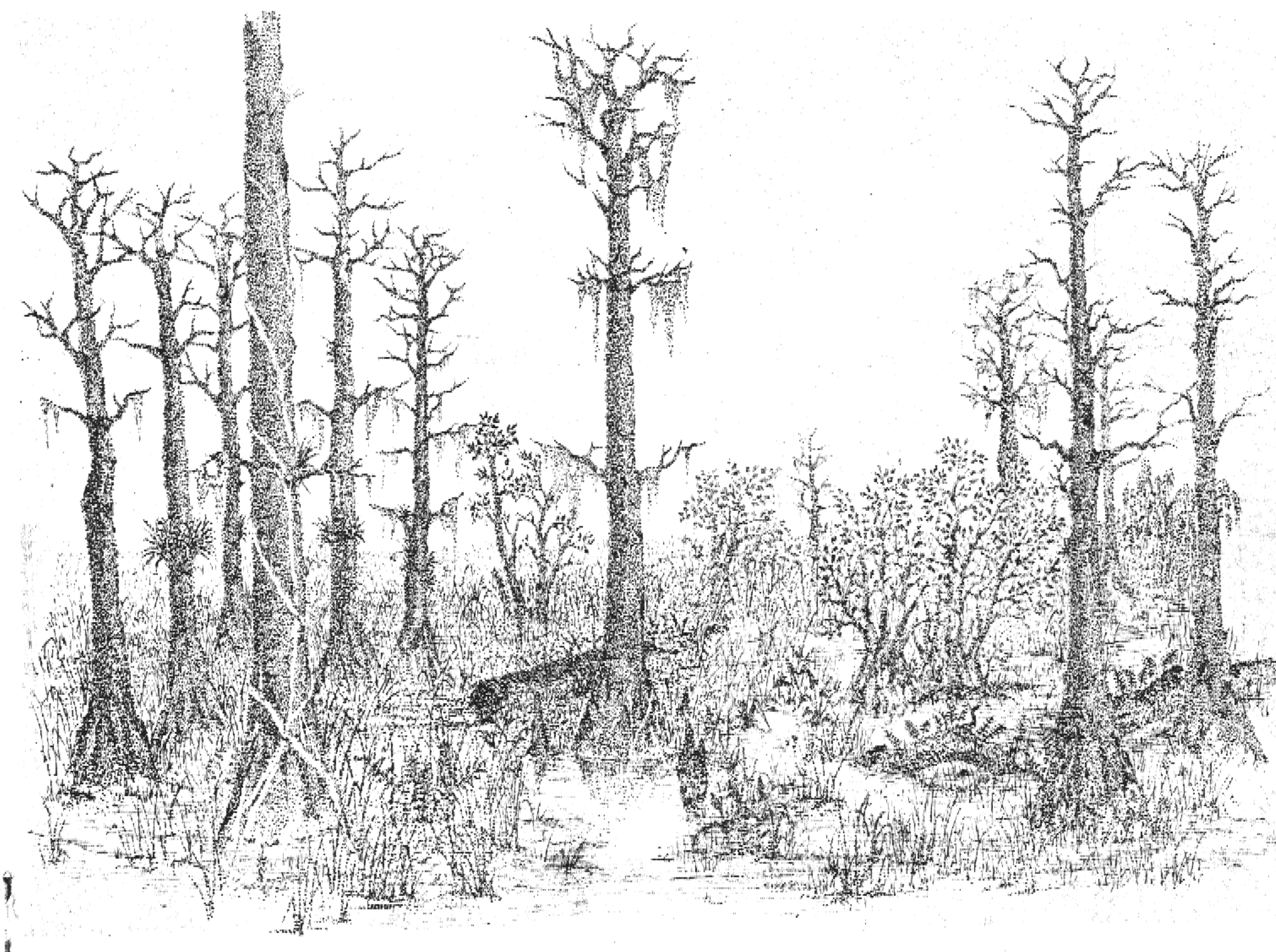
Ben McPherson, BFM 957

SOME HYDROLOGIC & BIOLOGIC ASPECTS OF THE BIG CYPRESS SWAMP DRAINAGE AREA, SOUTHERN FLORIDA

1970



UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

WATER RESOURCES DIVISION

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SOME HYDROLOGIC AND BIOLOGIC ASPECTS OF THE BIG CYPRESS SWAMP DRAINAGE AREA, SOUTHERN FLORIDA

BY

H. Klein, W. J. Schneider, B. F. McPherson
and T. J. Buchanan

OPEN-FILE REPORT

70003

Prepared by the

UNITED STATES GEOLOGICAL SURVEY

Tallahassee, Florida

May 1970

FRONTISPIECE

DEPARTMENT of the INTERIOR

news release

OFFICE OF THE SECRETARY

Winge (202) 343-6843

For release Friday, November 7, 1969

SECRETARY HICKEL ORDERS WATER RESOURCE
STUDY OF BIG CYPRESS SWAMP IN FLORIDA

Secretary of the Interior Walter J. Hickel today directed the U. S. Geological Survey to make a study of water resources in the Big Cypress Swamp watershed, site of the proposed jetport facility near Everglades National Park, Fla.

The Secretary also directed three other Interior agencies--the Bureau of Outdoor Recreation, National Park Service and Bureau of Sport Fisheries and Wildlife--to work with state and local agencies on how to best utilize the Big Cypress Swamp for fish, wildlife and recreation.

"Since the Big Cypress Swamp provides nearly 40 per cent of the water required to maintain the ecology of Everglades National Park," Secretary Hickel said, "it is essential that we know how much of the Swamp must be preserved to insure an adequate water supply for the Park."

"This will be a primary purpose of the Geological Survey effort," he added. "But another important benefit of the study will be to determine how much of the Big Cypress must be preserved to maintain an adequate supply of water to those communities on Florida's West Coast that depend upon the area for their domestic water needs."

The survey also will determine what is needed to maintain the adjacent estuaries which serve as a "nursery" for the State's important commercial fisheries industry.

Two recent studies of the impact of the proposed jetport on the ecology of south Florida--the Department of the Interior's "Leopold Report" and a report prepared under the auspices of the National Academy of Sciences--stressed the critical importance of the Big Cypress Swamp watershed, he pointed out. While both reports emphasized the importance of the Big Cypress, the question of precise boundaries was left open.

"The Geological Survey scientists will examine the hydrology of the Swamp in detail so that we can define the area to be protected," Secretary Hickel said.

The study will get underway immediately, with a preliminary report expected in 180 days.

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PURPOSE AND SCOPE

The prime purpose of the study of the hydrology of the Big Cypress, as expressed by the Secretary of the Interior in his news release of November 7, 1969, was to determine the importance of the Big Cypress in maintaining an adequate water supply for (1) the Everglades National Park, for (2) the expanding population of southwest Florida, and for (3) the adjacent estuaries, which constitute nurseries for fish, some of which are commercially important.

This preliminary report and the reconnaissance on which it is based were designed to provide the most essential available water and ecologic facts needed by the public and public officials in deciding upon the best utilization of the Big Cypress compatible with the broadening and somewhat conflicting needs of the people.

To define the role of the Big Cypress in the hydrology of south Florida, the following had to be determined, described, or delineated:

1. Boundaries of the Big Cypress drainage area;
2. Drainage features, flow patterns, and directions of flow;
3. Magnitude of water storage in and movement of water from the Big Cypress;
4. Quality of the water and the relation of quality to the biosystem;
5. Changes in water movement and quality caused by land development to date;
6. Possible effects of further land development on the water supply of the Big Cypress, the Everglades National Park, the nearby west-coast cities, and the adjacent estuaries.

SUMMARY AND CONCLUSIONS

The Big Cypress is a hydrologic unit of 2,450 square miles of flat, swampy area that merges into a coastal-marsh and estuarine environment. The ecology is water dependent and is rich in biota. Land is being developed in the western part of the drainage area as the city of Naples expands eastward.

Water, a principal resource of the Big Cypress, governs the ecology and influences the patterns of land development. Abundant but seasonal rainfall and slow natural drainage allow water to collect in ponds each year over as much as 90 percent of the undeveloped area for as long as 4 months. During the dry season, water in ponds and sloughs covers about 10 percent of the land. A shallow aquifer presently supplies most water for municipal use and irrigation. It extends from the land surface to a depth of about 130 feet in Naples, to about 60 feet near Sunniland, and wedges out near the east edge of the Big Cypress.

The Big Cypress is herein divided into three subareas, each having reasonably distinct internal drainage. Delineation of drainage boundaries and flow patterns were determined from aerial photographs and from hydrologic data obtained in November and December 1969. Subarea A, about 450 square miles in the north-eastern part of the Big Cypress, drains southeastward into Conservation Area 3 of the Central and Southern Florida Flood Control District and contributes part of the water that enters the Everglades National Park from Conservation Area 3. Subarea B, about 550 square miles in the western part, is characterized by an extensive system of canals that drains southward and westward into the Gulf of Mexico. Subarea C occupies the central part of the Big Cypress and drains southward toward the western part of the Everglades National Park. Its 1,450-square-mile area constitutes about three-fifths of the Big Cypress. It drains naturally except for two canals in the western part, the Barron River and the Turner River Canals.

Construction of the Golden Gate water-control system began in the early 1960's and has continued intermittently into 1970, thereby establishing a pattern for urbanization in subarea B. As a result of urbanization, runoff has accelerated, and water levels have lowered 2 to 4 feet in a 54 square-mile area east of Naples. Flow over the coastal weir in the Golden Gate Canal, the primary canal of the Golden Gate Estates, ranged from 2,390 cfs (cubic feet per second) on July 1, 1966, to 28 cfs on May 27, 1967. The average flow over the weir was 350 cfs during 1965-68.

Water is presently withdrawn from the shallow aquifer by the Naples municipal well field about 1 mile inland from the Gulf. Average pumpage from the field is 6 mgd (million gallons per day); the peak is 14 mgd. The lower water levels caused by pumping extend as far as 1 mile westward and eastward from the well field. The city is exploring 12 to 15 miles inland from the Gulf for its ultimate supply. The total water potential is not now known, but the average flow of 350 cfs from the Golden Gate Canal indicates that at least 10 times the present peak pumping might be available from the inland area without appreciable lowering of water levels.

The Everglades National Park annually receives an average of 541,500 acre-feet of water from subarea C, 56 percent of the total received by the park from outside sources. Water from subarea C, however, reaches only 16 percent of the park area.

Long-term hydrologic records from stations on the periphery of the Big Cypress reflect the cyclical rise in water levels during the rainy season and the decline during the dry season. The annual mean discharge through the Tamiami Canal outlets between 40-mile bend and Monroe during 1941-69 ranged from 75 cfs in 1956 to 620 cfs in 1960. Variations in monthly flow are wide; for example, the discharge through the same outlets during October, the wettest month, ranged from 2,700 cfs to less than 50 cfs. Long periods of no flow were recorded as follows: 9 consecutive months beginning December 1942; 8 beginning January 1944; 8 beginning January 1950; and 8 beginning November 1961.

The quality of the water flowing toward the Everglades National Park, in general, reflects natural conditions. The water has not been seriously altered or greatly contaminated by pesticides and nutrients. Concentrations of pesticides in sediments and biota and of nutrients in water were significantly lower than those from nearby urbanized areas but were comparable with those from other undeveloped areas of Florida.

The biota of the Big Cypress is in delicate balance with the seasonal fluctuations in water level. These fluctuations control the growth and concentration of organisms in the fresh-water environment and determine the brackishness of the estuaries, which, in turn, controls the estuarine ecosystem, a vital nursery and feeding area for many marine animals. The Fakahatchee Strand, in particular, is a unique water-dependent area rich in semitropical plants and in wildlife. The biota of the Big Cypress is interrelated with that of the Everglades National Park; many species migrate between the two areas.

Until the present time, land development in subarea C has been of little consequence and, therefore, has had no discernable effect on the quantity and pattern of water movement to the Everglades National Park. Significant land development involving flood-control and water-management practices would result in a change in the pattern of runoff and the period of inundation and would cause changes in the ecosystem of subarea C and the northwestern part of the park.

Continued canal construction farther eastward will lower water levels in progressively larger areas of subarea B. Water levels in subarea B during the dry season are partly regulated by a series of weirs, which controls canal flow and steps-up water levels from low elevations near the coast to higher elevations in the interior. The Barron River and Turner River Canals, constructed originally as borrow canals for highway construction, are not as effective in draining flood water as the canals to the west. They form a rudimentary drainage network that intercepts only shallow flow.

Current pressures for land development center in three general areas, the vicinity of Naples and eastward in subarea B; the southern coastal strip; and Gum Slough. The recent agreement between the Departments of the Interior and Transportation, the State of Florida, and Dade and Collier Counties regarding the proposed commercial jetport site has apparently reduced pressures for further land development in the eastern part of subarea C, at least temporarily.

Urban expansion along existing patterns would alter ecosystems in parts of the Big Cypress. The acceleration of runoff by canals would reduce the period of inundation in a large part of subarea B, which would bring about changes in biologic communities there; but efficient management of the water resources could moderate the change. Sufficient data are not available to predict the effect that specific water-management practices might have on changes in the fresh-water and estuarine environments.

A continuing program of hydrologic and biologic investigations in the fresh-water and estuarine environments in subarea B would furnish valuable information for determining the effects of drainage on water quality, water levels, and biota. This information would have transfer value in predicting changes in other parts of the Big Cypress if they are opened to further land development. Further investigations in subarea C would furnish benchmark information for monitoring changes brought about by future changes in hydrologic conditions.

PHYSICAL CHARACTERISTICS OF THE BIG CYPRESS

Boundaries and Drainage Patterns

The Big Cypress Swamp is a loosely defined but recognized physiographic province (Davis, 1943, fig. 1) southwest of lake Okeechobee. Some generalized flow patterns through the area were shown by Parker (1955, plate 11). Neither the physiographic boundaries nor the generalized flow patterns, however, are sufficient for the hydrologic interpretations required for this report.

Consequently, aerial photographs were taken specifically for the delineation of drainage boundaries and patterns of flow for use in this report. More than 580 aerial photographs of the general area, at a scale of 1:30,000, were taken in December 1969. A mosaic was made from the photographs; roads and cultural features were used for control. The resulting semicontrolled mosaic was used to delineate drainage boundaries and flow patterns. Where drainage boundaries and flow patterns were less distinct, the photographs were examined stereoscopically. Field observations at all culverts aided in the detail of flow patterns. These observations were made in November and December 1969, when water levels were high.

The drainage boundary is shown in figure 1. It encompasses a

2,450-square-mile area in which water flows generally southward in, through, and from the physiographic province of the Big Cypress Swamp. It defines the Big Cypress Swamp drainage area, hereinafter referred to in this report as the Big Cypress.

For this report, the Big Cypress has been divided into three subareas, as shown in figure 1. These have reasonably distinct internal drainage determined largely by topographic configuration and man-made drainage. Subarea A lies northeast of a low ridge and drains southeastward into Conservation Area 3 of the Central and Southern Florida Flood Control District. This 450-square-mile subarea is roughly one-fifth the total area of the Big Cypress and contributes part of the water that enters the Everglades National Park (hereinafter called the Park) from Conservation Area 3.

Subarea B includes 550 square miles at the west edge of the Big Cypress. It is characterized by an extensive system of canals, which drain southward and westward into the Gulf Coast estuaries.

Subarea C occupies the central part of the Big Cypress and drains toward the Park. It constitutes about three-fifths of the Big Cypress--1,450 square miles. At present, subarea C is drained naturally except for two canals in the western part, the Barron River and Turner River Canals.

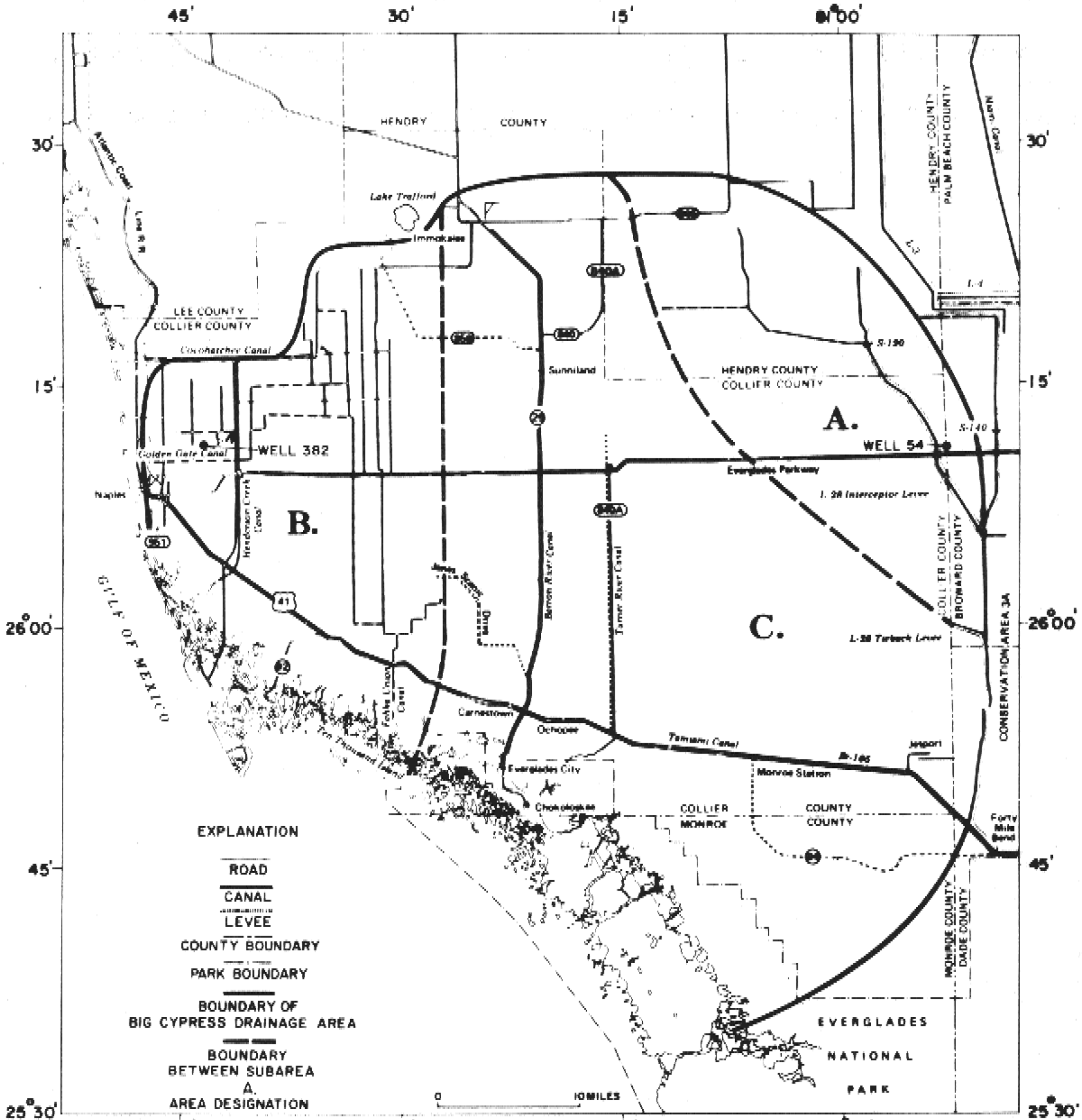

Figure 1.--Map of the Big Cypress showing the delineations of the drainage area and the subareas.

Because of the flat topography and slow natural drainage, there is no well-defined stream system in the Big Cypress except in the estuarine environment along the Gulf Coast, where drainage tends toward tidal channels. In the fresh-water environment, all drainage is through sloughs and strands and by canals, as shown in figure 2.

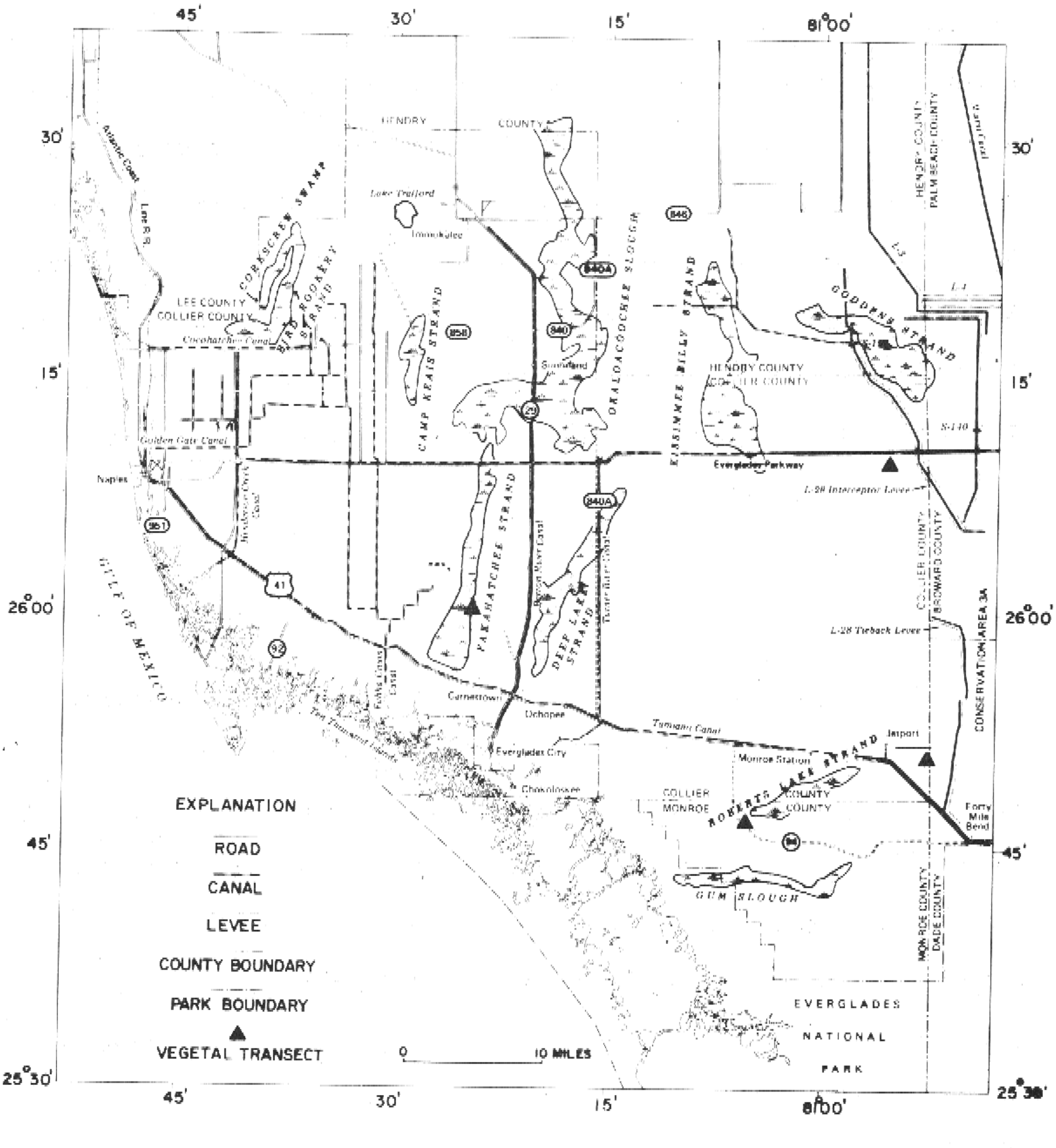

Figure 2.--Map of the Big Cypress showing the major sloughs and strands.

There are three generalized patterns of drainage in the Big Cypress. In the northeast, drainage is diverted eastward by a low, nearly imperceptible ridge extending from the Hendry-Collier County line in a broad eastward-bending arc to the Collier-Broward County line, north of the proposed jetport site. In the west, flow is through a system of canals that diverts water both westward to the Gulf and southward to the bays of the Ten Thousand Islands. Throughout the rest of the Big Cypress, drainage is generally southward and tends to concentrate in the Okaloacoochee Slough, the Barron River and Turner River Canals, and the Fakahatchee Strand (fig. 2). Details of the flow patterns are shown in figure 3.

The delineation of the Big Cypress is based on the unseasonably high water levels of December 1969. At still higher levels, some water would probably spill over the low dividing ridge from subarea A to subarea C; some water would enter the Big Cypress from Lake Trafford through the Camp Keasis Strand (fig. 2); and water from Bird Rookery Strand would enter through culverts under Road 846 just east of its junction with Road 858. Because of the flat terrain, boundaries are indefinite along the north edge of the Big Cypress, particularly east of Immokalee.

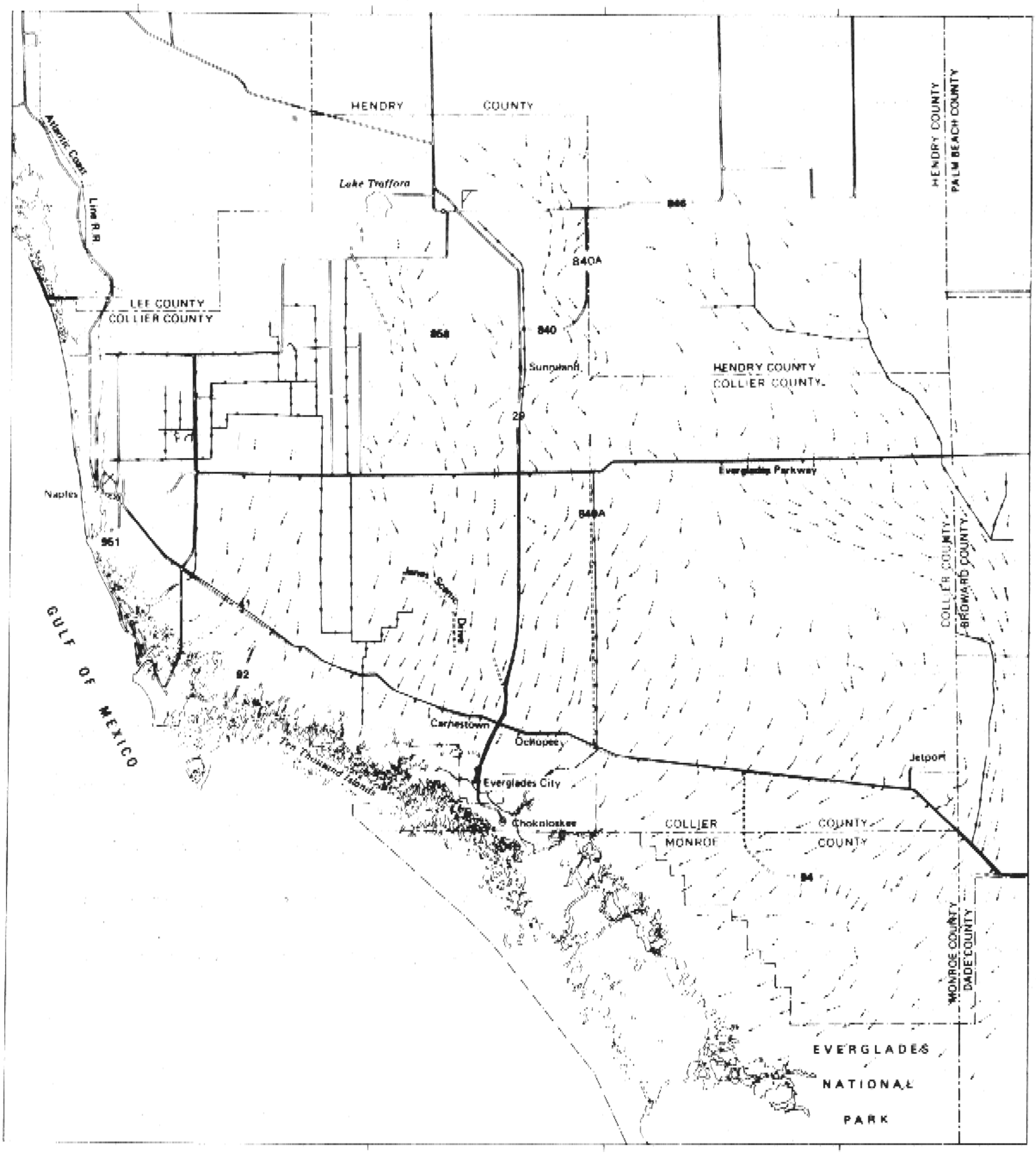

Figure 3.--Map of the Big Cypress showing flow directions in December 1969.

Ecology

The ecology of the Big Cypress is water dominated. During the wet season, as much as 90 percent of the undrained area is inundated; during the dry season, as little as 10 percent is inundated, mostly in shallow ponds and sloughs. Plants and animals are basically aquatic and have adapted to fluctuating seasonal water levels.

The major plant communities can be divided into the following: (1) pine-palm-palmetto forest, (2) wet prairie and marsh, (3) fresh-water swamp, (4) hammock forest, (5) cypress forest, (6) tidal marsh, and (7) mangrove swamp. In general, the hammock and pine-palm-palmetto forests grow on land only several inches to several feet higher than the surrounding wet prairies and cypress forests. The surface under pine-palm-palmetto forests is often inundated briefly after heavy rain and for perhaps several months during the wet season. The wet prairies and marshes are treeless areas of emergent vegetation that are seasonally inundated. Wet prairies are covered with several inches of water during the wet season and are usually dry during the dry season. Marshes have deeper water, but they may also become dry at times.

The fresh-water swamps are areas of forest with hardwoods and palms, epiphytic ferns, air plants, and orchids. These are inundated most of the year. The Fakahatchee Strand is the largest, although it contains some prairies, marshes, and hammocks. The plant life within the Fakahatchee Strand is abundant and varied. Thirty eight species of orchids alone grow there, seven of which are unique to the area (Luer, 1964). The cypress forests also are inundated most of the year. They are distinguished from fresh-water swamps in that the principal tree is cypress.

The fresh-water prairies and marshes gradually change to tidal marshes near the coast. These tidal marshes form a narrow band of salt-tolerant grasses and sedges between the fresh-water and estuarine environments. The mangrove swamps constitute a well-defined zone bordering the tidal creeks, ponds, and bays along the coast.

Animal life in the Big Cypress is both diverse and abundant. Many species are aquatic. In the fresh-water environment, they include prawns, mosquitofish, killifish, bass, and gar. Crabs, shrimps, mollusks, and fish inhabit the estuaries; redfish, tarpon, and snook invade the estuaries to reproduce and feed. The wildlife consists of numerous species of amphibians, reptiles, birds, and mammals. Seventeen of these are classified by the U.S. Fish and Wildlife Service as rare or endangered. The better known of these 17 include the American alligator, wood ibis, Florida everglade kite, Southern bald eagle, and Florida panther.

Land Development

In southern Florida, land development usually begins with the construction of canals to drain swampy lands and to assure protection from high water during the rainy seasons. Significant development affecting the Big Cypress began in the early 1920's, when two major roads were built--the north-south road from Everglades City to Immokalee, completed in 1926, and the Tamiami Trail, completed in 1928. Both were constructed of borrow material from continuous pits adjacent to the roads; the borrow pits became canals.

The north-south Barron River Canal, which furnished the fill needed for the Everglades-Immokalee road (Road 29), was the first major drainage canal in the Big Cypress. The Tamiami Canal, the east-west borrow pit along the north side of the Tamiami Trail, briefly intercepts water flowing southward and distributes the flow to many bridges along the Tamiami Trail. A total of 49 bridges along the 37-mile reach of canal between 40-mile bend and Road 29 distribute flow to the western part of the Park. Culverts and bridges along Road 94 similarly distribute flow.

Drainage was further modified in the late 1950's by construction of the major Turner River Canal. This canal was the source of fill for Road 840 A and extends from 1 mile south of the Tamiami Trail northward for 20 miles.

Water was further controlled in 1963 with the completion of Levee 28, the western boundary of Conservation Area 3A. The L-28 tieback levee and canal completed in 1965 assures the continued southeastward flow of water through the 7.1-mile gap in Levee 28; the Levee 28 interceptor canal, completed in 1967 (fig. 1), expedites flow southeastward into Conservation Area 3 of the Central and Southern Florida Flood Control Project.

The Everglades Parkway, commonly called Alligator Alley, was completed in 1967. It extends eastward from Naples to the Fort Lauderdale area and crosses the Big Cypress and Conservation Area 3. Numerous bridges along the parkway permit southward flow of water.

Land development for housing in subarea B began in the 1960's in the 188-square-mile Golden Gate Estates area in western Collier County (fig. 4). Drainage canals, notably the Golden Gate Canal and the Cocahatchee River Canal, have been dug to drain the western part of the estates. In November 1969, the Fahka Union Canal was completed to drain the southern part.

In 1966, the developers of Golden Gate Estates, acquired 105 square miles of land immediately west of Road 29 and south of the Everglades Parkway. This tract, which includes all the Fakahatchee Strand, has not been developed.

Areas currently under development or presumed to be planned for development are shown on figure 4.

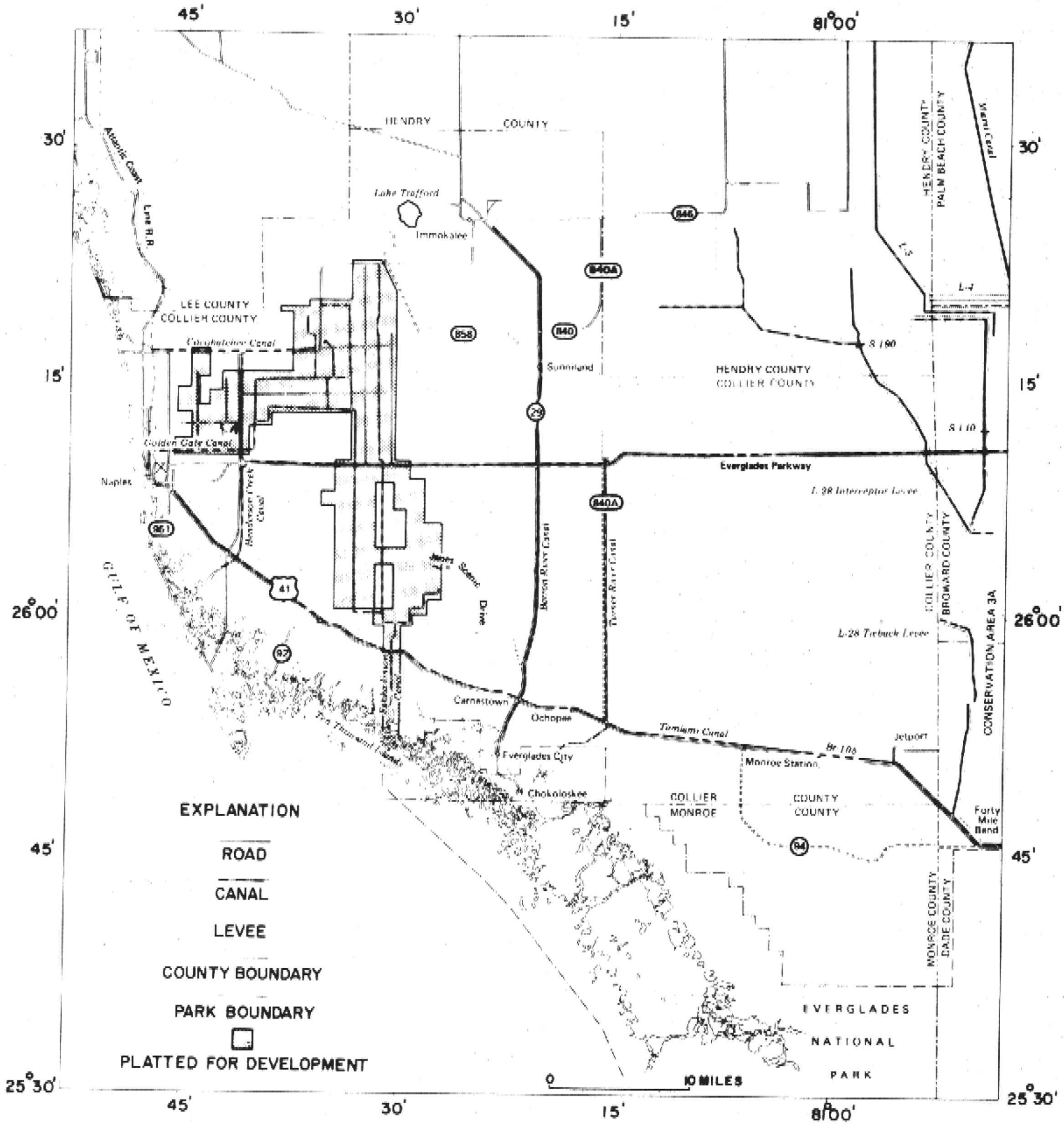

Figure 4.--Map of the Big Cypress showing the areas platted for development.

HYDROLOGIC CHARACTERISTICS OF THE BIG CYPRESS

Storage and Movement of Water

The undeveloped parts of the Big Cypress are largely inundated during the rainy season, generally May through October. Normal monthly rainfall for the Everglades and southwest Florida areas are given in table 1. Nearly 80 percent of the rain normally falls during the 6-month rainy season. Rainfall averages 53 inches per year, but it has ranged from 35 inches to 80 inches per year. Summer rains are usually short, intense, and frequent. Winter rains usually result from frontal systems and are of longer duration and of less intensity. Hurricanes occur most frequently in September and October and usually bring torrential rainfall.

During the rainy season, shallow depressions fill with water, and, because of the poor drainage, water stands on the land until it evaporates or slowly drains off. Thus, as much as 90 percent of the undrained part of the Big Cypress is inundated to depths ranging from a few inches to more than 3 feet at the height of the rainy season. As the dry season begins, the water level starts to recede. The recession normally continues into May, when perhaps 10 percent of the undrained area is covered by water in ponds and sloughs.

Table 1.--Normal monthly rainfall for the Everglades and Southwest Coast Division, Florida.

[Data composited from 12 stations of the U.S. Weather Bureau on the periphery of the Big Cypress.]

Month	Precipitation (inches)
Jan.	1.63
Feb.	1.91
Mar.	2.65
Apr.	2.98
May	4.32
June	8.29
July	8.18
Aug.	7.47
Sept.	8.47
Oct.	4.39
Nov.	1.53
Dec.	1.42
Year	53.24 (Total

Records of water-level fluctuations are available from a few sites, mostly near the outer edges of the Big Cypress. Water-level fluctuations for the Tamiami Canal at bridge 105, 12 miles west of 40-mile bend, are probably representative of the water conditions within subarea C; fluctuations in well 54, along the Everglades Parkway at the eastern Collier County line, are probably representative of conditions in part of subarea C; and records of fluctuations in well 382, a few miles east of Naples, are probably typical of well-drained conditions in the western part of subarea B. Hydrographs of the three stations for 1967 and 1968 are shown in figure 5.

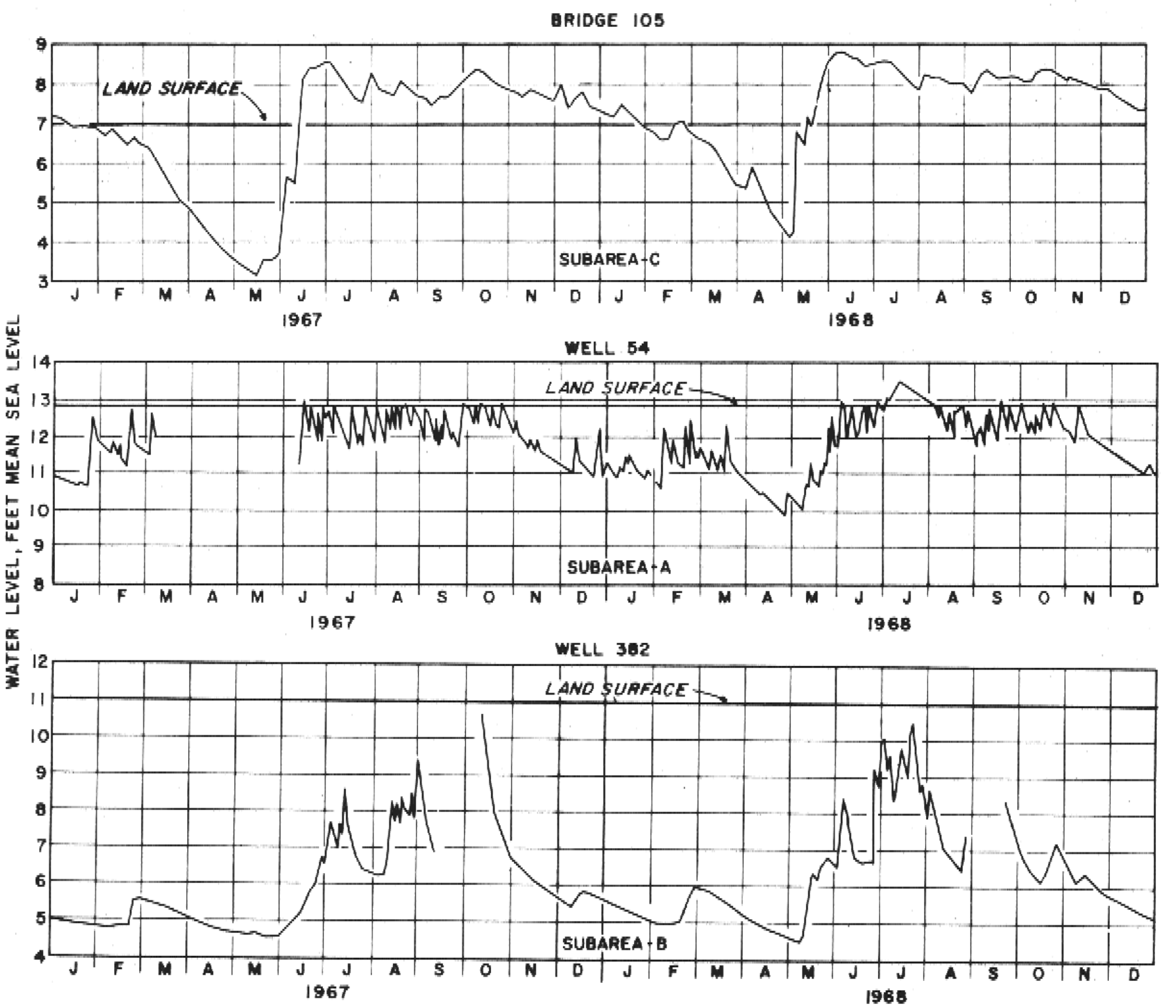

Figure 5.--Hydrographs of bridge 105, well 54, and well 382 for 1967 and 1968.

The three hydrographs in figure 5 reflect the cyclical rise in water levels during the rainy season and the decline in levels during the dry season. The graph for the Tamiami Canal at bridge 105 shows that inundation persisted for about 7 months in 1967 and for nearly the same period in 1968. Water levels there are unaffected by upgradient drainage and water-control works. The rate at which water levels recede after the rainy season is a rough measure of the runoff characteristics of the Big Cypress. The recession rates in the channel at bridge 105 were 0.02 to 0.03 foot per day when the area was inundated and 0.06 to 0.08 foot per day when levels were generally below the land surface. These rates confirm general observations that runoff from the Big Cypress is slow and that water is stored within subarea C for extended periods. Water-level fluctuations at bridge 105 reflect hydrologic events in the upgradient areas of subarea C as well as events in the immediate vicinity.

The hydrograph for well 54 shows hydrologic conditions at the eastern periphery of subarea A, where water levels are affected by water-management practices in the Levee 28 Interceptor Canal. The water levels remained a few feet below or slightly above the land surface throughout 1967-68.

The frequent showers and the consequent rapid drainage to the adjacent interceptor canal causes the sawtooth effect on the hydrograph during the rainy season. The lowest water level of record in the vicinity of well 54 was about 5 feet below the land surface at the end of the prolonged drought of 1962.

The hydrograph for well 382, a few miles east of Naples and 0.7 mile from the Golden Gate Canal, shows the contrast in pattern and magnitude of fluctuations where drainage has been established. The water level approached the land surface during the rainy seasons of 1967 and 1968. The rapid rate of recession of water levels demonstrates the efficacy of the drainage system.

The stage-duration curve for the Tamiami Canal observation station at bridge 105 (fig. 6) indicates the percentage of time

that a selected water level is equalled or exceeded at that site. Note that the curve represents water level and not water depth. The total range of water level during 1952-69 is 6.2 feet and represents the difference between extremes of flood and drought. During November 1969 to February 1970, the water level ranged from 8.0 to 8.9 feet above sea level, indicating that conditions in the interior of the Big Cypress were wetter than average and that inundation was widespread. At a level of about 7.5 feet the area of inundation is greatly diminished, and the stage-duration curve reflects the duration of ponded levels and ground-water levels in the general area. At a level of about 7.0 feet, inundated areas decrease to isolated ponds and the major sloughs; levels below 7.0 feet represent declines below the land surface.

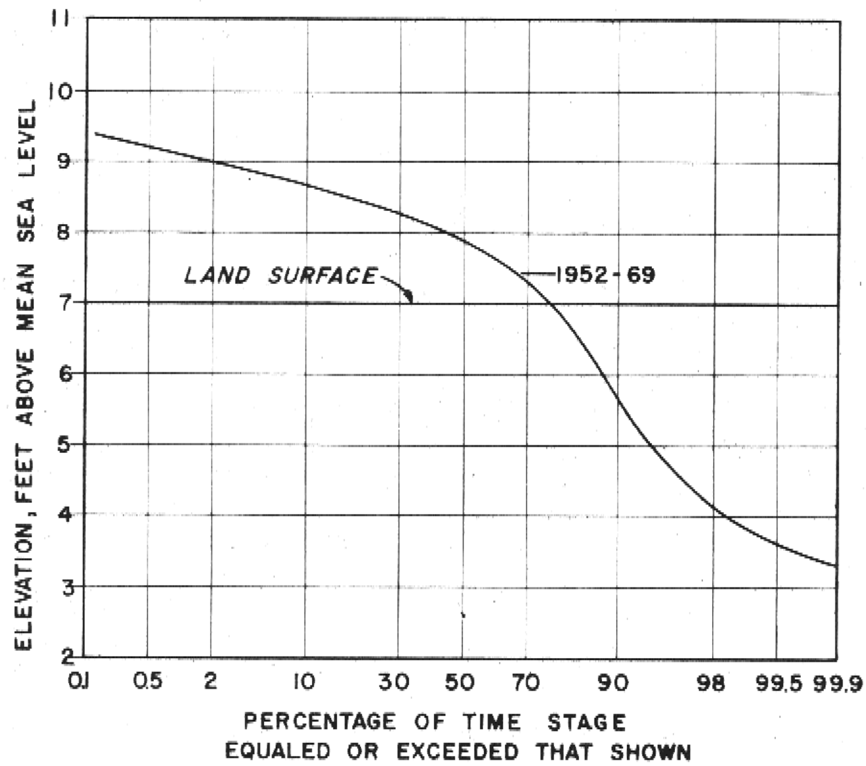

Figure 6.--Stage-duration curve for the Tamiami Canal at bridge 105 for the period 1952-69.

The long-term record of flow through the Tamiami Canal outlets within the reach represented by flow at bridge 105 (40-mile bend westward to Monroe) is shown in figure 7. The hydrograph shows the annual cycle of increased discharge during the rainy seasons and reduced discharge during dry seasons. It shows also the wide variation from year to year. Because changes by man within this subarea (C) have not been significant, the fluctuations in discharge reflect only the differences in the patterns of occurrence and the total annual rainfalls. The discharge during 1940-69 ranged from zero during droughts to more than 3,000 cfs after Hurricane Donna in 1960. The discharge is distributed through 29 bridges within about 20 miles. The longest periods of no flow were: 9 consecutive months beginning December 1942; 8 beginning January 1944; 8 beginning January 1950; 8 beginning November 1955; and 8 beginning November 1961.

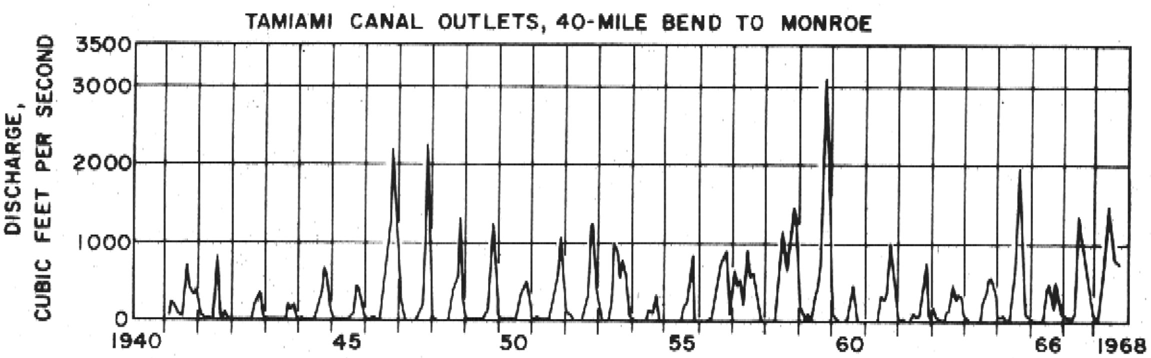

Figure 7.--Hydrograph of monthly mean discharge of the Tamiami Canal outlets, 40-mile bend to Monroe.

The annual mean discharge southward through the Tamiami Canal outlets from 40-mile bend to Monroe for the total period of record, 1941-69, ranged from about 75 cfs in 1956 to 620 cfs in 1960. The graph in figure 8 shows the wide variation in discharge possible

from year to year. Equally wide variations in discharge occur from month to month, as shown in figure 9. For example, the discharge

through these outlets for October, the wettest month, ranges from 2,700 cfs to 50 cfs, or perhaps less. Water levels at bridge 105 can change from 3.5 feet below the land surface to 1 foot above the land surface within a 2-week period.

Additional data on the distribution of flows were obtained for this report. Discharge was determined at 253 sites in November 1969. These discharge data and data from the Tamiami Canal outlets were used to determine the regional distribution of surface flows within Big Cypress. Figure 10 shows the distribution of flows measured

during November 18-20, 1969.

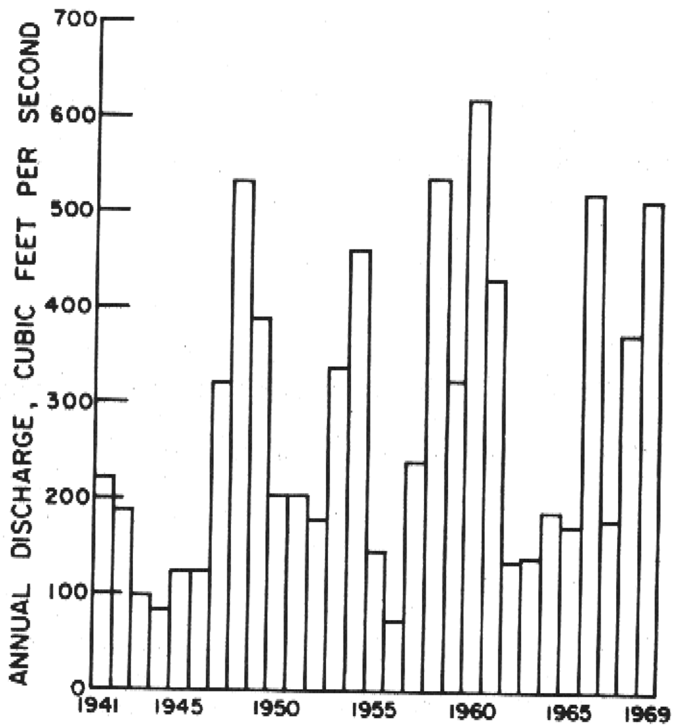

Figure 8.--Graph of annual mean discharge for the Tamiami Canal outlets, 40-mile bend to Monroe, for the 1941-69 water years.

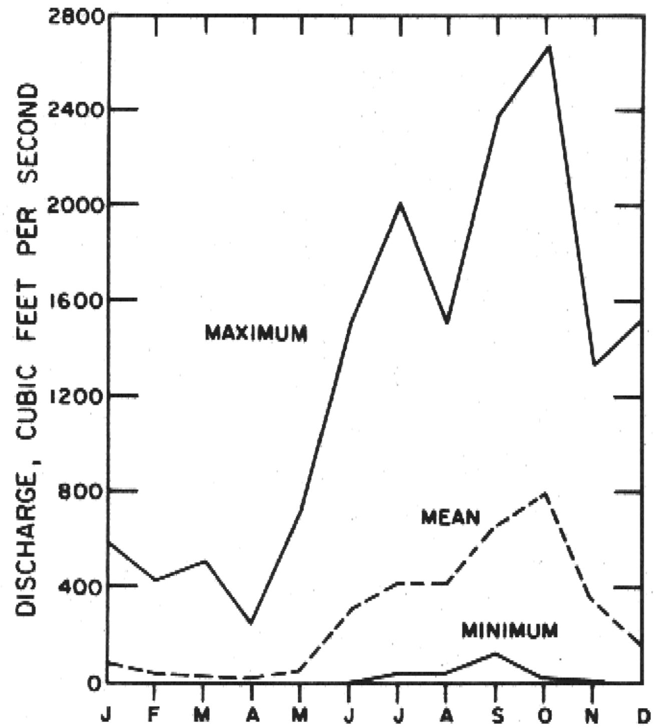

Figure 9.--Graphs of maximum, mean, and minimum monthly discharge for the Tamiami Canal outlets, 40-mile bend to Monroe, 1941-69.

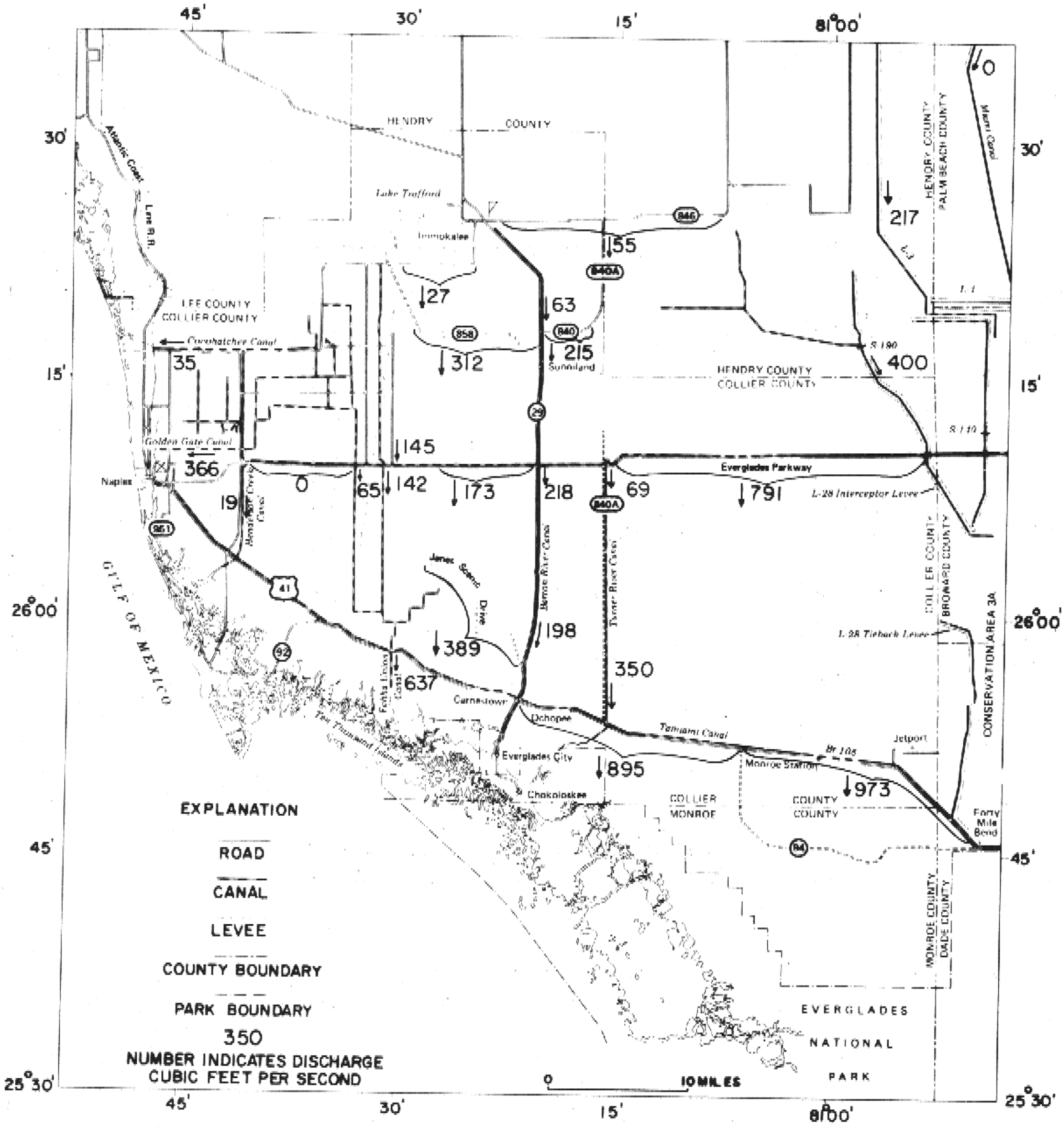

Figure 10.--Map of the Big Cypress showing the distribution of flows during November 18-20, 1969.

The flow generally increases from north to south; however, flow in the Barron River Canal decreased between the Everglades Parkway and the Tamiami Canal because water spilled over its banks into adjacent sloughs. North of the Everglades Parkway, the Barron River Canal picks up flow from the Okaloacoochee Slough (fig. 2). Intermittent records indicate a flow increase of about 150 cfs in that reach during the recent high-water season. Large volumes were also carried by drainageways in the Fakahatchee Strand.

Flow from the drainage system of the Golden Gate Estates was about 660 cfs (637 + 19) to the south and about 400 cfs (366 + 55) to the west. The Levee 28 Interceptor Canal, in subarea A, carried 400 cfs. Long-term discharge records of the Tamiami Canal outlets show that large volumes of fresh water are contributed by the Big Cypress to the Park. The November 1969 discharge measurements show that substantial volumes of water are contributed to estuarine areas along the Gulf Coast west of the Park.

Aquifers

The shallow aquifer presently supplies all water for municipal use and irrigation in Naples and adjacent areas. The aquifer is composed of the upper limestone of the Tamiami Formation, of Miocene age, and the Pamlico Sand and the Anastasia Formation, of Pleistocene age. Fine sand, clay, and marl in the lower part of the Tamiami Formation and the upper part of the underlying Hawthorn Formation are relatively impermeable and serve as a base for the shallow aquifer and as a confining unit for the deeper Floridan aquifer (McCoy, 1962, p. 24).

As indicated by McCoy (1962, p. 12), the Tamiami Formation underlies nearly all of Collier County, and in the southern and eastern parts of the county it lies at the surface or is covered by a veneer of younger deposits. The upper part of the formation in Collier County is composed of thin but highly permeable limestone. This limestone apparently wedges out a few miles west, south, and east of Immokalee. According to Schroeder and Klein (1954, p. 4), it does not occur near the Dade-Broward County boundary. In a test well due east of Immokalee at the Hendry County boundary, limestone of the Tamiami Formation was penetrated at a depth of 22 feet; it was more than 32 feet thick. The shallow depth of irrigation wells immediately east of Immokalee suggests a thinning of the limestone to the west.

In the vicinity of Naples, the top of the limestone of the Tamiami Formation ranges from about 25 to 55 feet below the land surface. In the southern and southeastern parts of Collier County it is at or near the surface. It is exposed in canals and ditches and is quarried extensively along U. S. Highway 41 and along Road 29, principally near Sunniland (McCoy, 1962, p. 13).

Limestone of the Tamiami Formation forms the principal part of the shallow aquifer in Collier County. Its high permeability and widespread occurrence are of extreme importance to the water resources of the Big Cypress.

The Anastasia Formation is exposed along the canal banks on the north side of Road 846. Two miles east of the intersection of Road 846 and U. S. Highway 41, a hard dense limestone layer in the formation occurs near the land surface. This layer dips toward the Gulf of Mexico.

McCoy (1962, p. 14) indicated that limestone of the Anastasia Formation is generally permeable, and, where the formation thickens, as in Naples, it forms an important part of the shallow aquifer.

In Collier County the Pamlico Sand is composed of fine to medium quartz grains. The bottom of the sand is 10 to 15 feet below sea level in Naples, where it overlies the Anastasia Formation. In the interior, the Pamlico Sand forms a thin blanket over the Tamiami Formation or the hard limestone layer of the Anastasia Formation. The permeable sand permits rapid infiltration of rainfall.

The shallow aquifer has a maximum thickness of about 130 feet in western Collier County, where limestone of the Tamiami Formation, the Anastasia Formation, and the Pamlico Sand are hydraulically interconnected. The aquifer thins eastward to about 60 feet near Sunniland and wedges out near Dade County. In southern Collier County it is composed of highly permeable limestone of the Tamiami Formation, which extends to a depth of at least 90 feet (McCoy, 1962, p. 24).

At present, water is withdrawn from the shallow aquifer for the city of Naples from its municipal well field about 1 mile inland from the Gulf of Mexico. Average pumpage from the well field is about 6 mgd (million gallons per day), and the peak is about 14 mgd, when lawns are irrigated heavily. Lower water levels caused by pumping in the well field extend westward and eastward for about 1 mile from the well field. The community of Golden Gate, just east of Naples also pumps about 1 mgd from the shallow aquifer.

Withdrawals from the shallow aquifer for municipal supplies and irrigation are small compared with natural discharge.

The water is a hard calcium bicarbonate type containing low concentrations of chloride, with the exception of coastal areas of salt-water contamination. McCoy (1962, table 3) states that shallow ground water in the interior is of excellent quality.

The Floridan aquifer at depths greater than 400 feet is capable of yielding large quantities of mineralized water (3,000 to 5,000 mg/l dissolved solids) to flowing wells. The aquifer is a potential source of supplemental water supplies for municipalities through desalination.

Salt-water intrusion

The known areas of salt-water intrusion in the shallow aquifer are within a few hundred feet of the Gulf of Mexico and Naples Bay and under the southern part of the city of Naples (McCoy, 1962, p. 53-57). Salt-water contamination occurs at a depth of 40 to 60 feet below sea level in the area extending from Naples eastward at least to Road 858. At depths less than 40 feet, the water contains less than 250 mg/l chloride, but the chloride content increases with depth. Other areas of salt-water intrusion are the low coastal marshes seaward of U. S. Highway 41 from Road 92 to Road 29 and possibly to Road 840A. The increase in municipal pumping in Naples has caused no noticeable inland migration of salt water in the shallow aquifer.

There are three possible sources of salt-water contamination in Collier County: (1) inland movement of sea water along tidal reaches of streams and canals, with resultant intrusion into the shallow aquifer when fresh-water levels are low; (2) residual sea water left in the sediments at the time of deposition or during past invasions of the sea; and (3) upward movement of mineralized water under pressure from the deep artesian aquifer. Critical sources of salt-water intrusion are uncontrolled reaches of streams and canals, which permit inland penetration of sea water in the flat coastal areas. Although mineralized water may move upward naturally, where the aquiclude is thin and moderately permeable, significant sources of contamination may be upward leakage from deep artesian wells through corroded well casings or through open well bores.

In 1968, the Collier County Commission established a "Salt Barrier Line" beyond which uncontrolled drainage canals may not be excavated. All new canals extending inland from this line are required to have an adequate control structure at this line to prevent further inland penetration of sea water. Although these structures are primarily intended as salinity barriers to prevent salt water from moving inland along canal channels, they serve a secondary purpose in regulating drainage of inland areas and in maintaining relatively high ground-water levels in coastal areas.

Water Quality

The water of the Big Cypress is relatively unpolluted. This conclusion is based on analysis of water from 15 sites (November 1969-March 1970), on some sparse data previously collected in April and July 1969, and on comparisons of these data with those from other areas in Florida. Generally, in the Big Cypress, concentrations of nitrogen, phosphorus, total organic carbon, and persistent pesticides, which often serve as indicators of pollution, are similar to concentrations in nearby, relatively uninhabited areas but are considerably less than those of nearby urbanized areas.

Nitrogen and phosphorus are the two principal nutrients of aquatic systems. In the Big Cypress, concentrations of total nitrogen ranged from 0.19 to 1.85 mg/l (milligrams per liter) and averaged 0.82 mg/l. About 81 percent of the total nitrogen was organic, indicative of a natural environment. Concentrations of total phosphorus (as PO_4) ranged from 0 to 0.33 mg/l and averaged 0.07 mg/l. For comparison, in 1969, concentrations of total nitrogen in the upper St. Johns River in east-central Florida ranged from 0.55 to 1.4 mg/l and averaged 1.06 mg/l. Concentrations of total phosphorus (as PO_4) in the upper St. Johns River basin ranged from 0.11 to 0.47 mg/l and averaged 0.26 mg/l (D. Goolsby, oral communication, April 1970). In comparison with the more heavily populated area of nearby Broward County, both the upper St. Johns River basin and the Big Cypress have significantly lower concentrations of nitrogen and phosphorus. Average concentrations of total nitrogen and phosphorus (as PO_4) in the canals of Broward County were 1.67 and 1.19 mg/l, respectively (table 2).

Table 2.--Nutrients, in mg/l, in water in the Big Cypress, April 1969-March 1970, and in water from canals in Broward County, Fla., December 1968-June 1969.

	The Big Cypress			Broward County Canals		
Constituent	Range	Mean	No. of samples	Range	Mean	No. of samples
Nitrate NO_3	0.00-2.8	0.28	26	0.00-12.0	1.26	63
Nitrite NO_2	0.00-0.03	0.01	26	0.00- 0.67	0.08	63
Ammonia NH_4	0.00-0.56	0.08	26	0.00- 3.5	0.62	43
Organic Nitrogen N	0.15-1.0	0.67	26	0.00- 2.0	0.86	43
Total Nitrogen N	0.19-1.85	0.82	26	0.44- 2.8	1.67	43
Total Phosphorus PO_4	0.00-0.33	0.07	27	0.01-24.0	1.19	58
Total Organic Carbon	4 -27	11	15			

Total organic carbon, which is a measure of the level of decay of vegetal matter and other wastes, ranged in concentration in the Big Cypress from 4 to 27 mg/l and averaged 11 mg/l (table 2). Similar concentrations (12 to 23 mg/l) are reported from sparse data from the Oklawaha and Withlacoochee Rivers in 1968 and 1969 (M. Kaufman, written communication, 1970). In Florida, vegetation is abundant, and its decomposition and oxidation probably result in this background concentration. Sparse data obtained during 1968-70 in southern Florida indicate that the concentration of organic carbon in rain is low, averaging 3 mg/l in 10 samples. Organic carbon also occurs in many types of waste, including sewage effluent. Total organic carbon concentrations as high as 420 mg/l have been measured in canals in Dade County. Concentrations of this magnitude are indicative of pollution.

Much of the abundant vegetation eventually becomes incorporated into the sediment, where it represents a large potential reservoir of organic carbon, nitrogen, and phosphorus.

In four ponds sampled in the Big Cypress, the sediment (dry weight) had concentrations that ranged from 33.1 to 46.0 percent total organic carbon and from 2.51 to 3.0 percent total nitrogen.

Sparse data from the upper St. Johns River basin indicate that total organic carbon and total nitrogen in sediment are similarly high in places. Sediment from a fifth pond in the Big Cypress had a low concentration of total organic carbon (7.9 percent) and total nitrogen (0.63 percent). The bottom of this pond was covered with fine silt, which presumably originated from construction of the adjacent highway, the Everglades Parkway. The sample contained much of this silt; consequently, it contained relatively less organic carbon and nitrogen.

Many trace elements and heavy metals are also essential for life. In excess, however, the same materials kill many organisms and pollute water. Concentrations of trace elements and heavy metals in the waters of the Big Cypress are generally below levels that are listed as the recommended upper limit for fish and wildlife (McKee and Wolf, 1963).

Although organophosphate compounds, such as parathion and malathion, are the most commonly used pesticides in Florida, persistent chlorinated hydrocarbons, such as DDT, dieldrin, and toxaphene, are also used and are found in the water, sediments, and biota. The use of persistent pesticides results in biologic magnification, a phenomenon in which toxins are increasingly concentrated in organisms up the food chain. As a result, large predators at the top of the food chain may have concentrations that interfere with reproductive processes or that result in chronic diseases. Components of the DDT family (DDT, DDD, DDE) are the most commonly detected pesticides in the Big Cypress ecosystem.

The concentration of the DDT family in the sediments of the Big Cypress is significantly lower than that in the sediments of canals in nearby Broward County (table 3). The average concentration was 5.09 μg/kg (micrograms per kilogram) in the Big Cypress and 62.91 μg/kg in the Broward Canals. The average concentration in the water, however, was higher in the Big Cypress, 0.07 μg/l (micrograms per liter), than in Broward, 0.02 μg/l. The high average in the Big Cypress is a result of three individually high analyses of water samples collected near areas of human habitation or activity. Sediment concentration is a better indicator of pesticide contamination than water concentration because sediment samples become more nearly integrated over a period of time. The concentration in a water sample, on the other hand, may reflect only temporary and local contamination.

Table 3.--Concentrations of the DDT family in water ($\mu g/l$) and sediment and biota ($\mu g/kg$) from Big Cypress, April 1969 to March 1970, and from canals in Broward County, December 1966 to June 1969. Concentrations of the DDT family ($\mu g/l$) in rainfall in southern Florida, 1968 to 1970.

Big Cypress			Broward County		
Range	Mean	No. of samples	Range	Mean	No. of samples
Water					
0.00-0.69	0.07	21	0.00-0.10	0.02	53
Sediment					
0.00-16.39	5.09	20	0.00-1,172.0	62.91	35
Aquatic plants 1/					
0.0-158		9	No data		
Fish 1/					
0.0-7,430		18	No data		

Rainfall

Southern Florida

Range	Mean	No. of samples
0-4.75	0.65	29

1/ Mean values not given because different species were sampled.

Aquatic animals and plants from the Big Cypress tended to contain higher concentrations of persistent pesticides than sediments (table 3). Aquatic plants had concentrations of these toxins as high as 158 μg/kg, and fish had concentrations as high as 7,430 μg/kg. Plants and fish from the Golden Gate Canal near Naples, had the highest concentration. Four fish (sunfish, large mouth bass, and Florida Spotted gar) collected in the canal had concentrations of the DDT family that ranged from 290 μg/kg to 7,430 μg/kg.

Water quality changes seasonally and diurnally in the Big Cypress. The changes are related to the natural hydrologic and biologic regimes. The seasonal recession of water levels triggers physical, chemical, and biological changes in water quality. During low water, diurnal fluctuations in dissolved oxygen are greatest as a result of the high concentration of organisms in the remaining water. During the day, plants produce excess oxygen by photosynthesis. Dissolved oxygen as high as 150 percent saturation was measured in one cypress pond in late afternoon. At night, dissolved oxygen decreases as photosynthesis ceases and respiration demands are met. Concentrations of dissolved oxygen may fall below 20 percent saturation (2 mg/l) before dawn. Fish-kills sometimes occur at this time. Dr. Burton Hunt has observed, during several years, spring fish-kills in the Tamiami Canal that usually began about 10 miles west of 40-mile bend, U.S. Highway 41, and often spread both east and west for several miles (oral communication, 1969). These kills occurred during periods of low dissolved oxygen.

The meager available data indicate that nutrient concentration in water changes seasonally in the Big Cypress. The average concentration of total nitrogen from six stations decreased from 0.96 mg/l in the dry period of April 1969 to 0.55 mg/l in the wet period of July 1969. Similarly, the average concentration of total phosphorous decreased from 0.16 mg/l in April 1969 to 0.01 mg/l in July 1969.

Hydrobiologic relations

The distribution and composition of the ecologic communities in the Big Cypress reflect the seasonal availability of water. Because of the seasonal fluctuation in water levels, the area is rich in aquatic and water-tolerant flora and fauna. They constitute a part of an ecologic system compatible with cyclic fluctuations in water levels and adaptable to the natural catastrophies of fire, flood, hurricane, and drought.

Because of the seasonal fluctuations in water levels, land elevation is a controlling factor in the type of ecologic community in a given location. Differences in elevation of 1 or 2 feet distinguish hammock forest from wet prairies and fresh-water swamps. These small differences, therefore, affect the ecology significantly.

Vegetal transects within the Big Cypress clearly show the close relations between water levels, land elevation, and vegetation. The transects are shown in figures 11-14; their locations are shown in figure 2. The water levels shown on transects of the pine-palm-palmetto forest (fig. 11) and the hardwood hammocks (fig. 12) represent a maximum (September 12, 1960), a minimum (May 30, 1962), and that at the time of field investigation, November-December 1969. They were interpreted for the sites from records of nearby Geological Survey gages. The transects for the cypress strand (fig. 13) and the Fakahatchee Strand (fig. 14) show only the water level at the time of field investigation, when water levels were somewhat above average. Because these transects are remote from gaged sites, no estimates could be made of maximum and minimum stages.

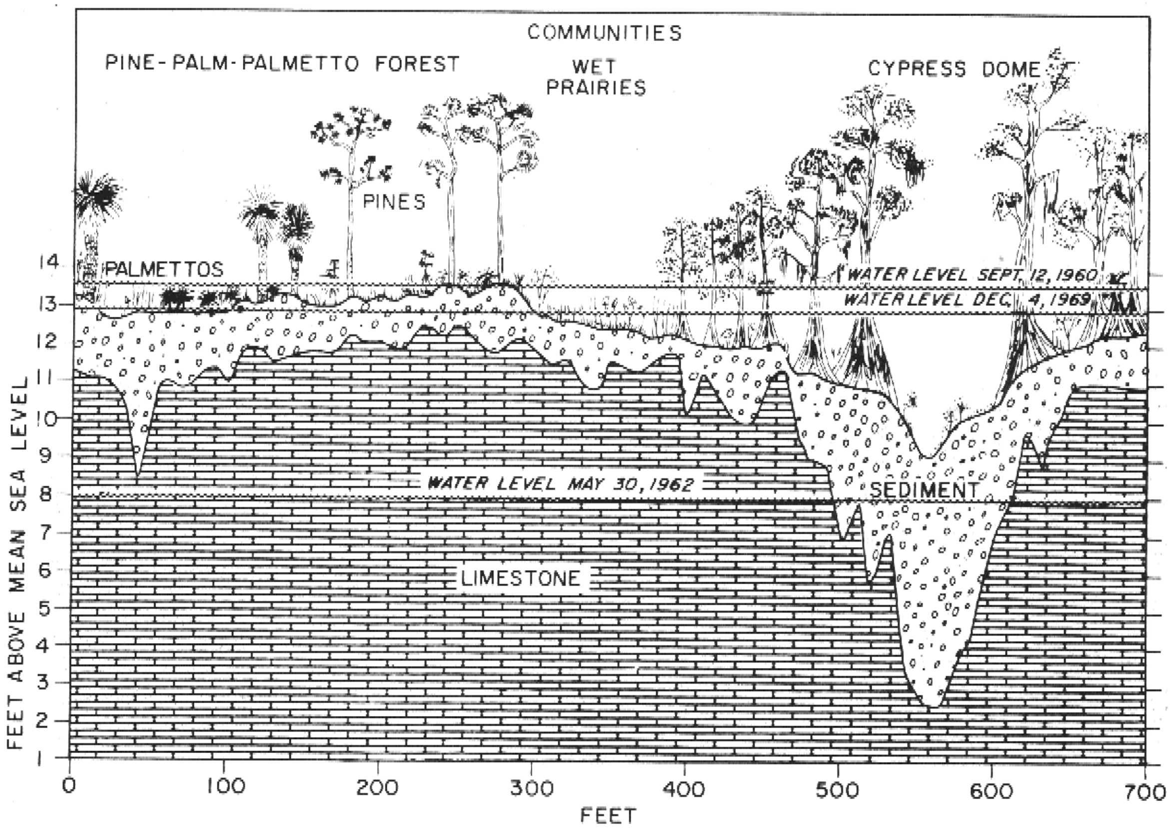

Figure 11.--Vegetal transect in the Big Cypress showing pine-palm-palmetto forest through a cypress-tree community.

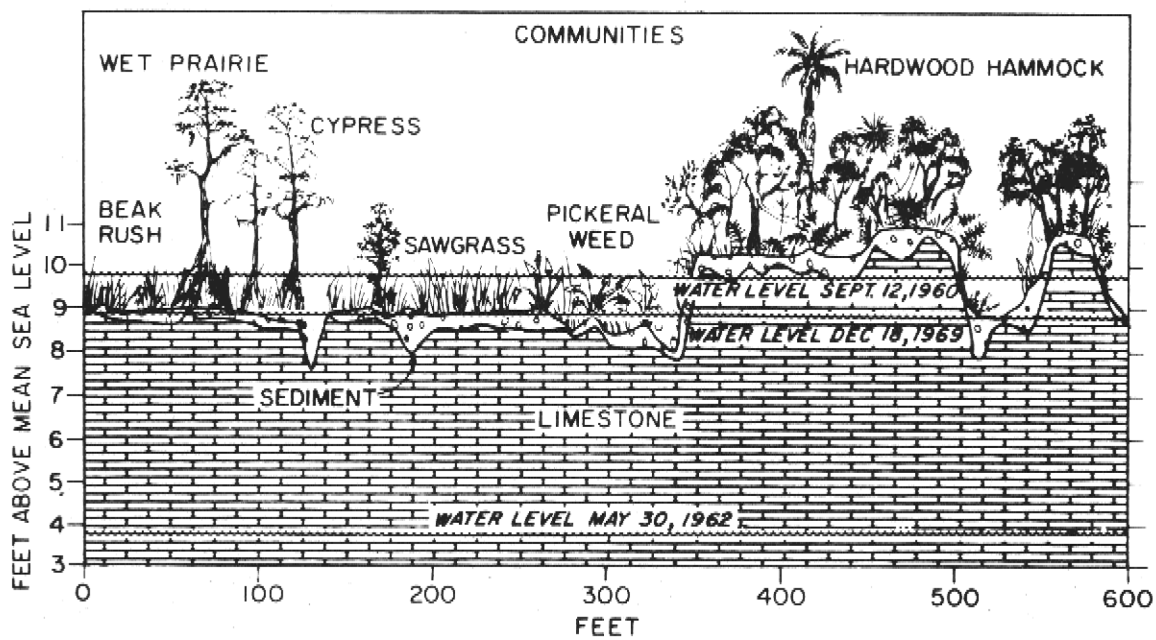

Figure 12.--Vegetal transect in the Big Cypress showing wet prairie into a hardwood hammock.

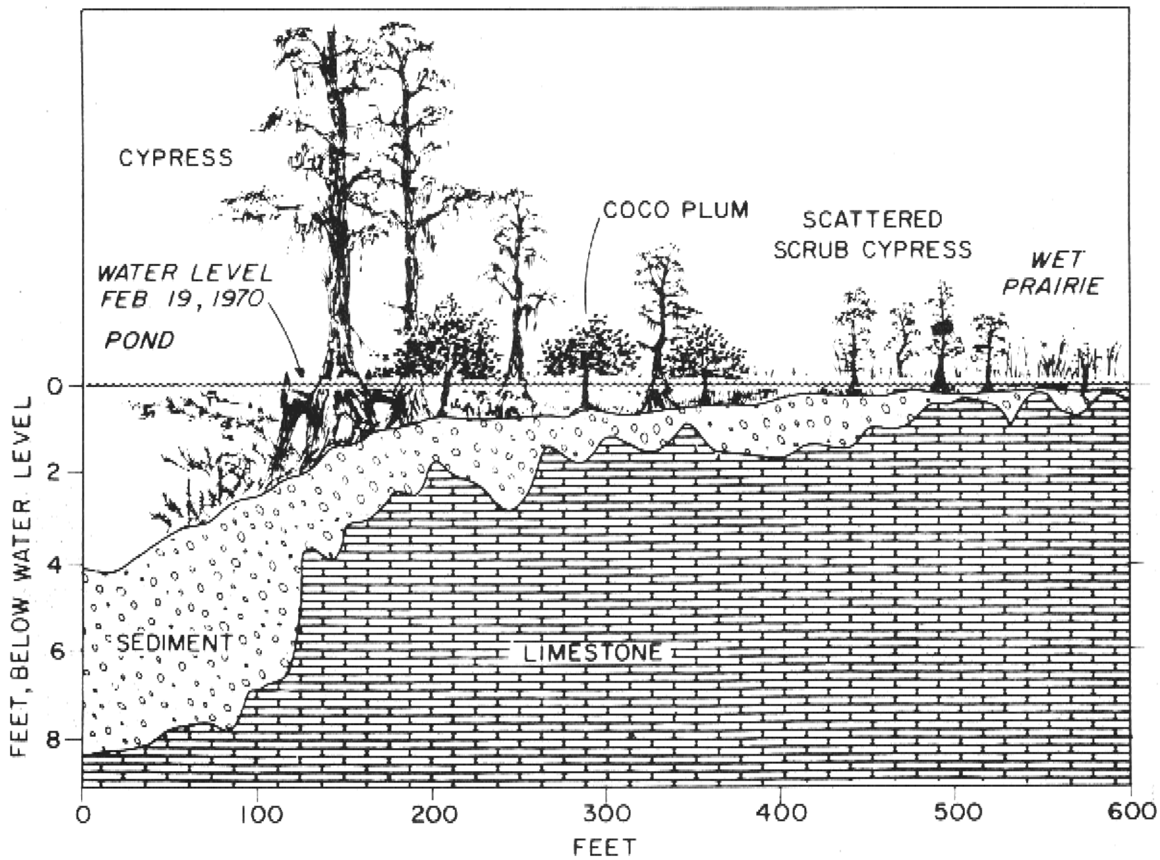

Figure 13.--Vegetal transect in the Big Cypress showing wet prairie into a cypress strand.

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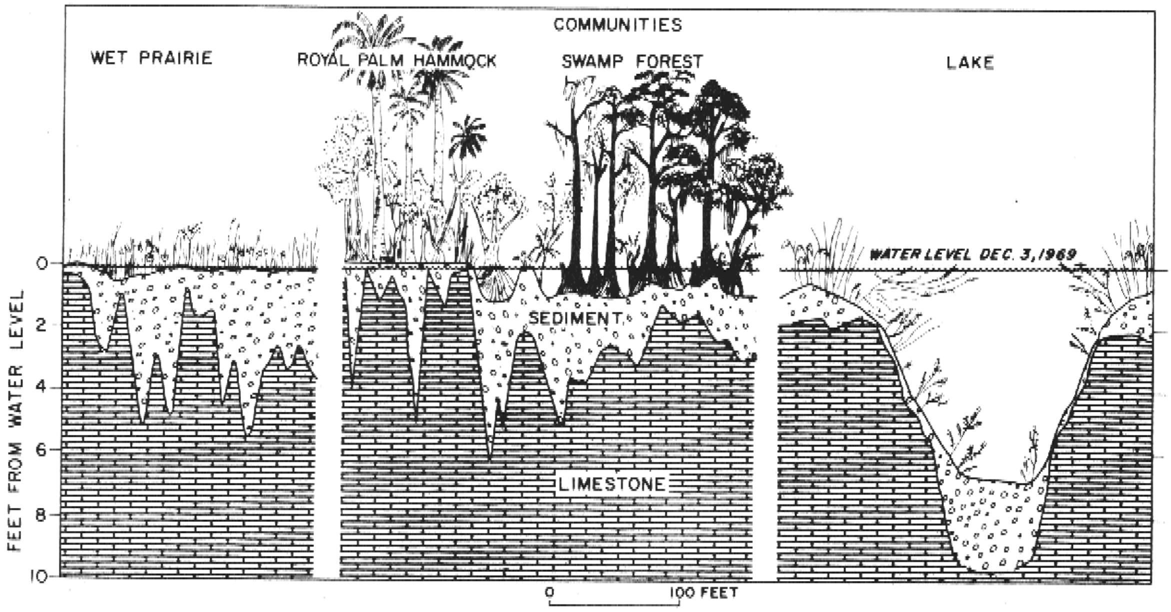

Figure 14.--Vegetal transect in the Big Cypress showing wet prairie, hammock, swamp forest, and lake in the Fakahatchee Strand.

As shown in figure 12, the hardwood hammock forest is established on land above high water. These hammocks are seldom inundated, but many have small, shallow depressions that contain water, at least during the wet season. The hardwood hammock at this site is surrounded by a wet-prairie and marsh environment that is covered with several inches of water during the wet season but is dry during the dry season.

Figure 11 depicts three distinct communities. The pine-palm-palmetto forest, although inundated for at least part of the year, occupies the higher elevations. A wet-prairie community grows where ground elevation is only inches lower than that of the pine-palm-palmetto forest. The cypress forest grows at the lowest ground elevation, as much as 2 feet lower than the pine forest. The cypress forests are inundated most of the year. They contain two distinct types of cypress: a small variety that grows in the shallow water and a large variety that grows in the deep water. In profile the large cypress-tree community is bell shaped, with the tallest trees in the center and successively shorter trees toward the edges. Open ponds occur within some of the tree communities; these are vital to survival of many plants and animals during drought. A somewhat similar transect is shown in figure 13. Again, the wet-prairie environment yields to scrub cypress and, at a slightly lower elevation, to a tall cypress-tree community in the form of a strand. Such strands, along with the ponds in the tree communities, are the last areas to become dry during the dry season; many contain water perennially except during extreme drought.

Figure 14 shows a transect into the Fakahatchee Strand. Although the Fakahatchee Strand is considered basically to be a swamp-forest environment, the presence of other communities is obvious. This strand contains more open water than any other fresh-water area in the Big Cypress. It is ecologically rich and is unique in its composition of flora (Finn, 1966).

As shown in the four transects, local ground elevations generally vary less than 3 feet. Although the extremes of variations in water levels are about 6 feet, the normal range is about 3 feet. Thus, the seasonal fluctuations in water levels result in extensive, almost complete inundation during the wet season and in localized concentration of water in the sloughs and ponds in the dry season.

The availability of food in the Big Cypress is related to seasonal water levels. During the seasonal high-water period, abundant food is produced in the flooded areas. Periphyton mats, growing as thick as 2 inches on submerged vegetation and on the flooded land, provide an abundant source of food for fish and invertebrates. During this period, these populations increase significantly. During the unseasonably high-water period between December 1969 and March 1970, fresh-water prawns, the dominant species trapped in a cypress slough near Road 94, increased from 31 specimens per trapping with a total wet weight of 3 grams to 123 specimens per trapping with a total wet weight of 10 grams (fig. 15). This

corresponds to the patterns of increase that have been measured in the Everglades during comparable wet periods. As water levels decline during the dry season, aquatic populations are forced to concentrate in the remaining water in the ponds and sloughs. Densities as high as 5,000 fish per cubic meter of water have been reported (Kahl, 1962).

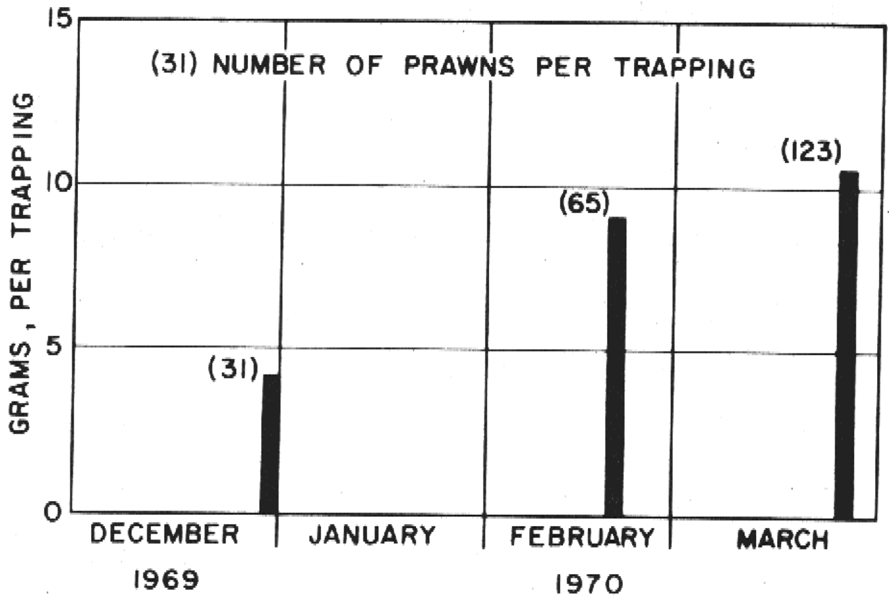

Figure 15.--Graph showing the number and wet weight of fresh-water prawns collected per trapping in a cypress strand in the Big Cypress.

The biomass concentrated in the ponds and sloughs is a rich source of food for larger animals, especially fish, snakes, alligators, and predatory birds. Large flocks of wading birds depend mostly upon this concentration of fish for their food. As many as 350 wading birds have been observed feeding in one small cypress pond less than 150 feet in diameter (Barry Michael, oral communication, 1969).

The estuarine environment is equally responsive to change in the fresh-water outflow from the inland areas. This fresh-water outflow mixes with the salt water in the estuaries to provide brackish conditions required by many marine and estuarine species during some or all phases of their development (Tabb, 1962; McPherson, in preparation).

The major vegetal food source in the estuaries is detritus from the red mangrove (Heald, 1969; Odum, 1970), which is decomposed by various microorganisms. The mangrove leaves and stems decompose more readily in brackish water than in fresh water or on land. Thus, the detritus-consuming organisms in the brackish environment, in turn, provide food for higher organisms. Because of the abundance of food and other salutary influences, the estuaries that drain the Big Cypress are habitats for several commercially important marine animals. Data from the Bureau of Commercial Fisheries indicate that more than two million pounds of marine animals with a value of more than $300,000 were landed in the vicinity of the Ten Thousand Islands in 1960. Sixteen commercial species in this area are dependent upon the brackish water of the estuaries at some stage of their life cycle (Tabb and Yokel, 1968).

Water levels in the Big Cypress are of major importance to the ecosystem because of the fact that a relatively narrow range in stage governs the complete range of plant communities in the fresh-water environment and the salinity balance in the estuaries. At any given location, the environment can range from fresh-water swamp to hammock forest within a range of average annual water levels of less than 3 feet. A dynamic but delicate adaptation of species to water levels prevails, and any abrupt and permanent changes of even a few inches in the water-level regimen would result in major changes in the ecology.

THE BIG CYPRESS AS A WATER SOURCE FOR EVERGLADES NATIONAL PARK

Contributing area

Nearly half the Big Cypress--1,160 square miles--contributes drainage directly to the Park. This half consists of that part of subarea C east of the Barron River Canal.

The Barron River Canal was delineated as the general western boundary of the contributing area on the basis of recent aerial photographs. Aerial photographs, field observation, and available hydrologic data indicate that the Barron River intercepts much of the flow of the Okaloacoochee Slough except during high water, when some water spills into the Fakahatchee Strand. In early April 1970, about 50 cfs of water was flowing across Road 29 from the Okaloacoochee Slough into the Fakahatchee Strand. Available hydrologic data indicate that the Barron River Canal intercepts as much as 150 cfs of the westward flow of the Okaloacoochee Slough. Although, at times, flow across Road 29 is eastward as a result of locally heavy rains, the net flow, undoubtedly, is predominately westward into the Fakahatchee Strand. Thus, the western boundary of the area contributing water to the Park is somewhat indefinite.

As a major drainage course through the Big Cypress, the Fakahatchee Strand carries a significant part of the runoff. The strand, however, does not pass through the Park, but lies just to the north and west of it. Nevertheless, the strand is hydraulically connected with the Park during high water. Further, some strand water probably enters the lower ends of the estuaries that extend inland into the Park.

Quantity of Water

The amounts of water entering Everglades National Park from the Big Cypress in relation to other surface supplies available to the Park are given in Table 4. The table shows computations of average discharge into the Park for two periods, one before (1941-62) and the other after (1963-69) the control of releases of water from the Everglades drainage system to the Park.

These flow values indicate that subarea C contributed between 55 and 60 percent of the surface inflow received by the Park during the 22 years before control of Everglades water at the northern boundary of the Park and also during the subsequent 7 years, when the Conservation Area 3 controls were in operation.

The inflow from subarea C of the Big Cypress supplies about 16 percent of the Park, an area of about 350 square miles at the extreme northwest end of the Park. Thus, 16 percent of the Park area receives between 55 and 60 percent of the total surface inflow.

Table 4.--Average flow to Everglades National Park, for the periods 1941-62 and 1963-69.

Location	Records Available	1941-62 Average discharge cfs	1941-62 Average discharge acre-feet per year	1963-69 Average discharge cfs	1963-69 Average discharge acre-feet per year
From Everglades and East Coast drainage systems:					
Taylor Slough near Homestead 1/	1961-69	46	33,300	45	32,600
Tamiami Canal outlets, levee 30 to levee 67A	1939-69	343	248,300	98	70,900
Tamiami Canal outlets, levee 67A to 40-mile bend	1939-69	172	124,500	659	477,100
Subtotal		561	406,100	802	580,600
From Big Cypress (subarea C):					
Tamiami Canal outlets 40-mile bend to Monroe 2/	1939-69	272	196,900	299	216,500
Tamiami Canal outlets Monroe to Carnestown 2/	1953-69	380	275,100	405	293,200
Barron River Canal near Everglades 2/	1953-69	96	69,500	102	75,800
Subtotal		748	541,500	806	585,500
Total average southward flow to Park		1,309	947,600	1,608	1,164,100

Note.--Hydrologic rather than calendar years are used in above table. For example, the 1941 hydrologic year begins October 1, 1940.

1/ Measured near Royal Palm Hammock but considered representative index of flow entering the Everglades National Park from the northeast.

2/ Drainage from Big Cypress considered as index of flow but does not include any flow originating in area between Tamiami Canal and the park boundary.

Shorter records were correlated with longer records from nearby stations and extended. The correlations, examples of which are shown on figure 16, are considered to be fairly good. The

locations of the various contributing segments of the drainage (table 4) are shown on figure 17.

The flows contributed to the Park from the Big Cypress, as calculated for this report, differ from those reported by Leopold (1969). Those in the Leopold report are based on an index of water needs in the Park, using the available data for the 10-year period ending in 1962, before water control in the Everglades. Flows in the Leopold report were modified to be comparable with the figure 260,000 acre-feet per year, widely used as the average annual water needs for the Park from the Tamiami Canal outlets from Levee 30 to 40-mile bend. The computations in the present report are based on historic flows during 1940-62, before control of water releases from the Everglades southward across Tamiami Trail.

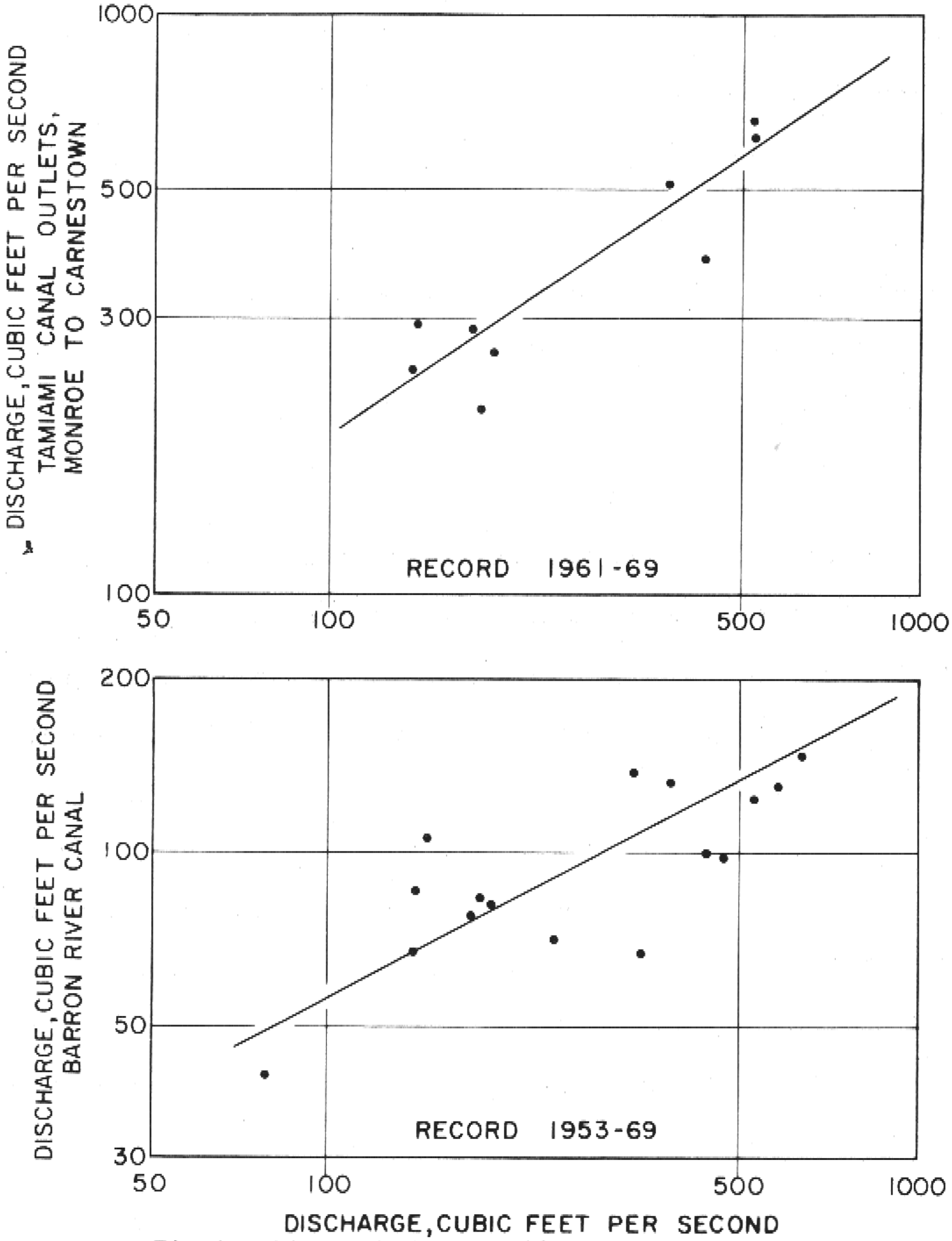

Figure 16.--Graph showing selected correlations of mean annual discharges used for extending streamflow records to the 22-year period, October 1940 to September 1962.

TAMIAMI CANAL OUTLETS

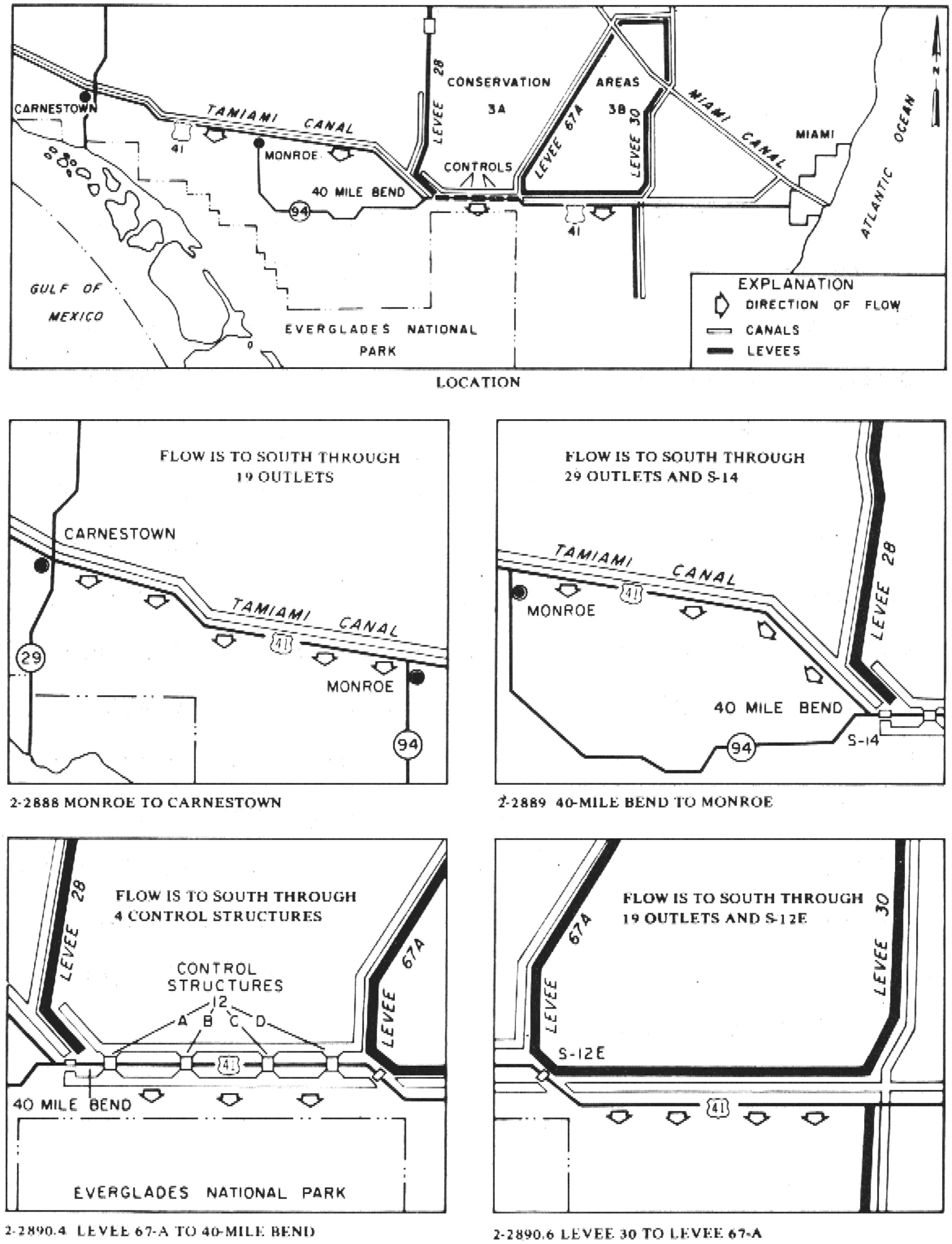

Figure 17.--Maps showing location of the Tamiami Canal outlets.

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WATER-CONTROL WORKS IN THE BIG CYPRESS

Golden Gate Estates System

Construction of the Golden Gate water-control system began in the early 1960's and has continued intermittently into 1970. The initial phase began with the excavation of the Golden Gate Canal, the primary canal that discharges water to the Gulf of Mexico at Naples (fig. 1). At about the same time, Road 846 from Naples to Immokalee, Road 858 east of Naples, and Road 951 southeast of Naples were nearing completion. The borrow canals adjacent to those roads were connected with the Cocohatchee River Canal in the north and with the Henderson Creek Canal in the south, thereby furnishing the basic network of a drainage system. Although the canals are shallow, they are moderately effective in draining water from the Golden Gate Estates, a 6-mile-wide rectangular area of about 54 square miles east and northeast of Naples. Before construction of the drainage network, the area inland from Naples was inundated each year during the rainy season, much as other parts of the Big Cypress are.

The Golden Gate Canal extends inland from the Gulf about 20 miles. The bottom of the canal is excavated to about 5 feet below sea level near the coast and to 6 to 8 feet above sea level in the interior. The shallow depth of the canal and the distribution of weirs in the canal network limit the drainage of water from the shallow aquifer in inland areas. By limiting the drainage from aquifer storage, regional water levels near the coast are not lowered enough for salt-water intrusion. Salt-water intrusion caused by uncontrolled drainage by canals in the early development of southeastern Florida was described by Parker (1951, p. 826-827).

When water levels are high, ground water moves to the canals and flows over the weirs. Soon after the rainy season, flow over the interior weirs ceases but continues longer in downstream reaches. Water has continued to flow over the primary weir near the outlet of the Golden Gate Canal since it was completed, about 1964.

Flow over the primary weir of the Golden Gate Canal has ranged from 2,390 cfs on July 1, 1966, to 28 cfs on May 27, 1967, with an average of 350 cfs (228 million gallons per day) during 1965-68. The pattern of daily flow over the weir for 1966 and 1968 is shown in figure 18. During the 1965-68 period of record, little or no

known flooding occurred in the area drained by the canal. An indication of the effectiveness of the canal in lowering water levels in adjacent areas is shown by the rapid rate of recession of water levels in well 382. (See fig. 5 for hydrograph.) Since the beginning of water control in the Golden Gate Estates area, water levels have been lowered by an average of 2 to 4 feet.

In 1968, construction was started on the Fahka Union Canal, 17 miles east of Naples and 6 miles west of the Fakahatchee Strand. When it is completed, this canal will extend northward nearly to Lake Traffard. The southernmost weir in this canal is 300 feet north of U.S. Highway 41. The crest elevation is 2 feet above sea level. Weirs will be distributed throughout this canal system also to limit the drainage of water from the shallow aquifer and to maintain water levels in conformance with the general slope of the land surface. Canals will connect the Fahka Union system with the Golden Gate system. The Fahka Union Canal system should be as effective as The Golden Gate system in lowering annual peak water levels and in reducing inundation in subarea B.

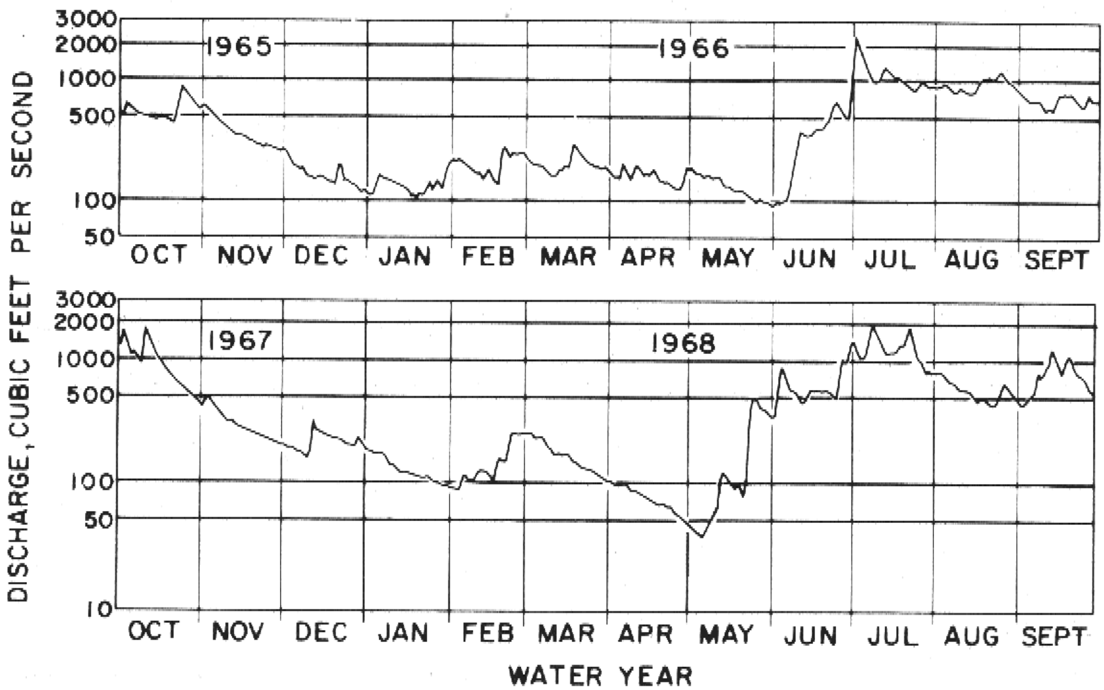

Figure 18.--Hydrograph of discharge for the Golden Gate Canal for the 1966 and 1968 water years.

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Barron River and Turner River Canals

The Barron River Canal excavated during the 1920's to obtain fill material for Road 29, extends from Everglades City northward to Immokalee. Similarly, the Turner River Canal, 5 miles east of the Barron River Canal, excavated during construction of Road 840A, extends from the Tamiami Canal northward to the Everglades Parkway. The two canals form the basis of a drainage system for the western part of subarea C south of the Everglades Parkway. The effect of the canals on lowering water levels has been relatively small. Records of flow are available for 17 years for the Barron River Canal, but only partial records of flow are available for the Turner River Canal. The discharge of the Barron River Canal during the 1966 water year is shown on figure 19. The hydrograph shows the

typical high discharge for the rainy season and the general decline in flow through the end of the dry season. The average discharge for 17 years of record is 102 cfs, with a maximum average year's discharge of 292 cfs and a minimum of zero.

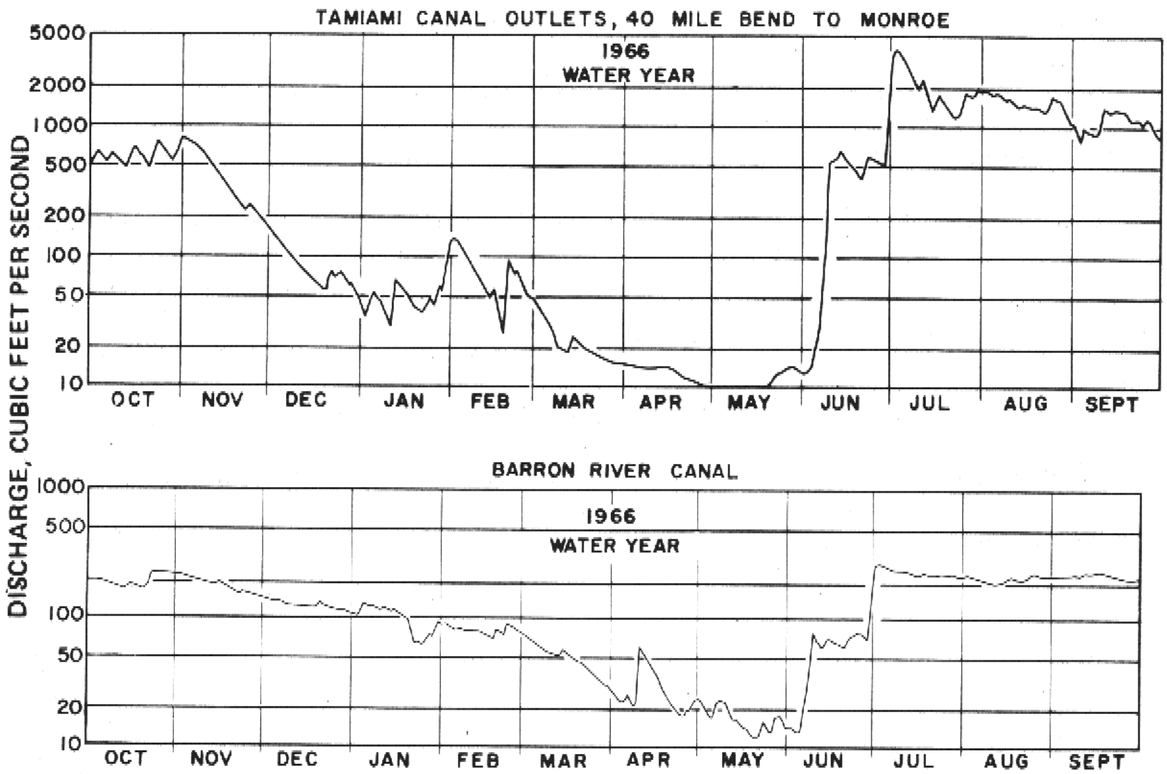

Figure 19.--Hydrograph of discharges for the Tamiami Canal outlets, 40-mile bend to Monroe and the Barron Canal for the 1966 water year.

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The flow of the Barron River Canal is controlled through a series of stop-log controls at seven sites north of U.S. Highway 41. In general, all boards are removed from the controls during the rainy season, and, as water levels decline after the rains cease, the boards are replaced to limit drainage from the shallow aquifer. Flow exceeds 100 cfs for several months, (see fig. 19), suggesting continuous contribution of water from the shallow aquifer. As the dry season persists, the water table continues to decline because of evapotranspiration and seepage to the canal. In the upper reaches, the canal goes dry when the water table declines to levels below the canal bottom. The Barron River and Turner River Canals receive substantial quantities of water from the Okaloacoochee Slough. Because the Barron River Canal is more than 40 years old, water levels in the vicinity have stabilized.

PROBABLE EFFECTS OF CONTINUED URBAN GROWTH ON WATER RESOURCES AND BIOTA

Expected Pattern of Urban Expansion

Existing water-control and drainage systems, the beginning of rudimentary drainage works, and areas already proposed and platted for housing suggest four general areas of urban growth in the near future. The major area of urbanization is the Golden Gate Estates complex, which is expanding east and southeast from Naples, as shown in figure 4. The primary Fahka Union Canal, which will provide water control for the inland phase of development, is nearing completion, and housing construction immediately inland from Naples is underway. As urbanization continues, secondary canals will be required for protection against high water levels.

The second probable area of urbanization is the low coastal zone from Naples southeastward to Ochopee. Development seaward of U.S. Highway 41 will probably start soon. Canals are being excavated from the highway to the coast to provide fill for home construction and to furnish access to the Gulf for small boats. Coastal urbanization of this type should accelerate because of the high desirability of waterfront housing with access to the ocean. Some scattered industrial growth may be expected adjacent to and immediately north of U.S. Highway 41, probably of the light-industry type associated with building construction and services.

A third probable site for development is 200 square miles west and east of the Barron River Canal between the Everglades Parkway and U.S. Highway 41, which includes the Fakahatchee Strand. Development plans here are not known, but the 100-square-mile area east of the Barron River Canal is bounded on both sides by canals, which represent the beginning of water control. This area, part of subarea C, contributes water to the Park. In 1970 a few scattered dwellings had been built, mainly along U.S. Highway 41; building will probably continue but at a slow rate, unless additional protection from high water is provided.

Gum Slough and vicinity, a 50-square-mile area immediately north of the Park, may be developed in the near future. A formal drainage district was proposed in 1969, but, because of objections, no further action has been taken.

The 39-square-mile area owned by the Dade County Port Authority, intended to become a jetport, is rather inactive. At present, one runway is operational for training under an agreement between the Departments of Interior and Transportation, State of Florida, and Dade and Collier Counties. Further development is precluded under the present terms of the agreement.

The remainder of subarea C east of the Turner River Canal, excluding the jetport site, is undeveloped and is not at present subject to pressures for development.

Effects on water resources

An area such as the Big Cypress cannot be urbanized until drainage and water-control measures are begun. Once a drainage system becomes operational, water supplies commensurate with projected water needs are required. Water control can be achieved by: (1) raising the land surface by filling to elevations above high-water levels; (2) excavating systems of controlled primary and secondary drainage canals; and (3) combining land fill and canal excavation. Each affects water levels differently. Excavation for land-fill operations results in a slight lowering of water levels because of increased space for ponding of water and increased evaporation from the more persistent excavated open-water areas; canal systems result in a significant lowering of water levels; the combination of land fill and canal excavation results in an intermediate lowering of water levels. Uncontrolled drainage, causing massive water losses, would probably change the aquatic ecosystems irreversibly. But areas of future urbanization will probably have similar patterns and methods of water control and management as those in the Golden Gate Estates, where controlled drainage is designed to lower the overall water level evenly and to prevent excessive draining of the shallow aquifer.

The first effect of urbanization in the eastern part of subarea B and the western part of subarea C would be to lower the annual high-water levels and to accelerate runoff adjacent to improved primary canals. Secondary canals would lower water levels in progressively larger areas. Thus, fresh-water runoff would be accelerated further. The net result of urbanization would be to lower water levels in the western half of the Big Cypress and to reduce the time the land is inundated.

The annual controlled discharge of the primary canals represents not only water discharged for protection from high water levels but also water potentially salvageable, through good water management, for urban use.

The ultimate configuration of the water table under urbanization would be similar to that of the present day but at a lower elevation. The system of controls (weirs) in the canals, under good water management, would permit discharge of flood water only and would step the water levels up from lower elevations at the coast to high elevations in the interior. The depth of canals below the water table would have a significant effect on ground-water pickup along canals, the seaward flow in canals, and the height of the regional water table.

Maintaining water levels above sea level (2 feet or more) in the coastal areas would be a major factor in preventing salt-water intrusion. With this safety factor, municipal well fields could be established near the coast to serve the expected coastal urban growth. Preferred sites would be inland from coastal control structures and adjacent to primary canals. Such sites would assure nearly constant well-field replenishment by infiltration from canals, thereby minimizing lowering of water levels.

The prime factors in the optimum development of water resources are design and subsequent water management commensurate with hydrologeologic conditions. Effective water management will have to include control of water pollution, as population increases. If urban planning and water management are haphazard, pollution could constrain the use of the shallow aquifer for water supplies and the lakes and canals for recreation. Pollutants in canals could readily move to adjacent well fields. When canal systems are fully operational and demand for water increases with population growth, flow in canals may decrease, resulting in less dilution and flushing of any pollutants reaching the canals. The control of pollutants reaching canals, therefore, may become of critical importance.

No estimate is available of the total water-supply potential of subarea B and the western part of subarea C. The present total water use in those areas is insignificant compared with the quantity evaporated, transpired, and discharged through the canal systems. The largest center of water use is the Naples area, where the peak daily water needs are about equal to the minimum discharge of the Golden Gate Canal (28 cfs, or 18 mgd), or to about 8 percent of the average discharge of the canal. The western part of the Big Cypress, therefore, can yield at least 10 times the present Naples water use without significantly lowering water levels. The Naples Water Department is presently exploring 12 to 15 miles inland for future municipal water supplies. No estimate is now available for the water potential of the remainder of subarea B and the eastern part of subarea C.

Effects on biota

Uncontrolled drainage of the Big Cypress, especially in the Fakahatchee Strand and other major slough areas, would undoubtedly alter the local ecology and would influence that in surrounding areas. The ecology of the Big Cypress would, of course, be changed, and biota in estuaries and the adjacent Gulf of Mexico would be affected.

Plants and animals of the Big Cypress depend on the seasonal fluctuation and movement of fresh surface water. In this environment, aquatic foods are produced seasonally. The widespread production of aquatic foods when most of the land is inundated and the subsequent concentration of this food in creeks, sloughs, and ponds as water levels decline in the dry season are most significant in maintaining the rich and varied biota.

Uncontrolled drainage of the Big Cypress would decrease the extent and the duration of fresh-water inundation, thus decreasing production of aquatic food and fish. Populations of the larger fish, reptiles, birds, and mammals that depend upon concentration of fish could be reduced or eliminated. Similarly, the estuarine environment would be affected by changes in water-flow patterns, as fresh-water inflow to the estuaries controls seasonal changes in salinity, a key factor in estuarine ecology.

In general, estuarine species are adaptable to wider ranges of environmental changes than marine or fresh-water organisms are, but they are susceptible to excessive variations in salinity, temperature, or turbidity (Hedgpeth, 1957), especially when the variations are rapid. Such variations or changes in the seasonal cycles of the above parameters would adversely affect the nursery function of the water. Drainage of subarea C comparable with that of the western part of subarea B would produce conditions that could not be tolerated by some estuarine species. Increased silt and mud in the estuaries from construction activities also would adversely affect benthic forms, vital to the food chain, by covering them, reducing light penetration, or covering hard substrata necessary for larval attachment.

Drainage and development of the Big Cypress undoubtedly would result in some increase in pollution. Pesticides are now at relatively low concentrations in the Big Cypress and are significantly lower than in the surrounding developed areas (table 3). Land development would probably increase pesticide levels in the water, sediment, and biota, and higher levels of organochlorine pesticides would be concentrated at the top of the food chain in the predatory birds, mammals, and fish.

These organochlorine pesticides increase the production of enzymes in birds. Excess enzymes break down steroid hormones essential to production of calcium, resulting in eggs with thin shells and in increased mortality of the young. The high level of these compounds in the American eagle and several hawks, probably accounts for their declining numbers in the United States in recent years (Hickey and Anderson, 1968).

Increased pesticide buildup in the estuaries would endanger the nursery function of the water, because young organisms are usually more sensitive to toxins than adults (Moore, 1958). Crustaceans, which constitute one of the larger estuarine groups, are intolerant of chlorinated hydrocarbons. Aldrin and endrin concentrations as low as 0.6 part per billion kills pink shrimp, the most commercially important crustacean in these waters (U.S. Department of the Interior, 1964).

Further drainage and development of the Big Cypress would likely result in increased nutrients in the canals and estuaries, which could lead to changes in species composition of both fresh- and brackish-water organisms and to eutrophication. Recent studies by Wood (oral communication, 1970) have shown that the species composition of periphyton in the Park has changed noticeably within the last few years. Wood believes that these changes may have resulted from increased nutrients.

The western part of the Big Cypress in subarea B is now being drained. The lowering of water levels and change in runoff patterns will result in biologic change. The change can be minimized only through careful planning and proper resource management.

Drainage with consequent loss of habitat has reduced the number of wood ibis in the Big Cypress from about 15,000 in the mid-1960's to less than 6,000 in 1969 (William Robertson, written communciation, 1969). At least 60 percent of the wood ibis of the United States nest in this area. To compensate for the loss of feeding area, as a result of this drainage, artificial ponds are being constructed near the Corkscrew Swamp to furnish adequate food for a major colony of wood ibis.

Water hyacinths are now common in the Golden Gate Canal and can be expected to spread. Extension of canals would facilitate the dispersal of some undersirable aquatic plants, including water hyacinth. This plant is common in most canals in south Florida and can extend its range into the interior swamps. Such spreading has been observed in some cypress ponds north of U.S. Highway 41, where the water hyacinth has replaced water lettuce, considered to be a more desirable plant. After this replacement, open-water areas in the ponds were reduced, and ducks were no longer observed in the area (Oscar Owre, oral communications, 1970).

Extensive drainage and development of the Big Cypress, particularly subarea C, would result in extensive change in the environment of downstream areas, including parts of the Park. The fresh-water ecosystem would be depleted and replaced by a terrestrial ecosystem. The present estuarine environment would be significantly altered. Wildlife, including rare and endangered species dependent upon aquatic environment or wilderness areas, would be further reduced in number and might be destroyed.

Effects on Everglades National Park

Continued eastward urban expansion in the Big Cypress, particularly into subarea C south of Everglades Parkway, would affect water flow, water quality, and biota of the Park.

At present, an average of 541,500 acre-feet of water per year moves toward the western part of the Park from subarea C. This water is of good quality and does not have high concentrations of undesirable contaminants. The annual wet and dry cycle, with its attendant inundation and recession, is conducive to production and concentration of aquatic foods, which support a wide variety of birds and animals in the Big Cypress and in the Park. Drainage and development would change the period and pattern of flow, would increase contaminants in the water, and would reduce aquatic production. These changes would adversely affect both the fresh-water and estuarine biota of the Park.

Large wading birds, such as the wood ibis and the roseate spoonbill, that congregate at times in the Park live in much larger areas than the Park. These birds move back and forth between the Park and the Big Cypress. Extensive drainage and development of the Big Cypress, therefore, would eliminate their northern habitat.

A continuing program of hydrologic and biologic investigations in the fresh-water and estuarine environments in subarea B would furnish valuable information in determining the effects of drainage on water quality, water levels, and biota. This information would have transfer value in predicting changes in other parts of the Big Cypress if they are opened to further land development. Further investigations in subarea C would furnish benchmark information for monitoring changes, both in the Big Cypress and in the Park, brought about by future changes in hydrologic conditions.

ACKNOWLEDGMENTS

All the people who have kindly lent assistance and who have freely given information vital to this report and the investigation on which it is based are here most gratefully acknowledged. All who aided would be too numerous to list, but they, as well as those listed below, who helped directly, should know that their contributions are much appreciated by the authors.

The following people provided information or assistance in the preparation of this report:

J. I. Garcia Bengochea	Black Crow and Eidsness
R. A. Ghiotto	Black Crow and Eidsness
B. T. Hunt	University of Miami
J. A. Kushlan	University of Miami
J. Kuperberg	Collier County Conservancy
M. Morris	National Park Service
F. Nix	National Park Service
J. C. Ogden	National Park Service
P. Owens	National Audobon Society
O. T. Owre	University of Miami
J. C. Raftery	National Park Service
W. B. Robertson	National Park Service
J. W. Rogers	Collier County Sheriff's Department

W. F. Savidge	City of Naples
J. B. Sitzler	Dade County Port Authority
Smally, Wellford and Nalven	
W. V. Storch	Central & Southern Florida Flood Control District
R. L. Taylor	Central & Southern Florida Flood Control District
W. H. Turner	Collier County
R. O. Vernon	Florida Department of Natural Resources
E. C. Winte	National Park Service

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