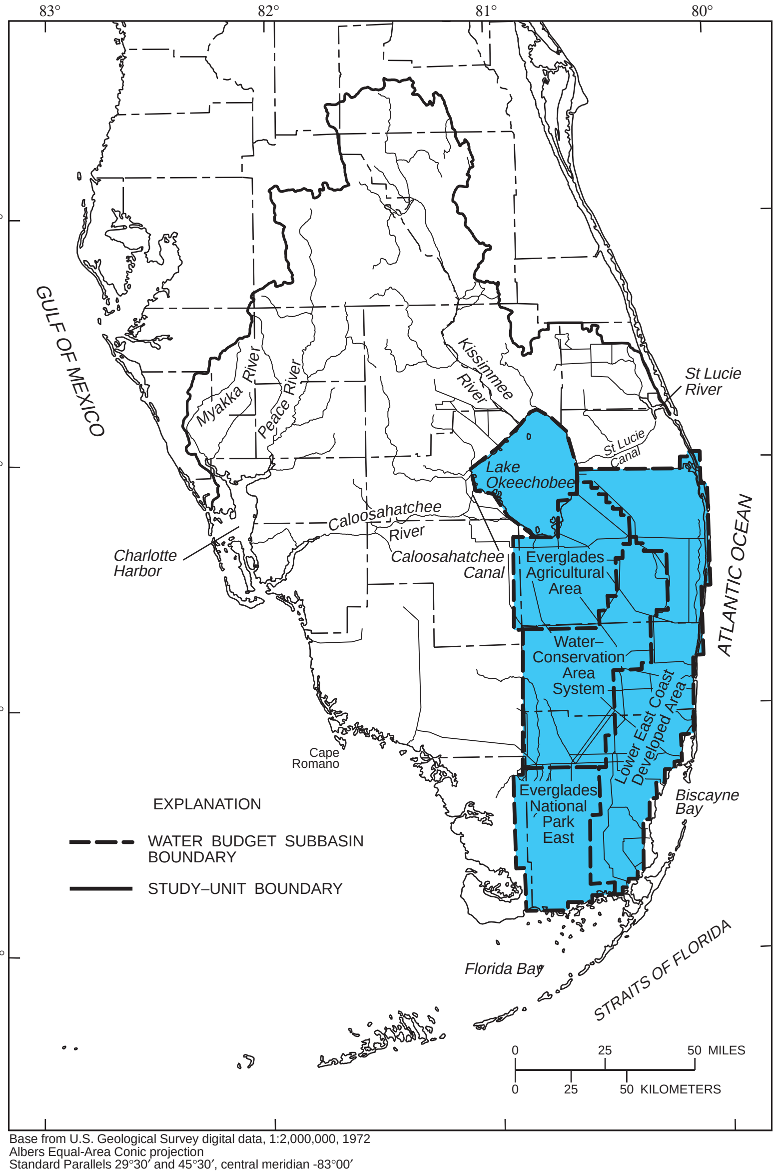
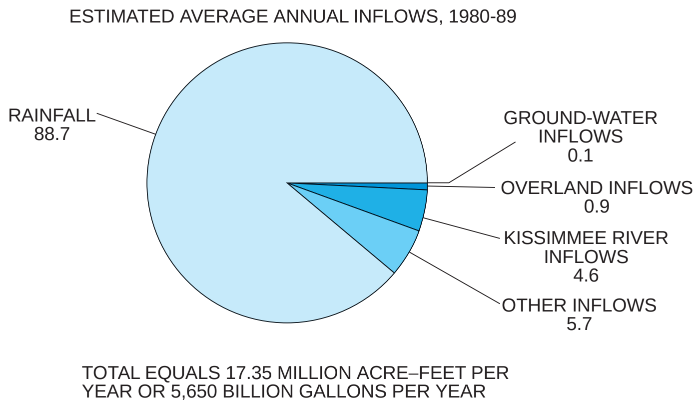


Figure 33. Major water budget subbasins of southeastern Florida. (South Florida Water Management District, 1993.)

model, the South Florida Water Management Model (SFWMM), which includes evapotranspiration, overland flow, ground-water flow, levee seepage, and both surface- and ground-water storage changes. There are varying degrees of uncertainty in the measured and the model estimates. Model results probably overestimate the coastal outflows and underestimate the evapotranspiration in developed areas (South Florida Water Management District, 1993). Although the model is capable of simulating a 25-year period, lack of contiguous structure-flow and canal-flow data in the developed area of the lower eastern coast prevented the development of water budgets for longer than the 10-year period (South Florida Water Management District, 1993, p. C–8). The 1980 through 1989 period includes typical hydroperiods although the entire period is considered to be somewhat dry compared with the long-term average (South Florida Water Management District, 1993).



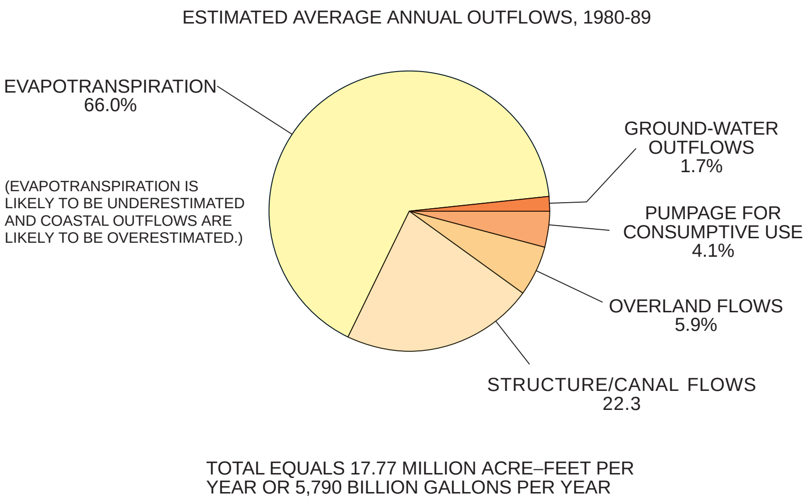


Figure 34. Comparison of estimated average annual inflows and outflows (as percentages) for the modeled region in south Florida. (South Florida Water Management District, 1993.)

The average annual budget summary for the modeled area shows that rainfall dominates inflow and that evapotranspiration dominates outflow *(fig. 34)*. Rainfall directly accounts for 89 percent of the total inflow, and river and stream inflows indirectly account for another 11 percent. Ground water contributes less than 1 percent of the total inflow, and evapotranspiration accounts for 66 percent of the total outflow. Canal discharge to tidewater is the next largest outflow (22 percent). Overland flow, which is primarily to the Shark River and Taylor Sloughs, and pumpage for consumptive use contribute about 6 and 4 percent, respectively, to the average total outflow.

A summary of the water budget *(table 3)* shows a negative change in storage, which indicates more

Table 3. Preliminary estimates of natural water budget, in 1,000 acre-feet, for the lower east coast area, south Florida, 1980-89

[area, 5,814 square miles. From South Florida Water Management District, 1993]

Component	Average annual (Jan.–Dec.)	Wet season (June–Oct.)	Dry season (Nov.–May)	1980–81 (June–May)	1988–89 (June–May)
Rainfall	15,398	9,336	6,050	12,237	13,694
Evapotranspiration	11,729	5,668	6,024	11,359	11,285
Net groundwater outflow	298	150	151	274	289
Structure/tributary outflow	1,794	904	934	473	1,113
Structure/canal outflow	3,956	1,953	2,032	2,857	3,015
Wellfield pumpage	723	301	424	663	847
Net overland outflow	905	583	326	753	1,212
Changes in storage	–338	+1,632	–1,937	–3,526	–1,971

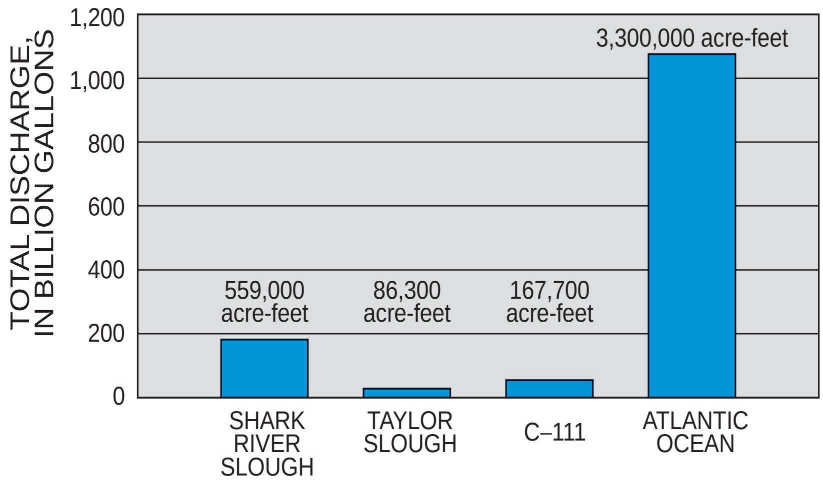


Figure 35. Total discharge to Shark River Slough, Taylor Slough, C–111, and the Atlantic Ocean, 1980-89. (Light and Dineen, 1994.)

outflow than inflow. Most of this change (–338,000 acre-ft/yr) occurs in the Lake Okeechobee part of the model and would amount to a lowering of the lake level by about 5 ft during the 1980s. According to the South Florida Water Management District (1993), the negative change in storage is merely the result of including a low-storage drought year (1989) as the last year in the model simulation. The report indicates that, if a longer time period had been used for the simulation, the change in annual storage would have more nearly approached zero (South Florida Water Management District, 1993, p. 11-10).

Most of the surface-water outflow from the modeled area goes into the Atlantic Ocean *(fig. 35)*. An annual average of 3.3 million acre-ft is estimated to have been discharged to the Atlantic from 1980 through 1989, whereas the combined discharges to the Shark River and Taylor Sloughs and C–111 averaged 813,100 acre-ft. (South Florida Water Management District, 1993; Light and Dineen, 1994). Annual measured discharges to the Atlantic Ocean (1980-89) at the 12 canals shown in *figure 32*, which represents a substantial but incomplete estimate of outflow to the ocean, was about 1.8 million acre-ft or about 1.5 million acre-ft less than the model estimate. Although coastal outflows to the Atlantic Ocean may be overestimated by the model because of uncertainties in the budget (South Florida Water Management District, 1993), the magnitude of the outflows suggest that capture or redirection of these flows represents a potential for additional water supply for Everglades restoration (Light and Dineen, 1994).

Models, like the SFWMM, have proven to be extremely useful management tools in the short term (periods generally less than a few years). Great care must be taken, however, when interpreting the results of simulated decadal-scale processes from models that are designed for short-term management objectives. Oreske and others (1994) observed that verification and validation of numerical models of natural systems is impossible. They concluded that models are most useful when used to challenge existing assumptions, rather than to validate them.

Water and Environmental Stress

As stated throughout this report, drainage and development have had severe environmental effects on the natural system of south Florida. The landscape has been greatly altered, and its natural functions eliminated or changed over large areas. Water quality has deteriorated. The native plant and animal communities have been reduced and stressed by the altered hydrologic system and by competing exotic species. Changes in the natural system also are adversely affecting the growing human population of the region.

Loss of Wetlands and Wetland Functions

Drainage and development have eliminated or severely stressed wetlands in south Florida. About half the original Everglades has been eliminated (Davis and others, 1994). All the custard apple and willow swamps south of Lake Okeechobee (148,260 acres), and most of the peripheral wet prairie (289,110 acres) and the cypress forest (30,000 acres) in the eastern Everglades have disappeared. About 50 percent, or 897, 000 acres, of the sawgrass-slough communities and 24 percent, or 146,000 acres, of the southern

Photo courtesy of the Florida Panther National Wildlife Refuge

marl marshes have been eliminated. Many of the remaining wetlands have been adversely affected by a reduced hydroperiod that has been caused by accelerated runoff in drainage canals. The increased frequency and spatial extent of wetland drying has reduced aquatic production at all levels of the food chain. Compared with the predrainage system, surface-water refugia that support populations of aquatic fauna and their predators during droughts are smaller and fewer and are relocated and subdivided in the currently managed system. In addition, these hydrologic changes have disrupted wading bird nesting, which depends on concentrated food supplies that occur under normal dry-season conditions (Kushland, 1991).

Loss of wetlands in south Florida has significantly reduced landscape heterogeneity, habitat options, and long-term population survival for animals with large spatial requirements. Wading birds, snail kites, and panthers, for instance, have become increasingly stressed by the fragmentation and loss of habitat (Robertson and Frederick, 1994). Wildlife populations generally have declined. At present, 18 species have been designated as threatened or endangered by the U.S. Fish and Wildlife Service and 12 more are under review to determine their status (South Florida Water Management District, 1992). The number of wading birds has decreased from about 2.5 million in 1870 to about 70,000 in 1973 (Crower, 1974). The large decreases in wading birds is a direct result of hydrologic alterations (Kushland and others, 1975).

Drainage and development in south Florida have increased the opportunities for exotic species to become established. Exotic species often compete with and replace native species. Perhaps the most dramatic invasion into the region is the rapid spread of melaleuca tree into the Everglades (Kushland, 1991). Melaleuca was introduced to Florida in the early 1900’s and now grows as dense strands that have replaced native vegetation in parts of the eastern Everglades.

Soil Subsidence

The intensive drainage and associated agriculture south of Lake Okeechobee in the EAA has caused a tremendous loss of organic soils. The compaction and oxidation of organic soils in the agricultural lands south of the lake was one of the first observed environmentally destructive effects of large-scale drainage. In most areas, 5 ft or more of organic soil had been lost by 1984 (Stephens and others, 1984). A recent calculated rate of loss in the EAA is about 1 in/yr (Barry Glaz, Department of Agriculture, written commun., 1994). The maximum thickness of this soil, which is underlain by limestone, was initially only 12-14 ft. The process of oxidative loss of soil continues, although the process has been slowed in some locations by reflooding fallow fields and maintaining a high water table.

Such a large loss of soil has affected hydrology and ecology of the Everglades in many ways. The altitude gradient from the upper to the central Everglades has been greatly affected by the soil loss. The loss of altitude has meant a loss of the hydraulic head that once caused water to flow south. The movement of water from north to south now requires pumpage, and the pumpage effort necessary to move water continues to increase with time as the soil continues to subside. The soil loss also has reduced water-storage capacity, which has caused a reduction in the ability of the area to absorb water and mediate seasonal and long-term variations in rainfall. The problems caused by soil loss are magnified by the enormous spatial extent of the loss. In fact, the loss is not confined to the EAA, but actually extends into the northern parts of WCA–1 and WCA–3A, where additional soil has been lost as a result of the diversion of water.

Degradation of Water Quality

Water quality has been degraded by human activities in large areas of south Florida. Water in urban and agricultural canals commonly has high concentrations of nutrients and toxic compounds compared to water in marshes that are remote from canals. *Figure 36* illustrates the wide variability in the concentration of the nutrient, phosphorus, in south Florida waters. Drainage of nutrient and toxic-ladened water from urban and agricultural lands has degraded lakes, streams, canals, estuaries, and bays of the region.

Urban Lands

A degradation of water quality has been noticeable in recent years in the urban-industrial areas along the eastern coast. Most degradation has been in urban canals, especially during periods of low flow when many of these canals are covered with algae and scum and are choked with aquatic weeds. These conditions have been brought about through the discharge of nutrient-laden sewage and stormwater runoff into canals. Runoff also carries bacteria, viruses, oil and grease, toxic metals, and pesticides into urban canals from which they can be discharged into coastal waters or can enter the ground-water system and the public water supply (Klein and others, 1975).

An ample supply of dissolved oxygen is most important for water of good quality, especially in urban areas where much of the oxygen is used in the decomposition of sewage. In contaminated canals with a luxuriant growth of plants, the dissolved-oxygen content is high during daylight. During the night, however, the dissolved-oxygen content may approach zero as the oxygen is depleted to oxidize sewage. Thus, many urban canals lack popular sport fish, such as bass, and are inhabited instead by gar and mullet, which are able to tolerate low levels of dissolved oxygen (Klein and others, 1975).

Chlorine chemicals, such as polychlorinated biphenyls (PCB’s), dioxin, and furans, which are generated and used primarily in urban and industrial areas, pose serious health hazards to fish, wildlife, and human populations (Colborn and others, 1993). PCB’s are a diverse family of compounds with a wide variety of industrial applications, which include use in transformers, plasticizers, rubber, adhesives, inks, sealants, caulking compounds, and other products. Although most uses of PCB’s have been banned since the late 1970’s, these persistent chemicals are still found in the environment. Dioxins and furans are byproducts of chlorinated industrial processes, which include incineration of hazardous, medical, and solid wastes; chemical manufacturing; plastic production; and chlorine bleaching of pulp and paper. Chlorine chemicals

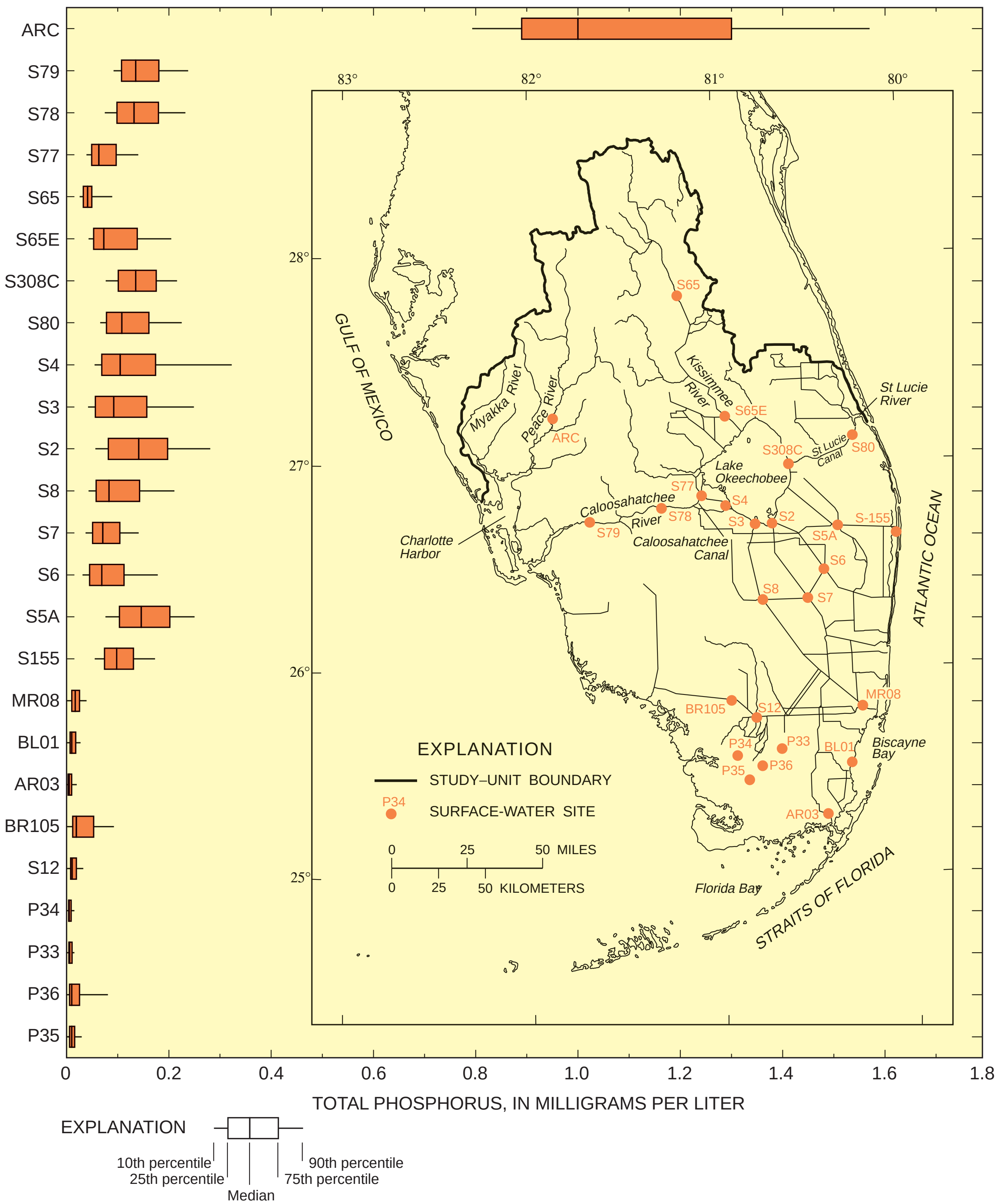
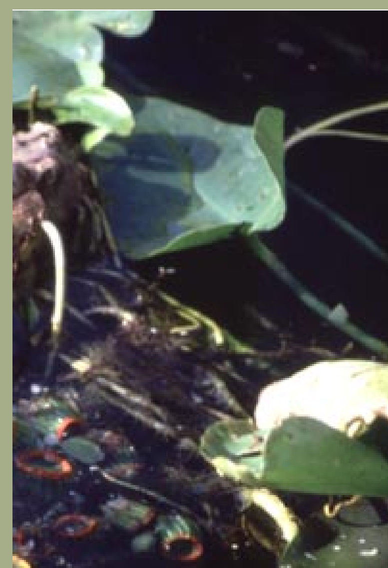


Figure 36. Total phosphorous concentrations in water at selected sites in south Florida, 1984-93.
(All data from South Florida Water Management District, except USGS data at Peace River.)

Floating aquatic plants in a pond bordered by cypress trees.



have long been known to have toxic effects on fish and wildlife, but it has been recently reported that these chemicals can disrupt the endocrine systems of fish and wildlife, which cause such problems as reproductive failure, birth deformities, demasculinization, defeminization and immune system disorders (Colborn and others, 1993).

PCB's are widely distributed in the south Florida environment (Klein and others, 1975). The wide distribution is probably a result of volatization and transport by aerosols and fallout with dust or rain (Pfeuffer, 1991). Concentrations, are probably highest in industrial urban areas. For example, fish from a canal at Miami International Airport contained PCB's in a concentration of 1,000 µg/Kg (Freiberger and McPherson, 1972). The high concentrations of these chemicals in industrial urban areas could pose a hazard for the drinking water supply by entering the shallow Biscayne aquifer (Klein and others, 1975).

Generally, ground water is less susceptible to pollution than surface water because it is filtered as it moves through sediments. However, because contamination in ground water is less readily detected than in surface water, and because of the difficulties associated with working below land surface, the contaminants can become widely dispersed and quite expensive to remediate by the time the magnitude of the problem is recognized. In past years, the prime threat to ground-water quality in south Florida has been that of seawater intrusion in coastal areas and near heavily pumped municipal wells. In recent years, however, seawater intrusion generally has been controlled by providing sufficient freshwater so that adequate high-water levels are maintained near the coast.

Rapid urbanization of the lower eastern coast and growth of agricultural areas pose additional threats of ground-water contamination by manmade liquid and solid wastes and by fertilizers and pesticides. Because of the benefits of seasonally heavy rainfall and dilution, however, the level of contamination probably has been excessive only in some areas. Ground water in the section of the Biscayne aquifer beneath the densely populated urban parts of southeastern Florida contains nutrients and coliform bacteria at shallow depths as a result of effluent from thousands of septic tanks and disposal wells and from seepage from polluted canals. These contaminants presumably have accumulated over the 60 years of urbanization. Although septic tanks operate effectively in the southeast, they provide only partial water treatment. Septic tanks can become ineffective from the lack of periodic maintenance. In such cases, raw wastewater seeps into the aquifer

and causes local pockets of pollution. The recent constraints on the use of septic tanks and the construction of sewer systems to service large urban sectors will further curtail the use of septic tanks in many areas and thereby reduce a potential cause of contamination to the ground-water system.

Solid-waste disposal in dumps poses another, but less widespread, source of pollution of shallow aquifers by contributing leachates from garbage and trash. Many materials in dumps are toxic and nonbiodegradable. Preliminary data from widely scattered study sites in southeastern Florida indicate that local pollution plumes exist downgradient from the dump sites but primarily in the shallow parts of the aquifer. Contaminated ground water near dumps also contains coliform bacteria and nutrients because sludge from many septic tanks and small sewage-treatment plants is disposed at some dumps. Traces of toxic metals and organics also have been found in the shallow ground water beneath the dumps. Because of the high permeability of the aquifer, contaminants can move readily to wells and estuaries in downgradient areas.

Agricultural Lands and Everglades Region

The marshes in the northern Everglades have been replaced, for the most part, by the EAA which includes about 700,000 acres of rich organic soils, most of which has been converted to intensively managed agriculture; the crops are primarily sugar cane and vegetables. Nutrients from the EAA soils are released as the result of periodic drying and oxidation of these organic soils by aerobic bacteria (soil subsidence). Once the soil is oxidized, large quantities of nitrogen and phosphorus are released and transported from these fields during subsequent rains. Nutrients are carried from the field through drainage ditches, water-control structures, and flood-control pumps into EAA canals. Water that drains the EAA farmlands contains low dissolved-oxygen concentrations; high concentrations of nitrogen, phosphorus, chloride, sodium and trace metals; high color; high specific conductivity; and occasional pesticides. Water quality generally is worse during periods of pumping than during those of no discharge.

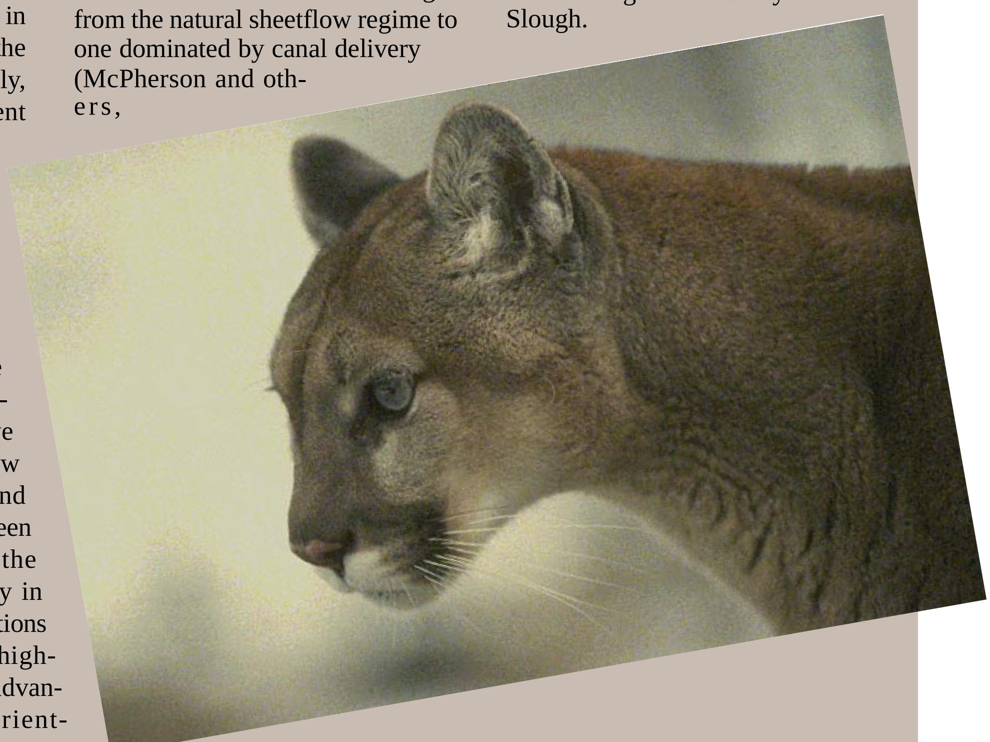
Present water-quality conditions in some northern parts of the Everglades are dramatically different than conditions that existed at the turn of the century. These changes are a result of the disruption of the natural flow patterns by drainage canals and the development of agriculture south of Lake

Okeechobee. Nutrient concentrations in water discharged from canals that drain the EAA are significantly higher than those in the marsh at locations remote from the canals. Average flow-weighted phosphorus concentrations at canal-control structures that discharge to the northern Everglades from the EAA range from 0.10 to 0.25 mg/L and represent a tenfold increase in nutrient levels compared with water at the marsh sites remote from the canals (South Florida Water Management District, 1992).

A number of studies have identified the Everglades marshes of the WCA's as a natural filtration system or nutrient sink that has a purifying, or "kidney effect," by reducing inorganic forms of nitrogen and phosphorus to background levels as the waters flow through the marsh (Jones and Amador, 1992). Much of the introduced nutrients are assimilated or incorporated into sediment and marsh vegetation. The marsh vegetation of the Everglades, however, has a limited capacity for nutrient uptake and is sensitive to small increases in nutrients which are measured in the parts per billion range. Historically, the Everglades was a low-nutrient system, limited primarily by phosphorus. The algae and vascular plants that comprise the marsh system have developed under conditions of low nutrient inputs that are characteristic of pristine rainfall. Sawgrass, a major plant component of the Everglades system, has a low nutrient requirement and is competitive with other vascular plants in a low nutrient environment (Steward and Ornes, 1973 a,b). Sawgrass has been replaced by cattail in parts of the northern Everglades, particularly in WCA–2 where nutrient concentrations are high. Cattails thrive under high-nutrient conditions and have an advantage over sawgrass under nutrient-enriched conditions (Davis, 1991). Algal species and bacterial populations also have changed at nutrient enriched locations in the northern Everglades. These changes include loss of the native periphyton mat, changes in algal species present, phytoplankton blooms, and changes in microbial populations that result in prolonged low dissolved-oxygen concentrations or anoxic conditions (Steward and Ornes 1973 a,b; Swift and Nicholas, 1987). These changes in Everglades vegetation appear to be due to combined effects of nutrient enrichment, hydroperiod change, and fire (South Florida Water Management District, 1992).

There is concern that the nutrient enrichment and ecological disruption in the northern Everglades will spread south and adversely affect the southern Everglades, which includes Everglades National Park. Long-term water-quality data have shown an increase in specific conductance and major ion concentrations within the Shark River Slough in the southern Everglades. These increases are due to changes from the natural sheetflow regime to one dominated by canal delivery (McPherson and others, 1976; Flora and Rosendahl, 1982). No changes in metal concentrations have been observed. Trace levels of pesticides occasionally have been detected in waters that enter the park. However, trace metals and pesticides are only slightly soluble in water and their presence in the park may be mainly in sediments and biota (Ogden and others, 1974). Average flow-weighted phosphorus concentrations discharged into the park from 1979 through 1988 was 0.011 mg/L for the four control structures (S–12's). Although these concentrations are much less than those in the northern Everglades, there is concern that nutrient concentrations at the S–12's may increase unless delivery of water by canals, such as C–67A, is replaced or supplemented by natural sheetflow (South Florida Water Management District, 1992).

Water quality in the southeastern Everglades (the northeastern part of the Shark River Slough, C–111 basin, and the Taylor Slough) is typically good. Flora and Rosendahl (1982) and Waller (1982) reported low nutrient concentrations within the northeastern part of the Shark River Slough and the Taylor Slough.



Current data collected by the SFWMD from 1979 through 1988 indicate that flow-weighted total phosphorus concentrations at S–333 in the northeastern part of the Shark River Slough *(fig. 23)* averaged 0.026 mg/L over the 10-year period of record. Concentrations were highest (0.043 mg/L) during the drought of 1985 as a result of water being routed from Lake Okeechobee to western Dade County well fields through L–29 for water-supply purposes. Total phosphorus values within C–111 at S–18C averaged 0.007 mg/L from 1985 through 1987 and were comparable to values recorded at interior marsh sites. C–111 water, however, contained moderate concentrations of dissolved minerals compared with the Miami and Hillsborough Canals. Canals that drain the urban and agricultural lands that lead to C-111 had detectable levels of such pesticides as atrazine and chlordane (South Florida Water Management District, 1992). The most significant water-quality effects observed within the C–111 basin has been the periodic removal of the S–197 structure from the mouth of the canal to alleviate upstream flooding. This removal released large amounts of freshwater into Manatee Bay, Barnes Sound, and other surrounding estuarine areas and caused severe impacts to marine biota (South Florida Water Management District, 1992).

Lake Okeechobee

Water quality in Lake Okeechobee has been degraded by large-scale inflow from streams that drain agricultural land on the northern side of the lake and by backpumping from canals in the EAA to the south (Klein and others, 1975). Agricultural wastes are washed from farmlands into canals during heavy runoff. During high-water periods, excess water is sometimes backpumped from the EAA into Lake Okeechobee to prevent crop damage. The average concentration of dissolved solids of the inflow from the north and from the EAA is higher than anywhere else in south Florida, excluding the saltwater areas, and at times, it is more than three times the average in the Big Cypress Swamp. The high concentration of dissolved solids is partly the result of irrigating with highly mineralized water (Klein and others, 1975).

Water-quality and biologic data collected in 1969 and 1970 indicate that Lake Okeechobee was in an early eutrophic condition by the late 1960’s (Joyner, 1971; 1974). The rate of eutrophication is of major concern because the lake is the primary surface reservoir in southeast Florida. Overenrichment could seriously impair its water quality and, thereby, affect downstream water users. Joyner (1971) reported that the growth of algae increased greatly between January and July 1970. The dominant species also changed from a green alga, which is indicative of early eutrophic conditions, to a blue-green alga, which is indicative of late eutrophic conditions. Inflow to the lake increased at this time because of channel improvement and accelerated inflow from its major tributary, the Kissimmee River. After channelization of the Kissimmee River, water flow through the flood plain marshes was reduced.

During the last 15 years, phosphorus concentrations have increased 2½ times in Lake Okeechobee; peak levels were reached in 1987-88. Recent occurrences of massive, lakewide blooms of blue-green algae are viewed as another sign that the lake is receiving excessive amounts of nutrients, primarily phosphorus, which threaten the overall health of the lake resources. Preliminary evidence indicates that the lake’s sediments may be losing their ability to assimilate additional phosphorus loadings. Lakewide nitrogen-to-phosphorus ratios also have declined over the same period and may have favored the shift from the normal algal flora of the lake to less desirable blue-green species. These data suggest the lake may be in a phase of transition from its present eutrophic condition to a higher trophic (hypertrophic) state. Loss of the lake as a recreational fishery or potable water supply would be a major economic loss to the region. Phosphorus has been considered to be the key element that controls the growth of these nuisance algae. Therefore, to prevent further eutrophication of the lake, the primary water management strategy has been to limit and control phosphorus inflows (South Florida Water Management District, 1992). Recent research, however, has shown that primary productivity is most often limited by nitrogen or light (N.G. Aumen, South Florida Water Management District, written commun., 1994).

Big Cypress Swamp

The quality of water in the remote, undrained parts of the Big Cypress Swamp is good and probably best reflects south Florida’s pristine water-quality conditions. The Everglades, on the other hand, has been affected more than the Big Cypress Swamp by land-use and water-management practices, and water quality, particularly in the northern part of the Everglades, is of poorer quality than that in the swamp. Most of the water-quality data described below were collected more than 20 years ago.

The concentrations of dissolved solids indicate general water-quality conditions of a freshwater environment. In samples collected in the Big Cypress Swamp in the 1960's, concentrations averaged about 250 mg/L (Klein and others, 1970). In the northern Everglades, for comparison, concentrations at three long-term stations (1950–70) averaged 471 to 541 mg/L (McPherson, 1973). Sources of dissolved solids include limestone, agricultural and urban runoff, salty artesian ground water, and seawater. In the northern Everglades, dissolved solids are attributable primarily to saline ground water and agricultural runoff, whereas in the Big Cypress they are attributable to exposed, soft limestone. Interestingly, dissolved-solids concentrations from samples collected at a long-term station (1950-65, 1969) in the southern Everglades averaged 205 mg/L (McPherson, 1973). The relatively low value probably reflects an environment with little exposed limestone. Concentrations of nitrogen and phosphorus in the surface waters of the Big Cypress also are usually low compared with concentrations in water in the urban and agricultural canals of south Florida (Klein and others, 1970).

Although water quality in the Big Cypress Swamp is good, it has been degraded to some extent by human activities. Canals in the western part of the swamp transport potentially toxic metals to the estuaries in concentrations and amounts that are greater than those transported by overland flow (Little and others, 1970). Magnesium, iron, cobalt, cadmium, copper, zinc, and lead have been concentrated above natural levels in Chokoloskee Bay presumably because of transport down the Barron River and the Turner River Canals from agricultural land to the north (Horvath, 1973; Mattraw, 1973). Concentration of pesticides are low in surface water of the Big Cypress Swamp,

but are concentrated in soils and biota (Klein and others, 1970). Although chloride concentrations tend to be low (averaging about 20 mg/L) in the interior parts of the Big Cypress, high concentrations (as much as 5,350 mg/L) have been detected around several exploration oil-well sites (Wimberly, 1974).

Nutrients transported from drained parts of the Big Cypress Swamp to the estuaries exceed those transported by overland sheetflow in the undrained areas. The Faka Union Canal *(fig. 23)* transports to the estuaries almost 5 times as much Kjeldahl nitrogen (ammonia and organic nitrogen), 10 times as much total phosphorus, and 7 times as much organic carbon as the Fakahatchee Strand transports by sheetflow (Carter and others, 1973). Trace elements concentrated in fine-grained organic sediments (less than 20 microns), also are transported to the estuaries by canals that extend to agricultural land in the north (Mattraw, 1973). Fine-grained sediments are readily transported when canal flow is high and are deposited with mangrove detritus in the estuaries. Because mangrove detritus is a major food source, its enrichment may provide a pathway for the metals to enter into the estuarine and marine food chains (Mathis, 1973).

Metals transported from the drained parts of the Big Cypress Swamp to the estuaries also exceeded those transported by overland sheetflow in the undrained areas. Chokoloskee Bay, which receives heavy metals from the Barron River Canal, has greater loads of these metals in its waters and sediments than more remote bays and estuaries to the south that do not receive canal flows (Horvath, 1973; Mattraw, 1973).

Charlotte Harbor Watershed

Much of the Charlotte Harbor watershed has been altered by human activities. Streamflow has declined significantly during 1934–84 in sections of the Peace River, probably as a result of ground-water pumping in the upper basin. Nutrient concentrations generally have increased in the rivers over the last

15 years because of an increase in wastewater effluent and agricultural runoff. In 1984, 114 facilities were permitted to discharge domestic or industrial effluents to waters tributary to Charlotte Harbor. One of these facilities is in the Myakka River Basin, 11 are in the coastal basin, 14 are in the Caloosahatchee River Basin, and 88 are in the Peace River Basin. Citrus and phosphate-ore processing account for most of the industrial effluent. Several locations in the headwaters of the Peace River show significant effects of receiving wastewater effluent. At some locations, dissolved-oxygen concentrations were lower than 2.0 mg/L, which is the minimum State standard for any class of surface water (Hammett, 1990).

The water quality of several lakes in the headwaters of the Peace River has been affected by citrus-processing effluent (Hammett, 1990). Citrus processing produces a strongly buffered, high carbon waste that can contain inorganic debris from washing, and can have a residue of pesticides and toxic peel oils (Lackey, 1970). The degradation of the waste produces objectionable odors and a high biochemical oxygen demand. Citrus production involves the use of numerous chemicals that include fertilizers, insecticides, herbicides, and fungicides. Benomyl, bromocil, diuron, dicofol, chlorobenzilate, ethylene dibromide, and aldicarb have been used or are currently in use. The trace elements copper, manganese, and zinc also are applied to citrus (Rutledge, 1987). Runoff or ground-water seepage from citrus groves has the potential of transporting any of these substances to the stream system.

The concentrations of phosphorus are naturally high in the Peace River because of extensive phosphate deposits in its basin. The phosphate deposits also are rich in radionuclides of the uranium–238 series, including radium–226. In the upper basin, these deposits are exposed in the riverbed. Extensive phosphate mining and processing have exposed additional deposits to surface runoff. Periodic spills of phosphate industry sediments are caused by the structural failure of retaining dikes and have resulted in the discharge of clayey wastes, known as slime, to the Peace River and has contributed additional phosphorus and radium–226 to the river and estuary. A single spill can contribute a phosphorus load equal to the annual loading in the Peace River at Arcadia (Miller and McPherson, 1987). The effects of these slime spills have been seen as long as 2 years after the event (Martin and Kim, 1977).

In phosphate ore processing plants, a mixture of organic chemicals, which include kerosene and fuel oil, is used to facilitate separation of phosphate ore from unwanted sands and clays. Runoff from sand tailings may represent diffuse sources of organic-chemical contamination (Rutledge, 1987). The chemical processing of phosphate ore into phosphoric acid produces a highly acidic process water. Organic chemicals, which include phenols, also are used in processing. The gypsum stacks, cooling ponds, and recirculation ditches of the chemical-processing plants are a potential source of contamination of the surficial aquifer (Miller and Sutcliffe, 1984). Runoff from phosphate mines may increase turbidity and significantly reduce light in the receiving bodies of water (Miller and Morris, 1981).

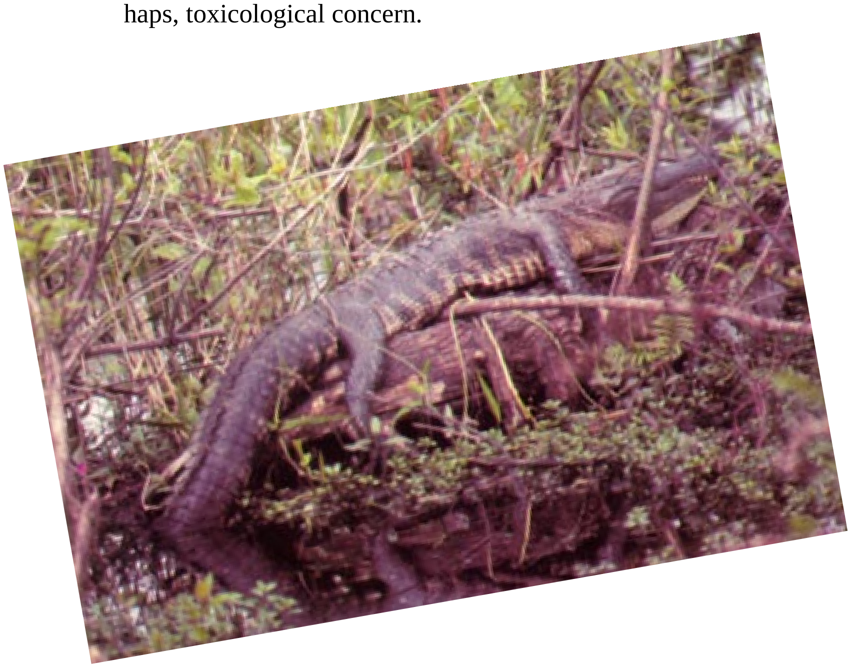
There are other potential sources of nutrient and pollutant loads to the Charlotte Harbor watershed. Ground-water inflow to the rivers and Charlotte Harbor is an apparent source of radium–226 (Miller and Sutcliffe, 1985; Miller and others, 1990). Background levels of radium–226 in the rivers and Harbor reported by Miller and others (1990) are an order of magnitude higher than those found in other parts of the United States (Elsinger and Moore, 1980; 1983; 1984). Runoff from pastures and cropland carries nutrients and, in some cases, pesticides to the river system. Septic-tank drainfields are another source of nutrients and a potential source of bacterial contamination. Runoff from urban areas may carry heavy metals, nutrients, bacteria, viruses, and pesticides. Marinas contribute oil and gas, as well as wastewater and metals, to the rivers and estuarine system. Rainfall and dustfall bring contaminants and nutrients by air to the river system and estuary.

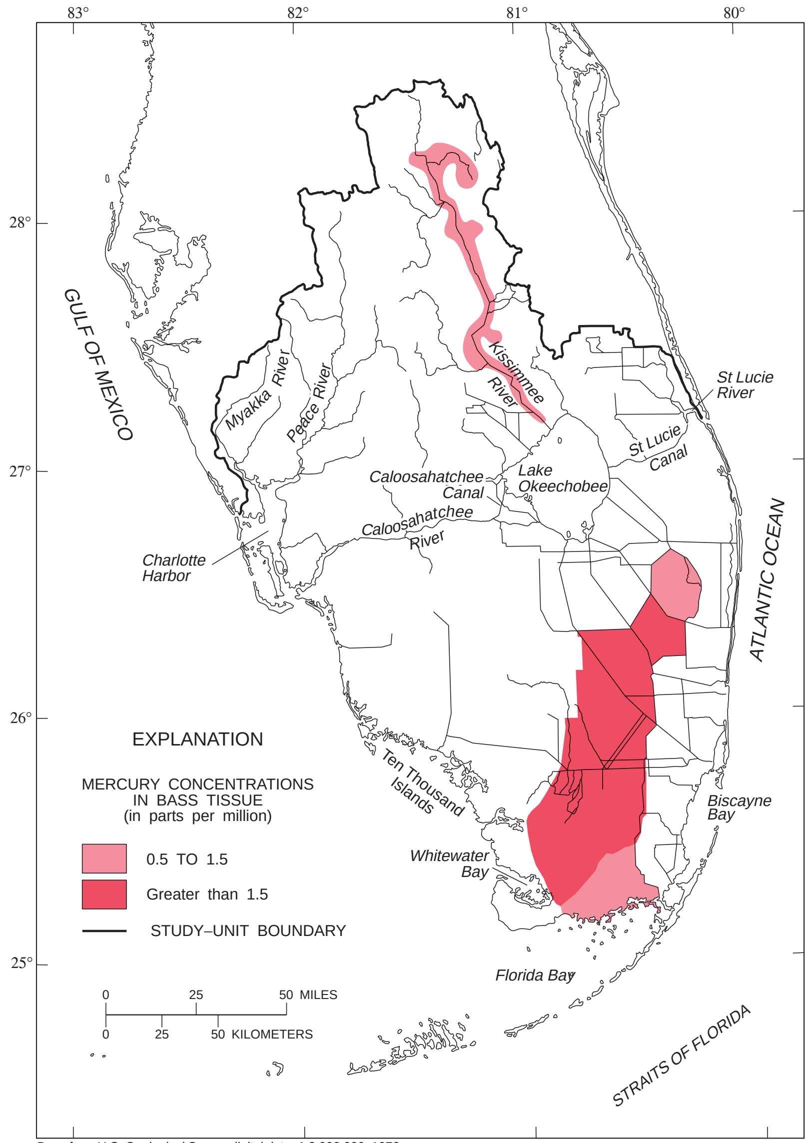
Numerous deep wells under high artesian pressure, drilled into the Floridan aquifer system many years ago, have been a source of brackish water contamination of shallow aquifers in southwestern Florida and south of Lake Okeechobee (Parker and others 1955; McCoy, 1972). These wells were not cased deeply enough or else the casings have corroded, allowing brackish water that is under pressure from the Floridan aquifer system to move upward along open well bores or through corroded sections and seep outward to contaminate large parts of shallow aquifers (Klein and others, 1964; Sproul and others, 1972).

Mercury Contamination

Mercury contamination is a significant problem for aquatic organisms and predators as well as a potential health risk for humans. Many lakes in the northern United States, southern Canada, and Scandinavia are affected by mercury contamination (Mierle, 1990; Hurley and others, 1991; Lindquist, 1991). Florida and 27 other states have issued health advisories that restrict consumption of fish because of high levels of mercury (Tom Atkeson, Florida Department of Environmental Regulation, written commun., 1992). The problems with mercury relate to two factors—mercury biomagnifies in the food chain to toxic concentrations, even though it is found at very low (sub-nanogram–per–liter) concentrations in water; and mercury is transported and deposited through atmospheric processes and is, thus, widely distributed. Methylmercury is the more toxic bioaccumulative species. As a result of environmental changes, increased rates of methylation may be contributing to toxic mercury problems. For example, a change from an aerobic to an anaerobic environment would favor increased mercury methylation (Winfrey and Rudd, 1990; Gilmour and Henry, 1991) and mercury uptake in the biota. Because of the existing burden of mercury in the environment, recycling of mercury between demethylated and methylated forms can provide a source of methylmercury even if atmospheric deposition ceased. However, estimates indicate that atmospheric mercury concentrations have nearly doubled over the last 50 years (Fitzgerald and others, 1991; Slemr and Langer, 1992). Increasingly evident is the fact that even modest increases in atmospheric deposition can translate into mercury levels in organisms that are of ecological and, perhaps, toxicological concern.

High levels of mercury have been measured in fish *(fig. 37)* and wildlife in south Florida, particularly in the Everglades. Roughly 1 million acres of the Everglades are under a health advisory that recommends that anglers and others completely avoid consuming large mouth bass and several other species of fish (Lambou and others, 1991). Mercury body burdens of large mouth bass collected in the Everglades were higher than those taken at Superfund sites noted for mercury contamination (Dan Scheidt, U.S. Environmental Protection Agency, personal commun., 1992). Alligators harvested from the Everglades cannot be sold for human consumption because of elevated mercury levels in their tissue. In 1989, a Florida panther died from mercury toxicosis (Lambou and others, 1991), and mercury is suspected as the causative agent in the deaths of two other panthers. Analysis of raccoons, a major prey of panthers, from certain areas of south Florida revealed very high concentrations of mercury in liver and muscle tissues (Lambou and others, 1991).





Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
Albers Equal-Area Conic projection
Standard Parallels 29°30′ and 45°30′, central meridian -83°00′

Figure 37. Areas in south Florida where mercury concentrations in large-mouth bass tissue equaled or exceeded one-half parts per million. (Lambou and others, 1991.)

The severity of the mercury problem in the Everglades may be the result of a combination of factors. Concerns are focused on two potential sources of the problem—local effects of municipal incinerators and other emission sources on the southeastern coast of Florida, and possible increased release of mercury or increased methylation of mercury from soils in the Everglades as a result of drainage and soil disturbance (Tom Atkeson, Florida Department of Environmental Regulation, written commun., 1992).

Additional research on mercury in south Florida continues. The Electric Power Research Institute, Florida Power and Light, and the Florida Department of Environmental Protection are currently funding a project to determine atmospheric deposition patterns and rates of mercury deposition in the region. The U.S. Environmental Protection Agency has initiated a study of mercury in the Everglades with the goal of establishing spatial trends of mercury concentrations in water, sediment, and biota. The USGS is planning research in the Everglades on processes that control mercury transport and cycling. Research studies are being planned by the State in the northern Everglades where a nutrient-removal project is underway as a result of concern that the effects of nutrient removal will promote the release of sediment-bound mercury or an increase in the methylation of mercury.

The result of a recently completed study in which 50 sediment cores were taken across the Everglades indicate that mercury accumulation rates increased about sixfold between 1900 and 1992 (Delfino and others, 1993). The greatest increases in mercury concentrations were in the northern Everglades, and the timing of the increases corresponded fairly well with alterations of Everglades hydrology and with agricultural and urban development in south Florida.

Effects on Estuaries, Bays, and Coral Reefs

Changes in coastal estuaries are due, in part, to such factors as an overall reduction of the amounts of freshwater flow through the Everglades, the effects of constructing levees and canals near the coast to provide drainage and flood protection, the changes in the quality of runoff water, and the maintenance of lower ground-water levels along the southeastern coast (Smith and others, 1989; Halley and Hudson, 1993). Although the amount of flow reduction is disputed, the effects of drainage activities are observed in the encroachment of mangrove forests into northern Everglades National Park in recent years, the replacement of freshwater marshes by saltwater marshes, and the decline of coastal mangrove forests in areas that have been deprived of natural overland flow. Today, many of these coastal estuaries, especially along the southeastern coast and the central part of Florida Bay, frequently experience hypersaline conditions during the dry season (Davis and Ogden, 1994; McIvor and others, 1994).

Water management has resulted in more short-duration, high-volume water flow and less life-sustaining base flows to estuaries. Regulatory releases to control lake and ground-water levels according to prescribed flood-prevention formulae result in pulses of freshwater entering estuaries, causing rapid, drastic decreases in salinity that stress estuarine organisms. In addition, water flows have been diverted from one receiving basin to another, which changes the long-term salinity regimes in both systems. The combined effects of reduced freshwater inflow to Florida Bay as a result of man's alteration of the natural flow regime and the natural evaporation of water in this semiconfined embayment, have resulted in salinities that can be more than double those of the open ocean. Widespread chronic hypersalinity in the bay is extreme and frequently reaches 50 ppt over large areas, with known maximums of 70 ppt in small areas during severe drought (Tabb and others, 1962; Tabb, 1963). Biscayne Bay sometimes exhibits negative, or reverse, salinity gradients, with hypersaline conditions inshore. On the other hand, salinities in Manatee Bay have declined from 36 to 0 ppt in a matter of hours as a result of an abrupt release of freshwater.

Florida Bay has undergone changes during the last decade that are unprecedented within the period of recorded observation and that reflect a degradation of the ecosystem, in terms of its productivity of living resources, biodiversity, and stability (Bancroft, 1993; Boesch and others, 1993). Seagrasses have died in large areas (Robblee and others, 1991) and microscopic algae have bloomed with increasing frequency and intensity, thus turning the once clear waters a turbid green. Populations of water birds, forage fish, and juveniles of species of game fish seem to have been significantly reduced, catches of pink shrimp have declined, and many sponges have died, causing a potential threat to the catch of spiny lobsters. These and other ecological alterations in the Bay were recently summarized in a research plan by the Interagency Drafting Committee (unpublished, 1994). Because the freshwater flow through the Everglades into Florida Bay has been greatly reduced by consumptive use and watershed drainage (McIvor and others, 1994), much concern has been directed to flow reduction as the root cause of the deterioration of the bay ecosystem. However, other causes may be implicated in changes in the bay; for example, nutrient stimulation from internal sources (benthic sediment releases) and external sources (runoff and seepage from the land) (Lapointe and Clark, 1992) and natural influences, such as the diminished frequency of tropical storms in the vicinity of the bay (Boesch and others, 1993).

The amount and distribution of nutrients that flow into coastal waters of south Florida are extremely important to the health of the bays, estuaries, and reefs (Lapointe and others, 1990; Fourqurean and others, 1992; Lapointe and Clark, 1992). Denitrification in Everglades sediments is not an effective means of removing excess nitrogen that may be introduced as nitrate into coastal waters (Gordon and others, 1986). The flow of freshwater and nutrients from urban and agricultural lands, extensive mangrove and marsh wetlands, and phosphate-rich river waters of southwestern Florida may create a blend of water that contains adequate concentrations of nutrients to support algal blooms and enrichment in the western part of Florida Bay. In addition, if freshwater flow to the Atlantic Ocean is rediverted to the Gulf of Mexico and Florida Bay, as is being discussed as part of the Everglades restoration plan, then nutrient loading to the bay and gulf might substantially increase.

In much of Florida Bay, the Florida Keys, and the reefs, the quality of marine water is widely recognized as important, if not more important, than restoring freshwater flow to Florida Bay (Hallock and others, 1993). Continued residential development in the Florida Keys will intensify problems of increased stormwater runoff, septic tank and disposal well leachate, and nutrients and heavy metal contamination from marinas and live-aboard vessels within the Florida Keys area. The EPA and NOAA Florida Keys National Marine Sanctuary prepared a plan to deal with the continuing development and associated water-quality changes (U.S. National Oceanic and Atmospheric Administration, 1995). However, significant changes in water quality may have already taken place, as indicated by the seepage of sewage components in marine ground water offshore from the Keys (Shinn, 1993; Shinn and others, 1994).

Changes in Florida coral reefs *(fig. 38)* have received increasing attention during the last decade (Ward, 1990). Some damage to the reef corals by ships or divers, for example, may be easily related to human intervention (Hudson and Diaz, 1988; Talge, 1992). Other changes, however, are slower and pose difficulties in determining their ultimate cause. For example, coral mortality is often the result of disease, such as "bleaching" that results when symbiotic algae are expelled from the coral tissue, thus causing the corals to lose their color (Brown and Ogden, 1993).

In the last two decades, coral diversity and the amount of seafloor inhabited by coral has declined in the reef tract off the northern Florida Keys (Dustin and Halas, 1987; Porter and Meier, 1992). The decrease in general coral health has been variously attributed to global warming, nutrient increases, disease, and hypersaline water. These possible causes have not been fully documented. Some changes on the reefs are difficult to identify with local, regional, or global change. Some of the observed change may be related to widespread change throughout the Caribbean (Rodgers, 1985) or may be the result of more local causes. The U.S. Environmental Protection Agency is currently funding studies to monitor reef and hard-bottom community changes in the Florida Keys National Marine Sanctuary (Continental Shelf Associates, Inc., 1995).

Figure 38. Long-term changes on a coral reef community are illustrated by photographs taken in 1976 and 1992 at the same location on a reef near Key Largo. The thick growth of staghorn coral (Acropora cervicornis) *evident in 1976 had largely disappeared in 1992. This change may be natural or related to human activities.* (E.A. Shinn, written commun. 1993.)

Summary and Research Needs

When Europeans first arrived in south Florida, the region was a lush, subtropical wilderness of pine forest, hardwood hammocks, swamps, marshes, estuaries, and bays. Wetlands dominated the landscape. The region contained one of the largest wetlands in the continental United States, the Everglades, which was part of the larger Kissimmee–Okeechobee–Everglades watershed that extended more than half the length of the Florida Peninsula. The Everglades and the Big Cypress Swamp stretched as a continuous wetland across the southern part of the peninsula south of Lake Okeechobee. These wetlands and the entire watershed provided the freshwater that sustained highly productive estuaries and bays of the region.

Drainage of the Everglades watershed began in the early 1880's and continued into the 1960's. The first drainage canals were dug in the upper Kissimmee River and between Lake Okeechobee and the Caloosahatchee River. Beginning with the Miami River in 1903, canals were cut through the Atlantic Coastal Ridge and into the northern Everglades. By the late 1920's, five canals had been dug between Lake Okeechobee and the Atlantic Ocean—one that passed north of the Everglades and connected the lake with the St. Lucie River and four that passed through the Everglades. Drainage opened land for agriculture to develop south of Lake Okeechobee. In the late 1920's, a low muck levee was constructed along the southern and southwestern shore of the lake to prevent flooding, but during the hurricanes of 1926 and 1928, the levee was breached, which resulted in destruction of property and lives. In response to these catastrophes, the Federal Government initiated flood-control measures that included construction of levees around the southern shore of Lake Okeechobee and enlargement of the Caloosahatchee and the St. Lucie Canals.

Drainage and development altered most of south Florida and caused severe environmental changes. These changes include large losses of soil through oxidation and subsidence, degradation of water quality, nutrient enrichment, contamination by pesticides and mercury, fragmentation of the landscape, large losses of wetlands and wetland functions, and widespread invasion by exotic species. Additionally, the large and growing human population and the active agricultural development in the region are in intense competition with the natural system for freshwater resources.

Recently, a consensus has begun to emerge among Federal and State agencies, as well as among environmental groups, that the Everglades should be restored to patterns similar to the original system. For concerned parties to discuss, let alone to implement, such recommendations requires a substantial increase in available scientific data and understanding of Everglades hydrology, geology, and ecology. The investigations needed to support restoration, which have been developed by the Science Sub–Group of the South Florida Ecosystem Task force, include hydrologically characterizing the predrainage system and comparing it to the present system; determining the key characteristics of the former natural hydrologic system that supported the rich diversity and abundance of wildlife that has been lost; designing structural and operational modifications of the Central and Southern Florida Project for Flood Control and other Purposes (C&SF) that would recreate the key characteristics of the natural hydrologic system; assessing the hydrologic and ecological results of these modifications through pre- and post-modification monitoring; and modifying the design of the C&SF project based on the assessment and monitoring of the hydrologic and ecological results of the changes.

The USGS is providing some of the scientific information necessary for protection and restoration in south Florida through several of its programs, which include the South Florida Initiative and the NAWQA Program. The U.S. Geological Survey is coordinating these efforts with other Federal agencies through the South Florida Ecosystem Interagency Working Group and the Science Sub–Group and through regularly scheduled liaison meetings of the Southern Florida NAWQA study unit. The South Florida Initiative is a collaborative effort by the U.S. Geological Survey, the fromer National Biological Service, and other Federal and State agencies to provide scientific insight into conflicting land-use demands and water supply issues in the south Florida, Florida Bay, Florida Keys ecosystem (McPherson and others, 1995). The proposed U.S. Geological Survey contributions include the following:

- Assessing the availability of water for competing requirements (public water supply, agriculture, fisheries, ecosystem protection/restoration) in south Florida and the Florida Bay area by measuring and modeling the movement of water.

- Assessing the water quality within south Florida, Florida Bay, and the Keys/Reefs by collaborating with other planned efforts and focusing on the additional needs for information, such as identifying processes that transform and transport nutrients and mercury.

- Determining the “natural state” of the south Florida regional ecosystem, which include the estuaries, bays, and coral reefs and their watershed.

- Developing a comprehensive and readily accessible quality-assured relational data base for spatial and point data, which include water, geology, soils, topography, vegetation, and remotely sensed data to support scientific investigation.

Regardless of the information obtained and the effort expended, the success of ecosystem restoration is uncertain because of the complexity of the interaction between the biological and abiotic components of the system. In writing about the Everglades, Davis and Ogden (1994, p. 789) state “This uncertainty of information becomes another force in support of a broad restoration premise; restoration of hydrology and natural environmental fluctuations is an appropriate target in the stepwise and still imprecise process of attempting to produce ecological restoration.”

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