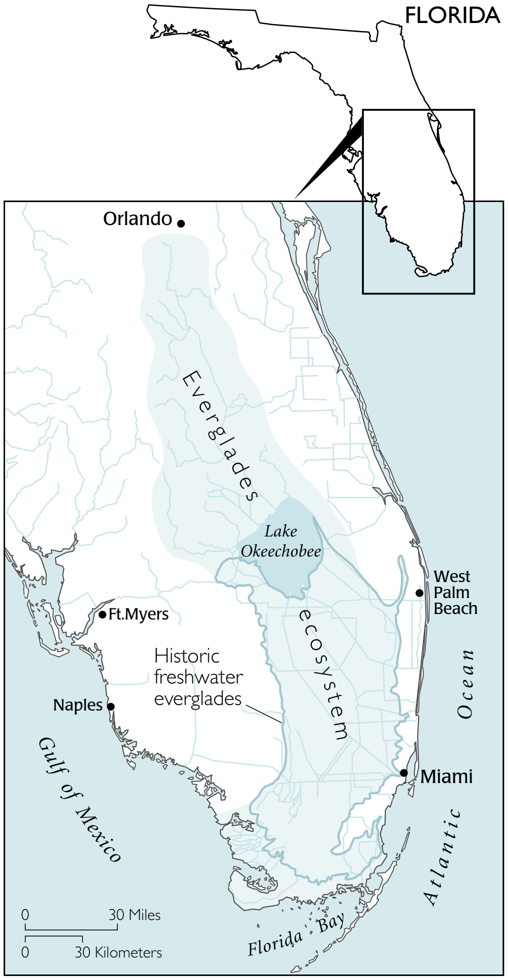
FLORIDA EVERGLADES

Subsidence threatens agriculture and complicates ecosystem restoration



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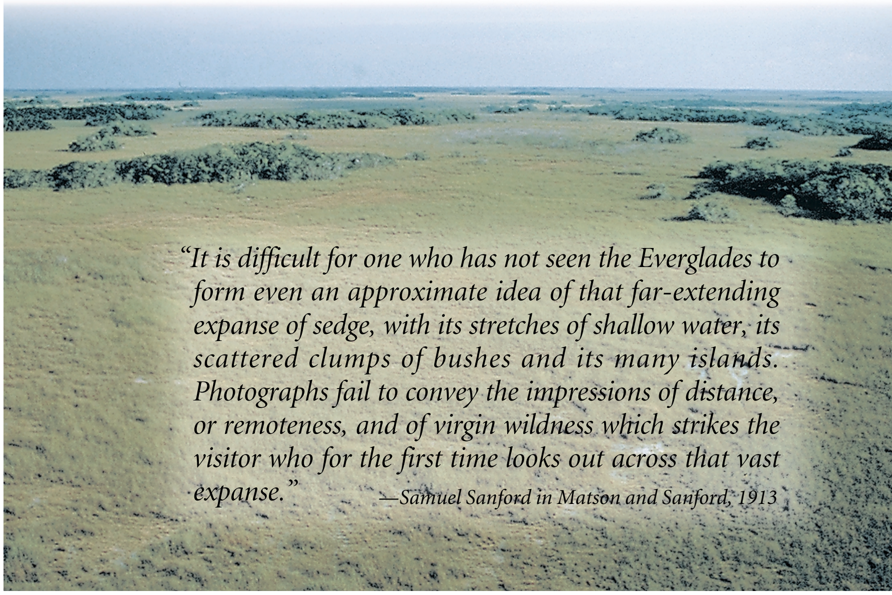
The Everglades ecosystem includes Lake Okeechobee and its tributary areas, as well as the roughly 40- to 50-mile-wide, 130-mile-long wetland mosaic that once extended continuously from Lake Okeechobee to the southern tip of the Florida peninsula at Florida Bay.

Since 1900 much of the Everglades has been drained for agriculture and urban development, so that today only 50 percent of the original wetlands remain. Water levels and patterns of water flow are largely controlled by an extensive system of levees and canals. The control system was constructed to achieve multiple objectives of flood control, land drainage, and water supply. More recently, water-management policies have also begun to address issues related to ecosystem restoration. Extensive land subsidence that has been caused by drainage and oxidation of peat soils will greatly complicate ecosystem restoration and also threatens the future of agriculture in the Everglades.



> *"It is difficult for one who has not seen the Everglades to form even an approximate idea of that far-extending expanse of sedge, with its stretches of shallow water, its scattered clumps of bushes and its many islands. Photographs fail to convey the impressions of distance, or remoteness, and of virgin wildness which strikes the visitor who for the first time looks out across that vast expanse."*
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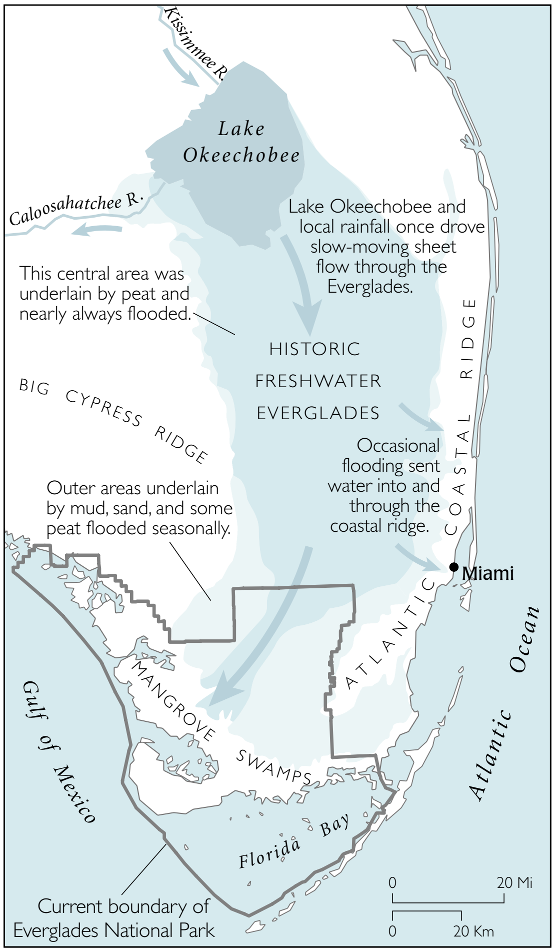
> *—Samuel Sanford in Matson and Sanford, 1913*

NATURAL FLOW PATTERNS (c.1900)



The Everglades were formed in a limestone basin, which accumulated layers of peat and mud bathed by freshwater flows from Lake Okeechobee.

> *"The outline of this Florida end-of-land, within the Gulf of Mexico, the shallows of the Bay of Florida and the Gulf Stream, is like a long pointed spoon. That is the visible shape of the rock that holds up out of the surrounding sea water the long channel of the Everglades and their borders. The rock holds all the fresh water and the grass and all those other shapes and forms of air-loving life only a little way out of the salt water, as a full spoon lowered into a full cup holds two liquids separate, within that thread of rim."*
>
> —*Marjorie Stoneman Douglas, 1947*

The Everglades ecosystem has, in fact, been badly degraded, despite the establishment of Everglades National Park in the southern Everglades in 1947. Prominent symptoms of the ecosystem decline include an 80 percent reduction in wading bird populations since the 1930s (Ogden, 1994), the near-extinction of the Florida panther (Smith and Bass, 1994), invasions of exotic species (Bodle and others, 1994), and declining water quality in Florida Bay, which likely is due, at least in part, to decreased freshwater inflow (McIvor and others, 1994).

Everglades National Park was created in 1947.

HISTORIC FLOWS WERE SEVERED

A thin rim of bedrock protects south Florida from the ocean. The limestone bedrock ridge that separates the Everglades from the Atlantic coast extends 20 feet or less above sea level. Under natural conditions all of southeast Florida, except for a 5- to 15-mile-wide strip along this bedrock ridge, was subject to annual floods. Much of the area was perennially inundated with freshwater. Water levels in Lake Okeechobee and local rainfall drove slow-moving sheet flow through the Everglades under topographic and hydraulic gra-

Hoover dike (center) was built with digging spoils obtained from a navigable channel (foreground). Lake Okeechobee is at the top of photo.

dients of only about 2 inches per mile. Lake Okeechobee, which once overflowed its southern bank at water levels in the range of 20 to 21 feet above sea level, today is artificially maintained at about 13 to 16 feet above sea level by a dike system and canals to the Atlantic and Gulf coasts.

Early agriculturalists began the drying process

The first successful farming ventures in the Everglades began in about 1913, not on the sawgrass plain itself but on the slightly elevated natural levee south of Lake Okeechobee (Snyder and Davidson, 1994). Early efforts to clear, farm, and colonize the sawgrass area had little success, being plagued by flooding, winter freezes, and trace-nutrient deficiencies. (The soil beneath the sawgrass was later shown to be too low in copper to support most crops and livestock.)

In the 1920s the State of Florida established an Everglades Experiment Station in Belle Glade, and the U.S. Department of Agriculture established a Sugarcane Field Station in Canal Point. The combined efforts of these units gradually solved the plant- and livestock-pathology problems experienced by early farmers. However, the land was still subject to frequent, sometimes catastrophic inundation. The great hurricane of 1928 caused at least 2,000 fatalities and flooded the Everglades Experiment Station for several months.

The damage caused by the 1928 hurricane convinced the Federal government to fund construction of a permanent dike around the southern perimeter of Lake Okeechobee. This more secure protection from flooding cleared the way for intensive settlement of the Everglades. It also permanently severed the natural connection between the Everglades proper and its headwaters. For millennia, the Everglades had been fed by intermittent, diffuse overflow of the imperfect natural levee south of the Lake. Now, its primary water source, other than local rainfall, would be a system of artificial canals.

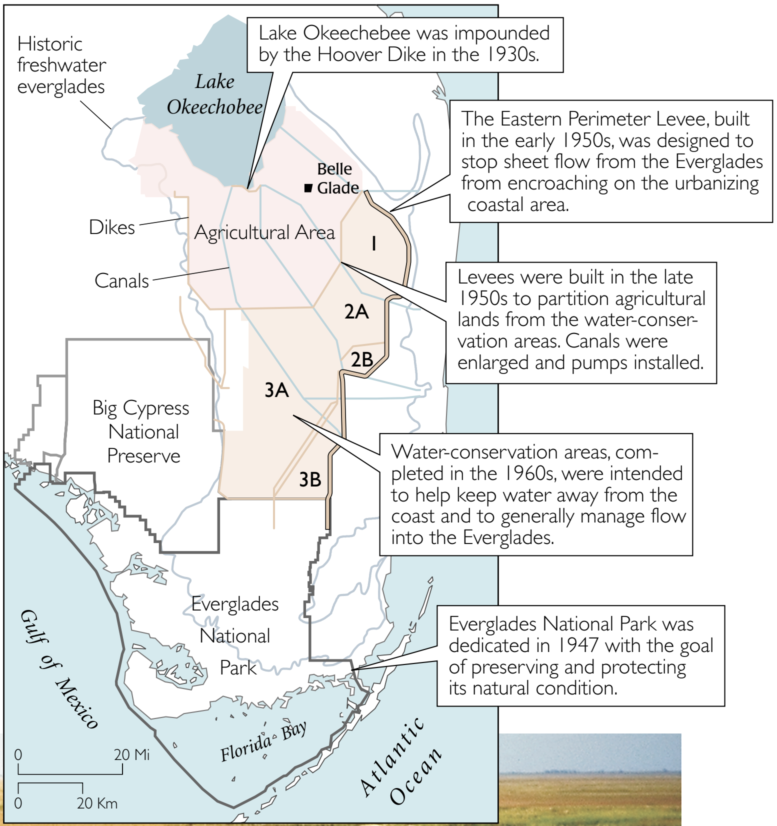
A network of dikes and canals controls water movement, providing optimum irrigation and drainage for sugar cane (left).

Further water-management efforts accelerated development

A comprehensive Federal-State water-management effort in the 1950s and 1960s was prompted by drought and widespread fires in 1944 to 1945 and renewed flooding in 1947 to 1948. The primary motivation was flood control and water supply for the growing urban areas along the Atlantic coast. The drying of the Everglades had clearly contributed to rapid saltwater intrusion in these urbanizing areas during the drought.

A regional flood-control district, the predecessor of today's South Florida Water Management District, was created by the State of Florida in 1949 to manage a coordinated water system. The urbanizing areas that extended west of the natural bedrock ridge were protected from flooding by a high levee known as the "eastern perimeter levee." Although it was originally built to protect and promote development of urbanizing areas along the southeastern

Water-control projects in the Everglades began in the early 1900s. After the fires and floods of the 1940s, much larger water-management projects were implemented.



Lake Okeechobee was impounded by the Hoover Dike in the 1930s.

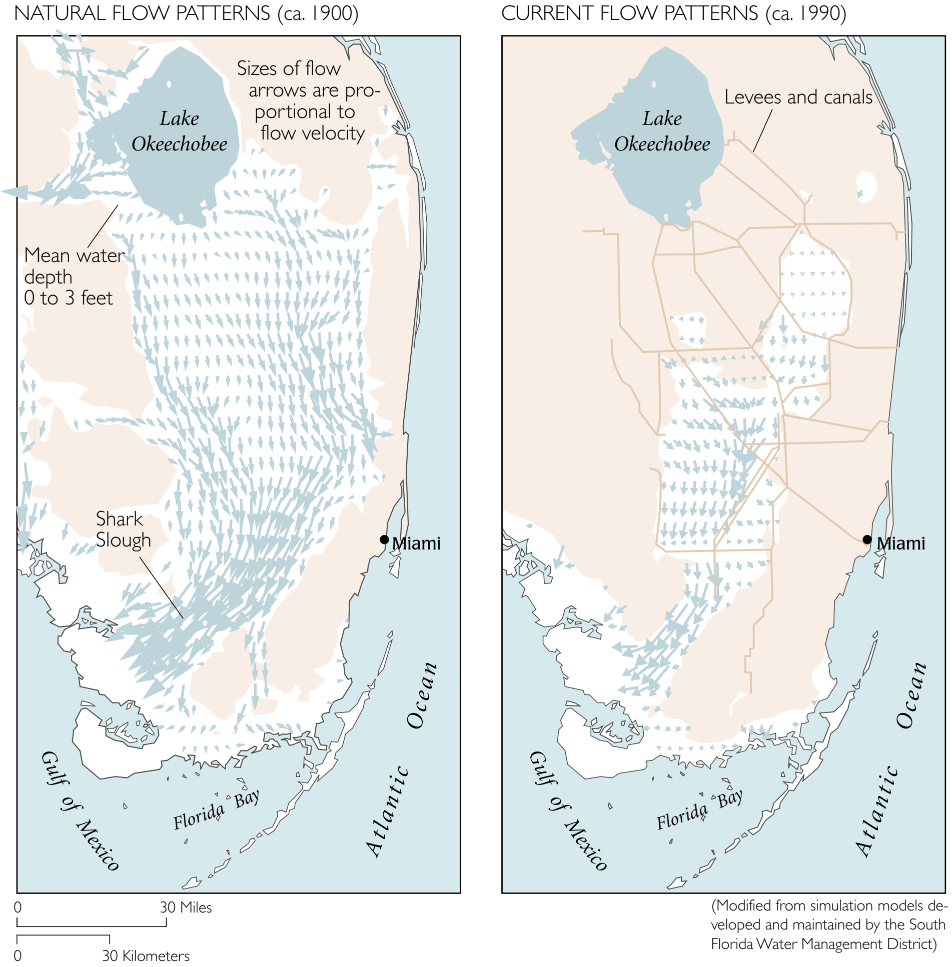
The Eastern Perimeter Levee, built in the early 1950s, was designed to stop sheet flow from the Everglades from encroaching on the urbanizing coastal area.

Levees were built in the late 1950s to partition agricultural lands from the water-conservation areas. Canals were enlarged and pumps installed.

Water-conservation areas, completed in the 1960s, were intended to help keep water away from the coast and to generally manage flow into the Everglades.

Everglades National Park was dedicated in 1947 with the goal of preserving and protecting its natural condition.

Water conservation area 2A is mostly covered with sawgrass.



(Modified from simulation models developed and maintained by the South Florida Water Management District)

Water management has brought significant changes to natural overland flow patterns.

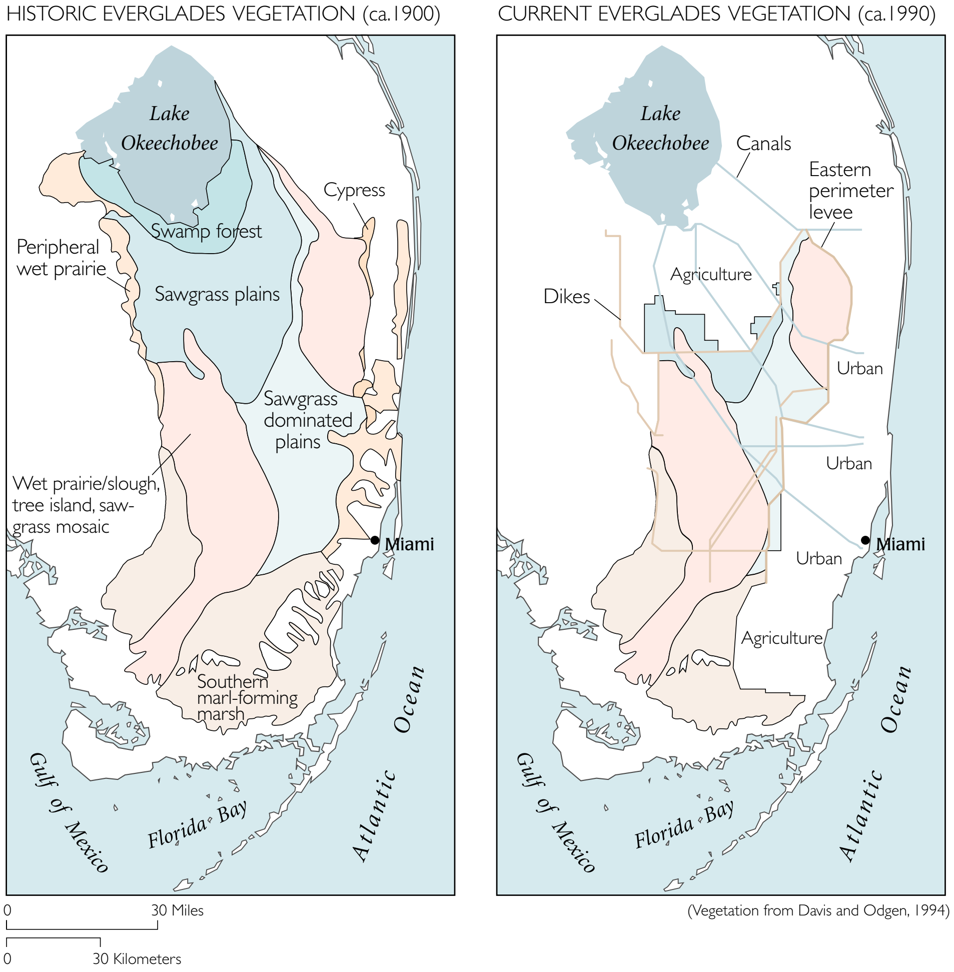
Under natural conditions surface water moved from Lake Okeechobee southward, then turned southwest through a constricted area called Shark Slough.

After canals and dikes were constructed for the agricultural and water-conservation areas, sheet flow practically disappeared from the northern Everglades and diminished to the south.

coast, this levee has, ironically, become the only effective barrier to more extensive urban development of the Everglades (Light and Dineen, 1994).

An area of thick peat soil south of Lake Okeechobee was designated the "Everglades agricultural area." Farther south, other areas of peat soils less suitable for agriculture were designated as "water-conservation areas." These areas are maintained in an undeveloped state, but a system of dikes and canals allows water levels to be manipulated to achieve management objectives that include flood control, water supply, and wildlife habitat.

During dry periods, the level of Lake Okeechobee drops as water is released to provide water to the agricultural area, to canals that maintain ground-water levels in urban areas along the Atlantic coast, and to Everglades National Park. At other times, drainage water pumped from the agricultural area is released into the water-conservation areas, providing needed water but also undesirable amounts of the nutrient phosphorus. In recent years, "best management practices" have helped reduce phosphorus loads from the agricultural area. The managed part of the remaining Everglades—approximately the northern two-thirds—now consists of a series of linked, impounded systems that are managed individually.



(Vegetation from Davis and Odgen, 1994)

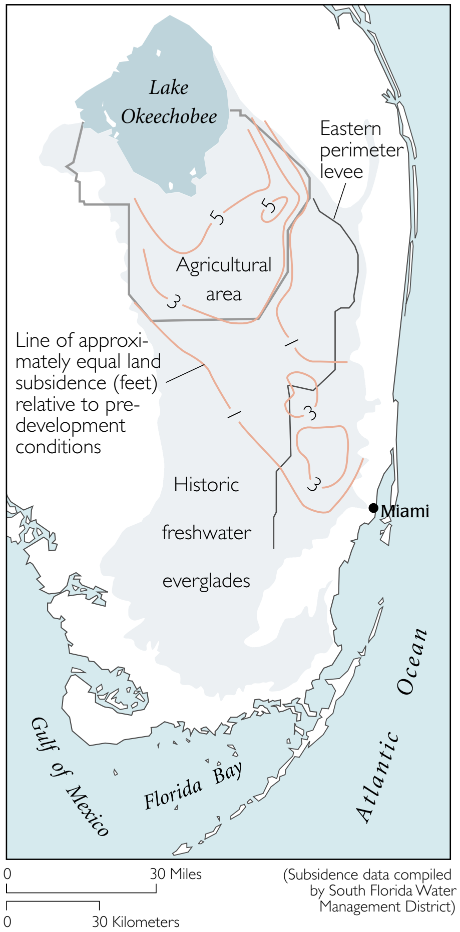
Water management has also changed vegetation patterns. The construction of canals and levees and subsequent draining and development of the land has all but eliminated natural vegetation in the agricultural area and the region east of the eastern perimeter levee.

Land subsidence followed in the wake of development

With the addition of trace nutrients, the peat soil or "muck" beneath the sawgrass proved extremely productive. But the farmers also saw

> "... the cushiony layer of dark muck shrink and oxidize under the burning sun as if it was consumed in thin, airy flames. As the canals and ditches were extended by the local drainage boards, and the peaty muck was dried out and cultivated, it shrank ... It is still shrinking. Every canal and ditch that drained it made a long deepening valley in the surrounding area. On the east and south the subsidence was so great that half that land [drains towards] the lowered lake."
>
> —Marjorie Stoneman Douglas, 1947

In today's Everglades agricultural area, evidence of substantial land subsidence can readily be discerned from the relative elevations of the land surface, the drainage-canal system, and the lake, and from the elevation of older buildings that were built on piles extending to bedrock. Precise measurements are relatively rare, except at particular points or along a few infrequently revisited transects. However, the long-term average rate of subsidence is generally considered to have been between 1 and 1.2 inches per year (Stephens and Johnson, 1951; Shih and others, 1979; Stephens and others, 1984).



(Subsidence data compiled by South Florida Water Management District)

Subsidence is greater in areas that were intentionally drained for urban and agricultural uses.

In uncultivated areas of the Everglades, subsidence is less obvious but probably widespread. Subsidence is not caused by cultivation, but occurs wherever drainage desaturates peat soil. Early engineering efforts focused on drainage alone, and, as a result, much of the area became excessively drained during drought years. The “river of grass” often became a string of drying pools, and great fires swept the Everglades. The drying triggered subsidence, which was then exacerbated by widespread fires. The persistent peat fires sometimes continued smoldering for months before being extinguished by the next rainy season.

Conventional surveying has always been extremely difficult in the Everglades. Stable bedrock bench marks are nonexistent or very distant, the surficial material is soft and yielding, and access is difficult. Current best estimates suggest that there have been 3 to 9 feet of subsidence in the current Everglades agricultural area and that an equally large uncultivated area has experienced up to 3 feet of subsidence. Such elevation changes are tremendously significant to a near-sea-level wetlands system in which flow is driven by less than 20 feet of total relief.

The current management infrastructure and policies have abated land subsidence in undrained areas of the historic Everglades to some extent, although comparison of recent soil-depth measure-

This building at the Everglades Experiment Station was originally constructed at the land surface; latticework and stairs were added after substantial land subsidence.

A sugar mill outside Belle Glade is surrounded by sugar cane fields. Note the dark peat soils in the lower photograph.

ments by the U.S. Environmental Protection Agency (Scheidt, US EPA, written communication 1997) with 1940s estimates of peat thickness (Davis, 1946; Jones and others, 1948) suggest that there has been widespread subsidence in the water-conservation areas over the past 50 years. The northern parts of individual water-conservation areas may still experience some minor subsidence. The southern or downstream parts of the impoundments are generally wetter and may be accumulating peat (Craft and Richardson, 1993a, 1993b), very gradually increasing in elevation. In the drained agricultural and urban areas, subsidence is an ongoing process, except where the peat has already disappeared entirely.

SUBSIDENCE CLOUDS THE FUTURE OF AGRICULTURE

The Everglades agricultural area is now mainly devoted to sugarcane, with considerably smaller areas used for vegetables, sodgrass, and rice. The value of all agricultural crops is currently about $750 million (Snyder and Davidson, 1994).

The eventual demise of agriculture in the Everglades has been predicted for some time (Douglas, 1947; Stephens and Johnson, 1951). The agriculture depends upon a relatively thin, continually shrinking layer of peat soil that directly overlies limestone bedrock. Agronomists have known for many decades that peat-rich soils (histosols), which form in undrained or poorly drained areas, will subside when drained and cultivated. The causes include mechanical compaction, burning, shrinkage due to dehydration, and most importantly, oxidation of organic matter. Oxidation is a microbially mediated process that converts organic carbon in the soil to (mainly) carbon dioxide gas and water.

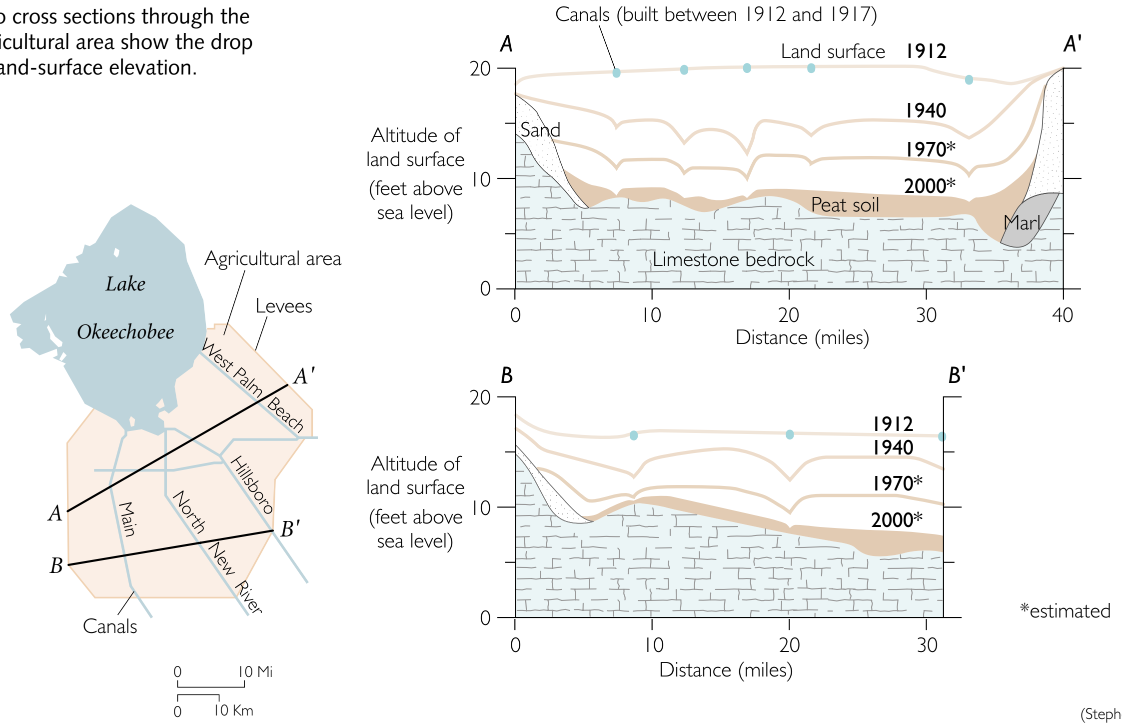
Through photosynthesis, vegetation converts carbon dioxide and water into carbohydrates. Under natural conditions, aerobic microorganisms converted dead plant material (mostly sawgrass root) to peat during brief periods of moderate drainage. Vegetative debris was deposited faster than it could fully decompose, causing a gradual increase in peat thickness. In what is now the Everglades agricultural area, a delicate balance of 9 to 12 months flood and 0 to 3 months slight (0 to 12 inches) drainage for about 5,000 years, with sawgrass the dominant species, led to a peat accretion rate of about 0.03 inches per year. Drainage disrupted this balance so that, instead of accretion, there has been subsidence at a rate of about 1 inch per year.

Peat soils may virtually disappear

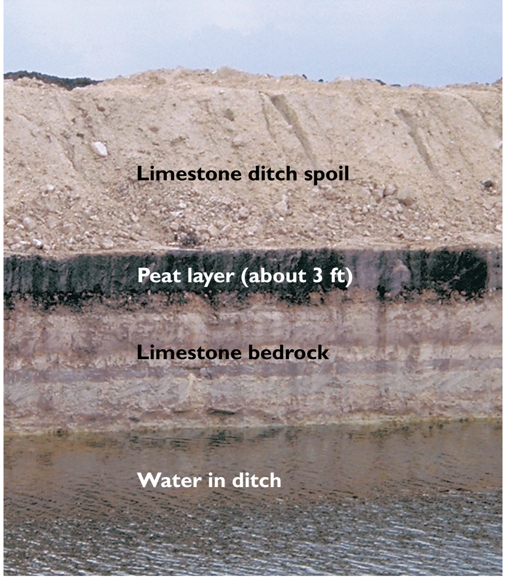
Rates of subsidence in the Everglades are slower than those in the Sacramento-San Joaquin Delta of California, the other major area of peat-oxidation subsidence in the United States; in the Delta, average subsidence rates have been up to 3 inches per year. However, the preagricultural peat thickness was much greater in the Delta (up to 60 feet) than in the Everglades, where initial thicknesses were less than 12 feet. The subsidence rates observed in the Everglades are similar to those observed in the deep peat soils of the English fens during the past 100 years (Lucas, 1982; Stephens and others, 1984).

In the Everglades agricultural area, the initial peat thickness tapered southward from approximately 12 feet near Lake Okeechobee to about 5 feet near the southern boundary. In 1951, Stephens and

Two cross sections through the agricultural area show the drop in land-surface elevation.



(Stephens and Johnson, 1951)



A ditch excavation east of Belle Glade shows peat soil overlying limestone bedrock.

Johnson extrapolated contemporary subsidence trends to predict that by the year 2000 the peat soil would be less than 1 foot thick in about half of the area. They further inferred that much of the area will by then have gone out of agricultural production, assuming that cultivation would not be possible with less than 1 foot of soil over limestone bedrock.

Although the extrapolation of peat thickness done by Stephens and Johnson (1951) appears consistent with measurements made in 1969 (Johnson, 1974), 1978 (Shih and others, 1979), and 1988 (Smith, 1990), little land has yet been retired from sugarcane. One reason is that farmers have managed to successfully produce cane from only 6 inches of peat, by first piling it in windrows to allow successful germination. It also appears possible that the rate of subsidence has slowed somewhat (Shih and others, 1997), due to the combined effects of an increasing nonorganic (mineral) content in the remaining soil, a thinner unsaturated zone dictated by the decreasing soil depth and, perhaps, an increasing abundance of more recalcitrant forms of organic carbon.

The soil-depth predictions of Stephens and Johnson (1951) may prove to have been somewhat pessimistic, but it is clear that agriculture as currently practiced in the Everglades has a finite life expectancy, likely on the order of decades. Extending that life expectancy would require development of an agriculture based on water-tolerant crops that accumulate rather than lose peat (Porter and others, 1991; Glaz, 1995).

SUBSIDENCE COMPLICATES ECOSYSTEM RESTORATION

In a wetland area where natural hydraulic gradients were on the order of inches per mile, and one half-foot land-surface altitude differences are ecologically significant, the fact of several feet of land subsidence substantially complicates ecosystem-restoration efforts.

Subsidence makes true restoration of the Everglades agricultural area itself technically impossible, even in the event that it were po-

Canals and a levee separate constructed wetland from the agricultural area to the right.

litically and economically feasible. Land there that once had a mean elevation less than 20 feet above sea level has been reduced in elevation by an average of about 5 feet. Differential subsidence has significantly altered the slope of the land, precluding restoration of the natural, shallow sheet-flow patterns. If artificial water management and conveyance were now to cease, nature would likely reclaim the land as a lake, rather than the predevelopment sawgrass plains. With removal of the "sponge" of peat and native vegetation, the agricultural area has also lost most of its ability to naturally filter, dampen, and retard storm flows. Other strong impediments to restoration of the Everglades agricultural area include loss of the native seed bank, accumulations of agricultural chemicals in the soil, and the potential for invasion by aggressive exotic species.

A tree island in the Everglades

Subsidence will also complicate efforts to manage the water-conservation areas to the east and south in a more natural condition. For example, the wetlands in these areas are speckled with tree islands, which are an important ecosystem component. Though definitive data are lacking, these tree islands likely have subsided, possibly more than the surrounding area. Thus, restoration of the water-conservation areas will require careful management of water levels in a depth range sufficient to promote appropriate wetland species without further damaging tree islands.

CAREFUL WATER MANAGEMENT IS A KEY TO THE FUTURE

Because of peat loss, agriculture as currently practiced in the Everglades will gradually diminish over the next decades. R.V. Allison, the first head of the Everglades Research Station, likened the peat soil to "the cake which we cannot eat and keep at the same time." His confident prediction that

> "As the use of Everglades lands for agricultural purposes approaches the sunset of ... production, there is little doubt that transition into a wildlife area of world fame will follow, perhaps in an easy and natural manner." —Allison, 1956

now seems overly optimistic. This is still a possible scenario but, as we have noted, the result would be very different from the natural system, due to subsidence. There are also alternative possibilities, including urban development or invention of a sustainable agriculture.

A sustainable agriculture in the Everglades would require at least zero subsidence and, optimally, some peat accretion. Glaz (1995) discussed a program of genetic, agronomic, and hydrologic research aimed at gradually (over a period of 20 to 40 years) making a currently used sugarcane-rice rotation sustainable. Achievement of this goal may prove difficult. However, documented water tolerance of sugarcane (Gascho and Shih, 1979; Kang and others, 1986; Deren and others, 1991), a recently discovered explanation for this water tolerance (Ray and others, 1996), and rapid gains in molecular genetics combine to suggest that substantial reductions in subsidence might be attainable.

Even in the complete absence of agriculture in the Everglades, the existing pattern of urban development and land subsidence would prevent restoration of the natural flow system. Engineered water management and conveyance will be required indefinitely. Land subsidence over a large area south of Lake Okeechobee has created a significant trough within the natural north-south flow system, thereby preventing restoration of natural sheet-flow and vegetation patterns.

The Everglades are currently the subject of a major Federal-State ecosystem restoration effort. "Restoration" is perhaps a misnomer, as the focus of this effort is on more natural management of the remaining 50 percent of the Everglades wetlands, not on regaining the 50 percent that has been converted to urban and agricultural use. Even improving the natural functioning of the remaining wetlands will be a complex problem, due to the lost spatial extent, the hydrologic separation from Lake Okeechobee, and land subsidence. The Everglades will likely continue to be an intensively managed system. However, much as the major engineering effort in the 1950s and 1960s halted the destructive fires and saltwater intrusion of preceding decades, the current restoration effort has the potential to halt and reverse more recent environmental degradation. A major challenge will be to deliver water from Lake Okeechobee through the extensive subsided areas so that it arrives in the undeveloped southern Everglades at similar times, in similar quantities, and with similar quality, as it did prior to drainage and subsidence.