WATER AND THE SOUTH FLORIDA ENVIRONMENT

by Howard Klein and others

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Increasing population and the concomitant urban sprawl and industrial growth in South Florida has caused concern to agencies involved in land-use planning and water management as to the adequacy of water supplies, determination of water quality and changes in environmental factors. This report describes the physical system, past and present, the environmental problems that exist now, and provides alternative solutions to these problems with emphasis on alternatives that might be used to minimize deleterious effects on the environment of south Florida in years to come.

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South Florida Water
Management District
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U. S. Geological Survey

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FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert the English units published herein to the International System of Units (SI). Subsequent reports will contain both the English and SI unit equivalents in the station manuscript descriptions until such time that all data will be published in SI units.

Multiply English units	By	To obtain SI units
	Length	
inches (in)	25.4	millimetres(mm)
	.0254	metres(m)
feet (ft)	.3048	metres(m)
yards (yd)	.9144	metres(m)
rods	5.0292	metres(m)
miles (mi)	1.609	kilometres (km)
	Area	
acres	4047	square metres(m^2)
	.4047	*hectares (ha)
	.4047	square hectometre(hm^2)
	.004047	square kilometres(km^2)
square miles (mi^2)	2.590	square kilometres (km^2)
	Volume	
gallons (gal)	3.785	**litres (l)
	3.785	cubic decimetres (dm^3)
	3.785×10^{-3}	cubic metres(m^3)
million gallons (10^6 gal)	3785	cubic metres(m^3)
	3.785×10^{-3}	cubic hectometres (hm^3)
cubic feet (ft^3)	28.32	cubic decimetres (dm^3)
	.02832	cubic metres (m^3)
cfs-day (ft^3/s-day)	2447	cubic metres(m^3)
	2.447×10^{-3}	cubic hectometres (hm^3)
acre-feet (acre-ft)	1233	cubic metres(m^3)
	1.233×10^{-3}	cubic hectometres (hm^3)
	1.233×10^{-6}	cubic kilometres(km^3)
	Flow	
cubic feet per second (ft^3/s)	28.32	litres per second (l/s)
	28.32	cubic decimetres per second (dm^3/s)
	.02832	cubic metres per second (m^3/s)
gallons per minute (gpm)	.06309	litres per second (l/s)
	.06309	cubic decimetres per second (dm^3/s)
	6.309×10^{-5}	cubic metres per second (m^3/s)
million gallons per day (mgd)	43.81	cubic decimetres per second (dm^3/s)
	.04381	cubic metres per second (m^3/s)
	Mass	
ton (short)	.9072	tonne (t)

*The unit hectare is approved for use with the International System (SI) for a limited time. See NBS Special Bulletin 330, p.15, 1972 edition.

**The unit liter is accepted for use with the International System (SI). See NBS Special Bulletin 330, p. 13, 1972 edition.

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INTRODUCTION AND PURPOSE

Ecological problems are a major concern to Florida as well as to the Nation. National attention was focused on these problems in September 1968, when the Port Authority of Dade County began to construct a jetport for supersonic aircraft on a 39-square-mile tract 6 miles north of Everglades National Park and on the east edge of the Big Cypress Swamp. Conservation groups and citizens raised questions as to the effects of a regional jetport and the attendant satellite growth on the water resources and biological communities of the National Park. The Department of the Interior began studies to investigate the situation. One study, Leopold (1969), reported on the unfavorable ecological effects of the attendant satellite growth.

The Secretary of the Interior, Walter J. Hickel, directed the U. S. Geological Survey to study the water resources of the Big Cypress to determine which parts of the Big Cypress contribute the major part of the water necessary to maintain adequate water supplies for Everglades National Park. This was done in a report by Klein and others (1970).

At about the same time, the Departments of Interior and Transportation, the State of Florida, and the Dade County Port Authority concurred in assigning to the Secretary of the Interior certain responsibilities for planning, developing, and coordinating an ecological study of south Florida. A primary objective of the ecological study is to provide information that will assist in the formulation of land-use policy consistent with the protection of the environment of Everglades National Park, the adjacent estuaries, and the public water supplies.

The part of the investigation describing the surface-water and ground-water resources of south Florida was assigned to the Geological Survey. The quantity and quality of surface water and ground water and their interrelation with estuarine and marine waters are here considered. Also considered are the problems, present or future, related to the hydrologic environment that involve human, animal, and plant life. Changes taking place, apparent trends, and projections for the future are also considered, as well as alternatives for water management.

The Geological Survey effort began in January 1971, when aerial photography and selected qualitative hydrologic data were obtained. However, most of the information upon which this report is based was obtained by the Geological Survey in cooperative programs with several local, State, and Federal agencies since about 1940. The long-term support of the U.S. Army, Corps of Engineers, the National Park Service, U.S. Navy, Florida Department of Natural Resources, Central and Southern Florida Flood Control District, Dade, Broward, Palm Beach and Collier Counties, Miami and Miami Beach, Ft. Lauderdale, Naples and others in the collection of data is gratefully acknowledged.

A prolonged drought throughout south Florida from September 1970 to May 1971 accentuated the importance and timeliness of the study. The drought brought about a readvance of sea-water intrusion in many coastal areas, which necessitated restrictions on water use. The effect of drought on the regional water supply, continued population growth and increased water demands, and deterioration of the water quality in many of the canals and waterways of the urban areas accentuated the need for improved water management and land-use planning.

As a result of the water crisis, the Governor of Florida called a special conference in September 1971. The conference, attended by foremost scientific and government personnel, proposed creation of an agency that would develop and implement comprehensive land and water-use plans for south Florida that would minimize environmental degradation.

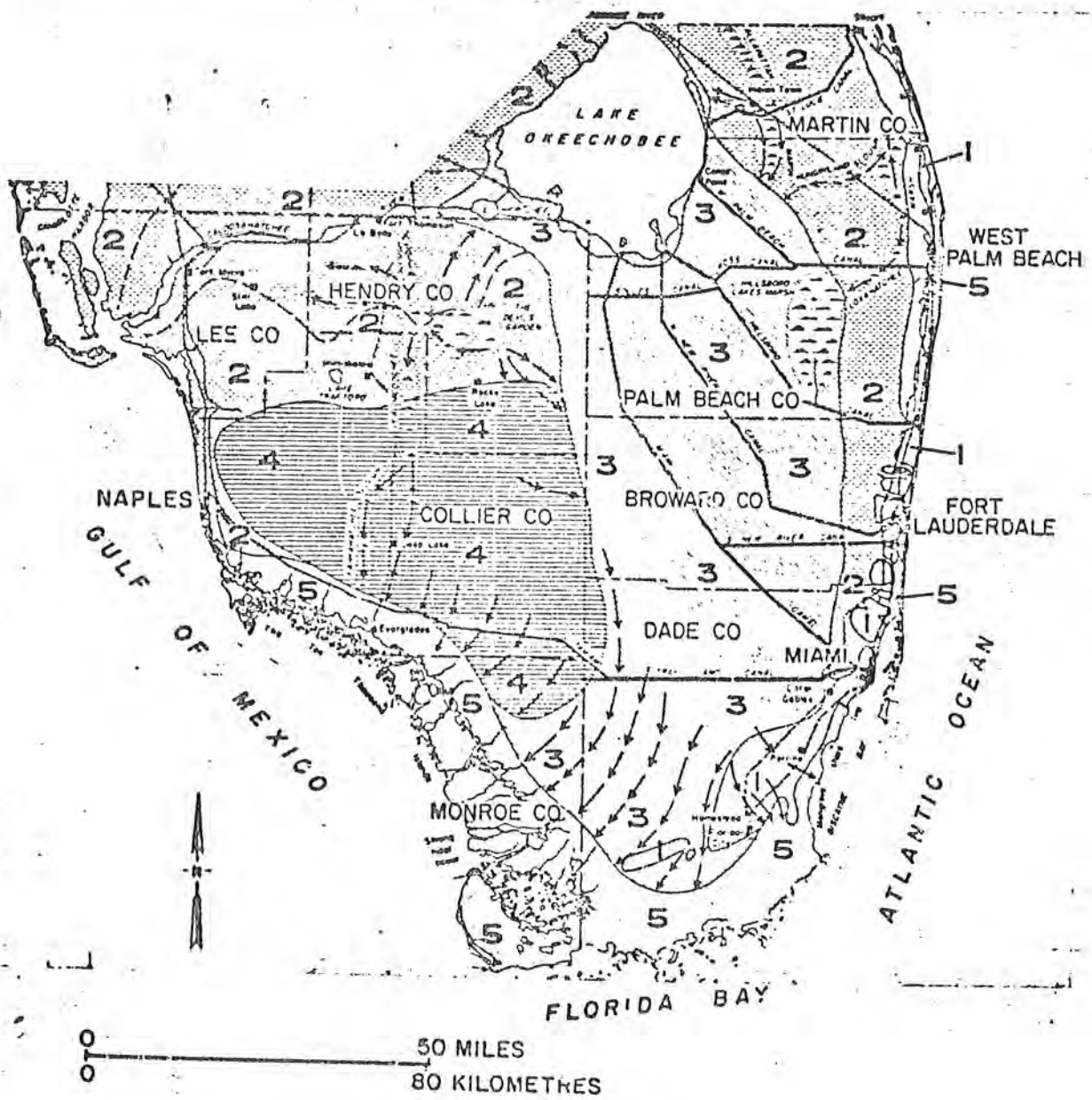
PHYSICAL FEATURES OF SOUTH FLORIDA

Physiographic Provinces

South Florida, generally flat and low-lying, occupies about 10,000 square miles of southernmost Florida. Davis (1943) divided south Florida into five physiographic provinces: the Atlantic coastal ridge, sandy flatlands, the Everglades, the Big Cypress Swamp, and the mangrove and coastal glades.

The Atlantic coastal ridge averages about 5 miles wide and ranges in elevation from 8 to 24 feet above sea level. It is breached in many places in Dade and Broward Counties by shallow sloughs known as transverse glades and by drainage canals constructed through the transverse glades. Drainage is generally eastward. Most of this province is densely populated.

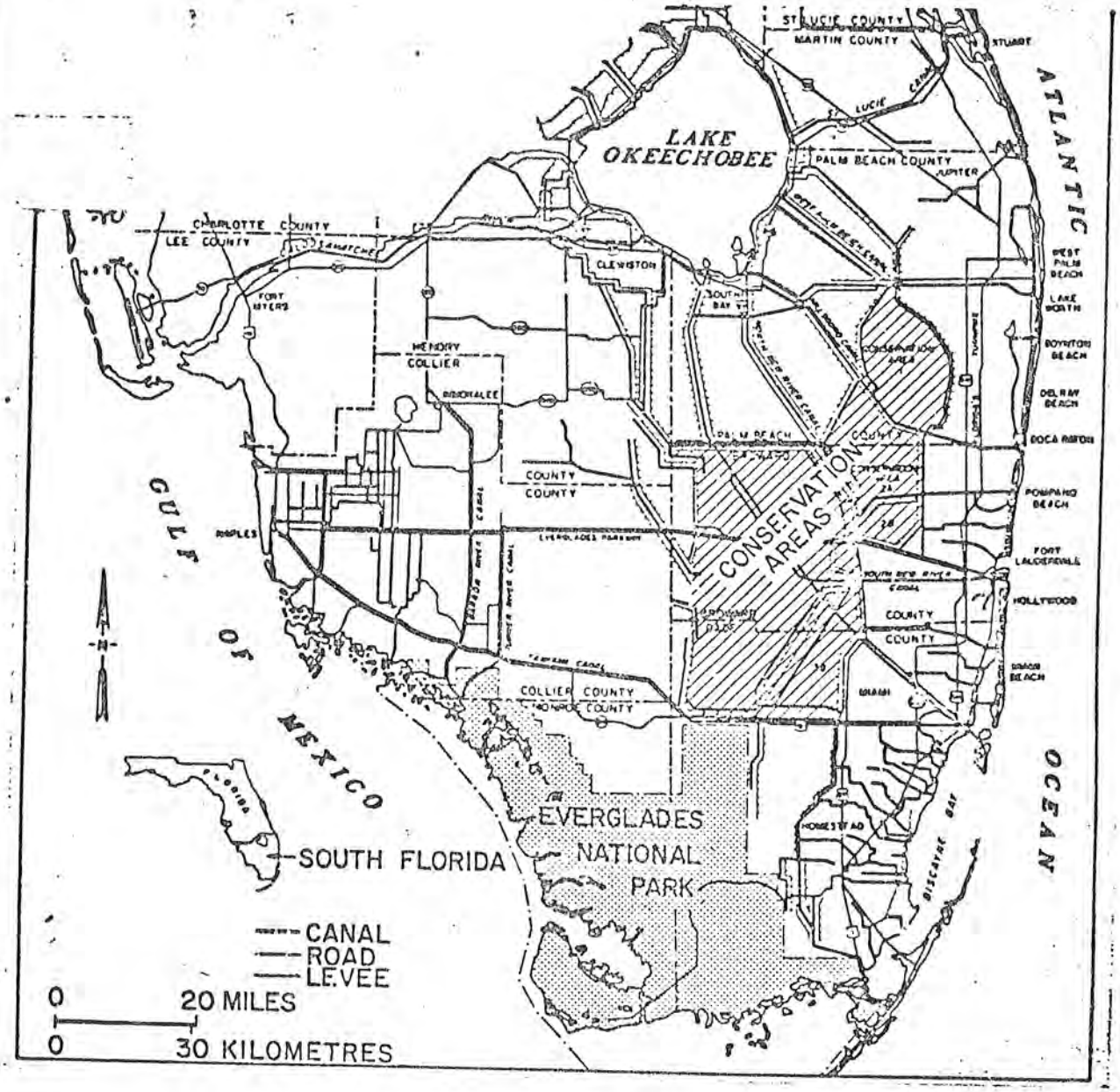
The sandy flatlands has two parts: one between the Everglades and the Atlantic coastal ridge and the other generally north of the Big Cypress Swamp. Both parts are characterized by low-lying poorly drained lands. Elevations range from 6 feet near Miami to 20 feet near Lake Okeechobee and from 5 feet near Naples to 40 feet near Immokalee. Drainage in the east is generally to the south and east, whereas in the west it is generally to the north and west. Both parts of this province are extensively farmed.



EXPLANATION

1 ATLANTIC COASTAL RIDGE
2 SANDY FLATLANDS
3 EVERGLADES
4 BIG CYPRESS SWAMP
5 MANGROVE AND COASTAL GLADES

South Florida includes five physiographic provinces (Davis, 1943). Drainage is generally in the directions indicated by arrows (Parker and others, 1955, Plate 12).



Hundreds of miles of canals and levees are used to control and manage the water resources of south Florida.

The Everglades is slightly lower than the sandy flatlands and extends southward from Lake Okeechobee to the mangrove and coastal glades near Florida Bay. The Everglades has an almost imperceptible slope--averaging less than 2 inches per mile. Elevations range from 14 feet near Lake Okeechobee to sea level near Florida Bay. The Everglades under natural conditions was seasonally inundated. Drainage was slow and generally to the south. Historically, the Everglades was known as the "River of Grass." Today the northern part has been drained for agriculture. The central part has been surrounded by levees and cut by canals for water management. The southern part is reserved within the Everglades National Park.

The Big Cypress Swamp is characterized by flat poorly drained marshes and numerous tree islands. Most of the province is less than 15 feet above sea level and slopes gently toward the Gulf of Mexico. Drainage is sluggish and generally southward, although some water flows eastward into Conservation Area 3A of the Central and Southern Florida Flood Control District. Much of this province is inundated during the wet season and is virtually undeveloped.

Most of the mangrove and coastal glades province lies along the Gulf Coast of south Florida. It is characterized by tidal streams, bays, lagoons, and thousands of small islands. Here mangrove swamps and salt-water marshes are subject to tidal inundation, providing an environment that fosters proliferation of many marine and estuarine communities.

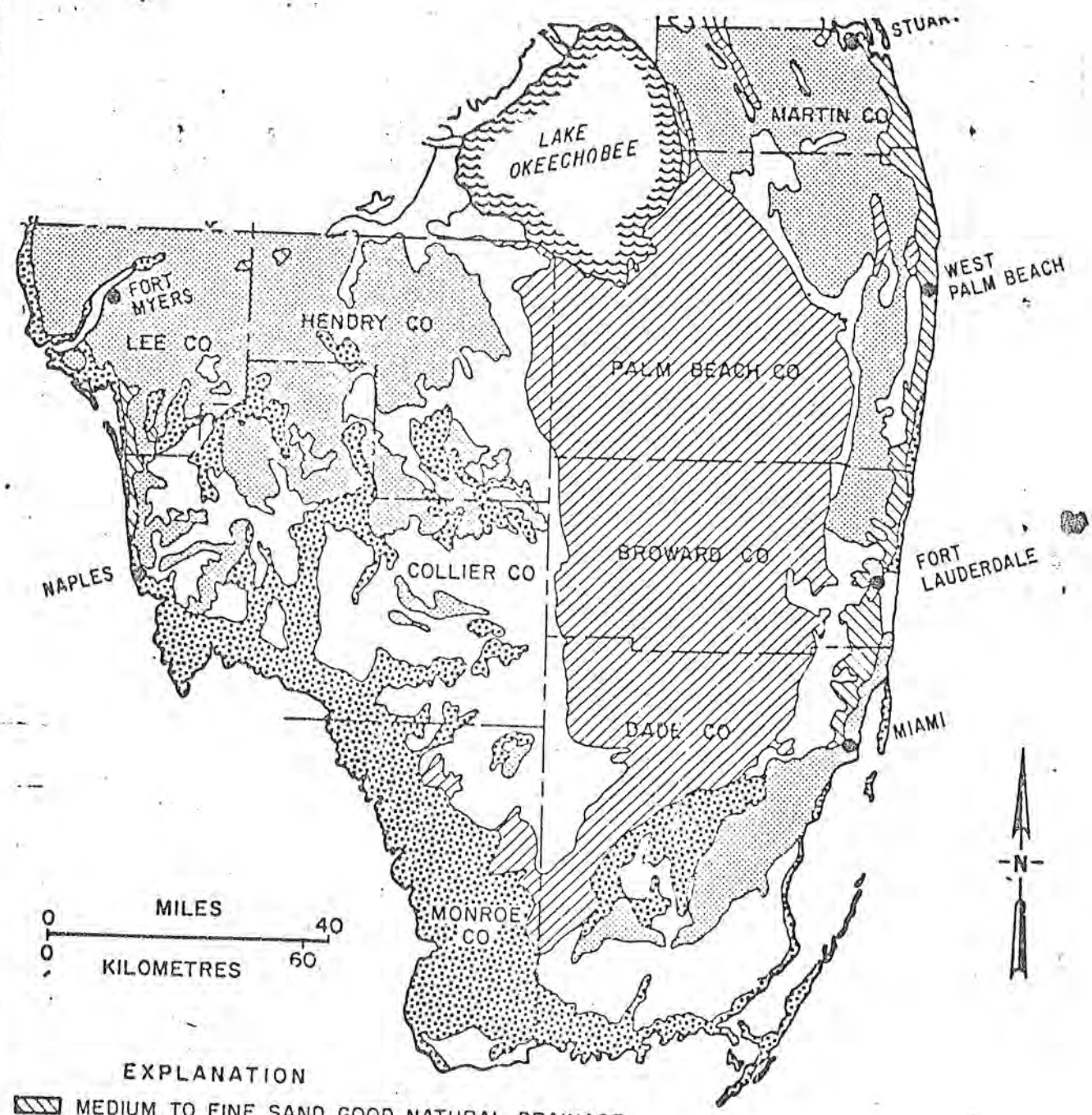
In addition to the five physiographic provinces, several offshore features relate to the area. The Continental Shelf (the edge of which approximates the 300-foot depth contour) is a habitat for most marine organisms. The west edge of the Gulf Stream, which coincides with the 600-foot depth contour, ranges from about a mile to several miles offshore from the east coast and strongly influences both the climate and the ecology.

Soils

Soils in south Florida range from poorly drained and swampy to well drained. In most of Dade County and the southern half of Collier County, the soil is generally only a veneer on an eroded limestone surface. It thickens northward and in the transverse glades (the natural drainageways) along the coastal ridge in Dade County.

Five general soil types are recognized in south Florida on the basis of drainage characteristics. The urban areas of coastal Dade, Broward, Palm Beach, and western Collier Counties are covered by well-drained to moderately well drained medium to fine sand. Near the coast much of the sand is quartz; elsewhere it is chiefly calcium carbonate eroded from limestone. The quartz was derived from the Pamlico Sand, of Pleistocene age, which covers nearly all the area north of the latitude of Miami but does not extend into the Everglades.

Most of Collier County is covered by a marly soil veneer derived from weathered surficial limestone. The veneer supports grasses and scrub cypress trees. Within the large sloughs and transverse glades the soil is thick and supports dense vegetation, including large trees.



EXPLANATION

- MEDIUM TO FINE SAND, GOOD NATURAL DRAINAGE
- FINE SAND, MODERATE NATURAL DRAINAGE
- MARL AND FINE SAND, POOR NATURAL DRAINAGE
- ROCKLAND, FRESH WATER OR TIDAL MARSH, AND COASTAL BEACH
- PEAT AND MUCK

The most prominent soil type in south Florida is the peat and muck of the Everglades. Natural drainage in most of the area is poor because of fine sediments and lack of relief. To accommodate urban growth, drainage has be effected by many canals to make land available for housing and to protect those lands from flooding. (Adapted from Ceneral Soil Map of Florida, Soil Conservation Service, 1962).

The most prominent soil type in south Florida is the peat and muck of the Everglades, extending southward from Lake Okeechobee more than 100 miles. The Everglades comprises more than 2 million acres and is the largest tract of peat and muck in the world. This soil has undergone drastic changes since the turn of the century, chiefly as a result of drainage, water control, and agriculture. For example, near Lake Okeechobee where peat soil is thick and extensive, land surface has subsided nearly 6 feet in about 40 years (Stephens, 1969), primarily by oxidation of the peat as a result of lowered water levels. According to Stephens, 83 percent of the peat and muck in the Everglades will have disappeared by the year 2000.

Soils in south Florida will not produce crops without regular use of fertilizers. Truck crops and sugar cane are grown chiefly in the north and east parts of the Everglades. Sugar cane is grown along the south shore of Lake Okeechobee. Citrus production is increasing in Lee, Hendry, and Palm Beach Counties.

Where soils are highly permeable, such as along the east coast, and particularly in urban areas where water levels are kept low by water-control practices, septic tanks are used extensively. In much of Dade County, soil is too thin for septic tanks and there they are installed directly in the shallow limestone where they still operate successfully.

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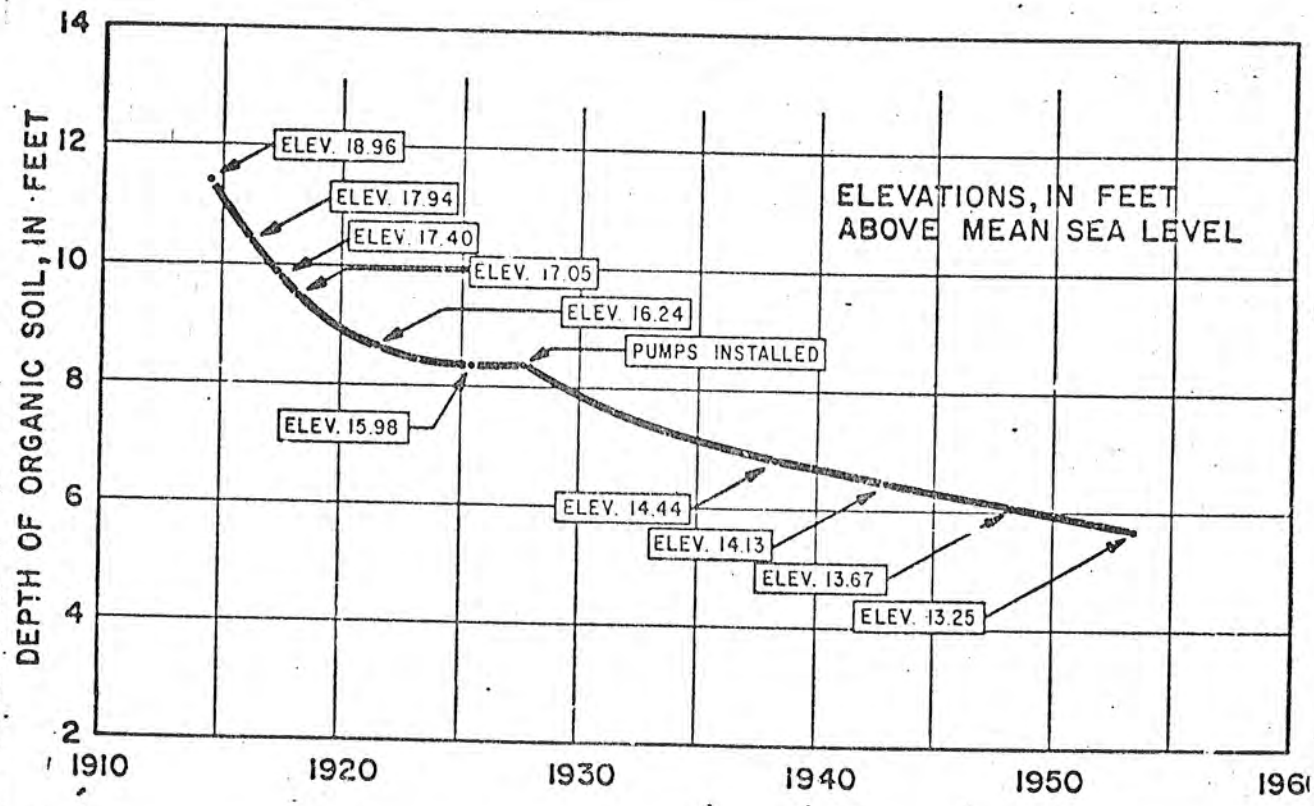

By 1953 soil subsidence near the south shore of Lake Okeechobee was nearly 6 feet (Stephens, 1969).

Plants and Animals

An ecosystem is the sum of all microbe , plant, and animal species, their physical environments, and their interaction with one another and the total environment. Each species depends in varying degrees on other species; the elimination of a few species can disrupt or damage an entire ecosystem.

The plants and animals of south Florida consist of both tropical and temperate species. The tropical species reach their northern limit in the southeast. They are abundant in the Keys and on the extreme south and southeast coasts. To the north and west, the number of tropical species decreases, and the temperate species become numerous. In the marine environment coral reefs also illustrate this pattern. They occur only along the extreme southeast coast, where higher water temperatures prevail.

The marine life is affected not only by water temperature but also by salinity. Each species has a specific tolerance of and requirement for salinity. Most species from the open ocean require water of about 35 parts per thousand salinity and will tolerate little deviation. Most estuarine species are much more tolerant, but their salinity requirements often vary during their life cycles.

The estuarine environment of south Florida closely relates to land-drainage patterns and marine currents. Coastal areas that receive the greatest amount of fresh-water runoff, such as the southwest coast, typically are estuarine and have large seasonal fluctuations in salinity. Areas that receive little fresh-water runoff are predominately marine and are affected mostly by tides and currents.

The estuarine environment is highly productive. Sixteen commercial animal species depend upon the brackish water of the estuaries at some stage of their life cycle. Of particular commercial importance is the pink shrimp, which spends much of its juvenile life in brackish water before migrating to offshore spawning grounds.

On the land, plants and animals of south Florida are mostly aquatic or water-tolerant and are adapted to seasonal inundation. Plant and, to a lesser extent, animal distribution is controlled partly by the depth and duration of inundation. High areas, seldom flooded, usually support pine or hardwood forest or grasslands. Wet prairies, marshes, and swamp forests, flooded part of the year, support various species, depending on whether they are inundated with salt, brackish, or fresh water.

The major plant associations are closely related to elevation of the land surface, the duration of inundation, and the type and depth of soil . Extensive changes in vegetation have resulted from urbanization, agriculture, and water management. Changes have been greatest along the east coast and in the northern Everglades. All areas, however, have been affected to some extent by man's activities. For example, the former large expanse of hammock forests along the shore of Florida Bay and the Caloosahatchee River have greatly diminished.

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The original distribution of the plant associations in south Florida is as follows: PINE FOREST occupies a narrow band along the east coast and a large area from north of the Caloosahatchee River into the Big Cypress. GRASSLAND mainly occupies the area west and southwest of Lake Okeechobee. Both pine forest and grassland develop on relatively high, seldom flooded land that is subject to periodic fires. CYPRESS FOREST is most extensive in the Big Cypress. It occurs on shallow marl or sand soils that are seasonally inundated. MIXED SWAMP FOREST is usually confined to narrow, elongate regions along drainageways and creeks. It is most extensive in the Big Cypress. HAMMOCK FOREST is scattered over much of south Florida on small tree islands, on river banks, within swamps, along the coast of Florida Bay, on the east coast keys and along the larger rivers that drain into the Gulf. It often represents a climax community developed in the absence of fire. Areas protected from fire are surrounded by relatively deep water or are humid, with dense vegetation and high soil moisture. FRESH-WATER MARSHES and PRAIRIES predominate in a wide band in the center of the State that extends from north of Lake Okeechobee to Florida Bay. It is a seasonally inundated region that includes the Everglades and adjacent marshes and prairies. The EVERGLADES MARSH includes vast areas of sawgrass interspersed with deep-water sloughs and small tree islands. Soil in the marsh is peat; it is more than 10 feet thick near Lake Okeechobee and thins southward. Soils in the adjacent marshes and prairies are usually shallower and more marly than those of the Everglades. SALT WATER MARSHES and COASTAL FOREST

forms a crescent-shaped band around the coast--widest in the vicinity of the Shark River and narrowing in both directions, being reduced to only a few yards near Naples and Miami. This plant association is subject to varying degrees of salt-water inundation, depending on distance from the ocean, elevation, amount of fresh-water runoff, and weather.

Because much of south Florida is flooded seasonally, most of the organic matter is produced by aquatic plants or those inundation tolerant. In marshes and prairies organic material is produced by herbaceous plants and periphyton, and in swamps it is produced primarily by trees. Some organic material enters the aquatic food chain and forms the energy base for all water-dependent animals.

Many animals adapt to and depend on seasonal water fluctuations. During high water, aquatic production abounds; the energy stored by plants is passed on to the small crustaceans and fish. During the dry season, the small aquatic animals are forced to concentrate in scattered ponds, tributary creeks, and sloughs, and the concentrated biomass becomes a rich source of food for larger fish, alligators, snakes, birds, and mammals.

Many of man's activities adversely affect plants and animals of south Florida. These activities include drainage, dredge and fill, and lumbering, that destroy habitats, and those such as pollution, poaching, overhunting, and overfishing, that destroy life directly. As a result, extensive areas of estuaries, wetlands, and forests have already been destroyed, and the prospects of further destruction are great.

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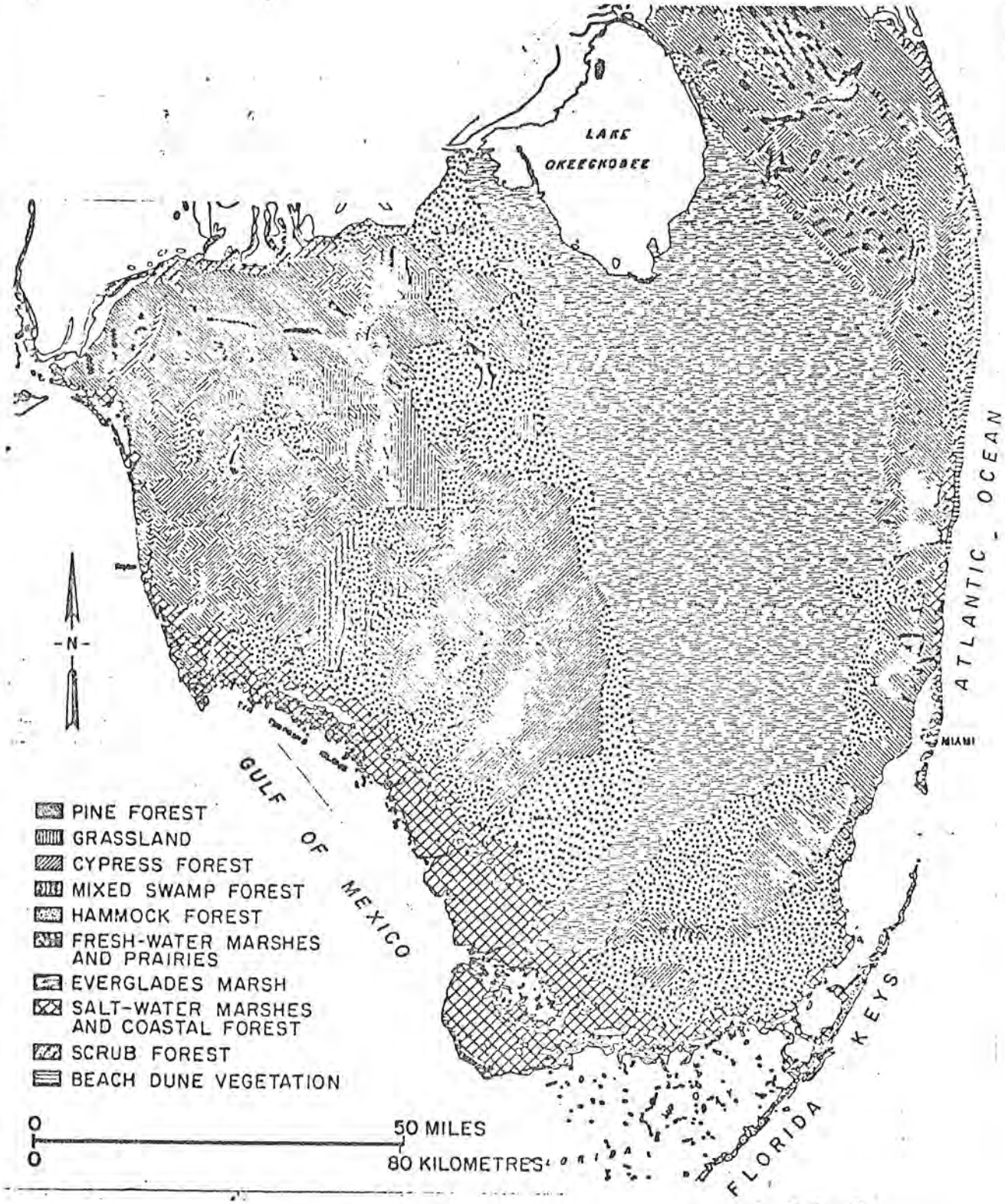


Before man's development of south Florida, pine forests and fresh-water marshes were the dominant vegetation communities (Davis, 1943).

POPULATION

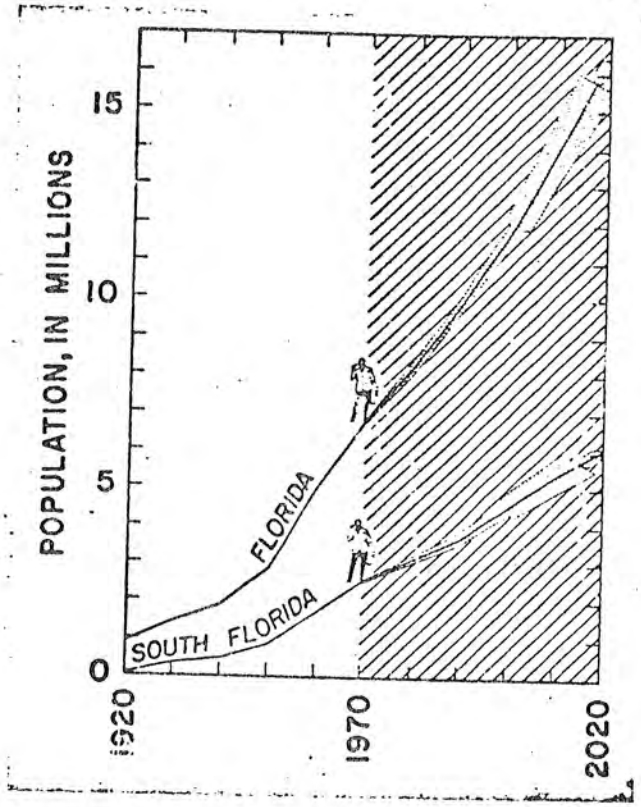
During the last three decades the population of the seven-county area increased from less than half a million to about 2½ million. Almost all this increase has been in urban areas. Urban population, as defined by the Bureau of the Census, includes all persons living in cities of 50,000 or more and those living in places of 2,500 or more outside urbanized areas. Dade and Broward counties, the two most populous, having a combined population of 1.9 million, are 98 percent urban.

The population of Florida increased 37 percent since 1960, and the population of south Florida increased about 50 percent. Nearly half the State increase was caused by the increase in south Florida. In 1920, for every 100 persons living in Florida 23 lived in south Florida. In 1970, 36 of every 100 Florida residents lived in the south.

In Collier County the population increased more than 140 percent during the last 10 years. This percentage was larger than that in any other county in the State. Much of the increase was caused by the growth of retirement communities within the county. Though the population of Collier County, about 38,000, is still relatively small, it is expected to increase to about 73,000 by the turn of the century.

Along with the rapid increase in permanent population, the visiting population of south Florida also increased, and was more than 4 million in 1970.

The Office of Business Economics projects that by the year 2000 south Florida will have more than 4.4 million residents, an increase of more than 80 percent over 1970. When the increasing stress placed on the hydrologic system of south Florida by population is considered, the need for far-sighted and viable management of water resources becomes evident.



In the past 50 years south Florida's population has risen from 6 percent to 36 percent of the State's total population.

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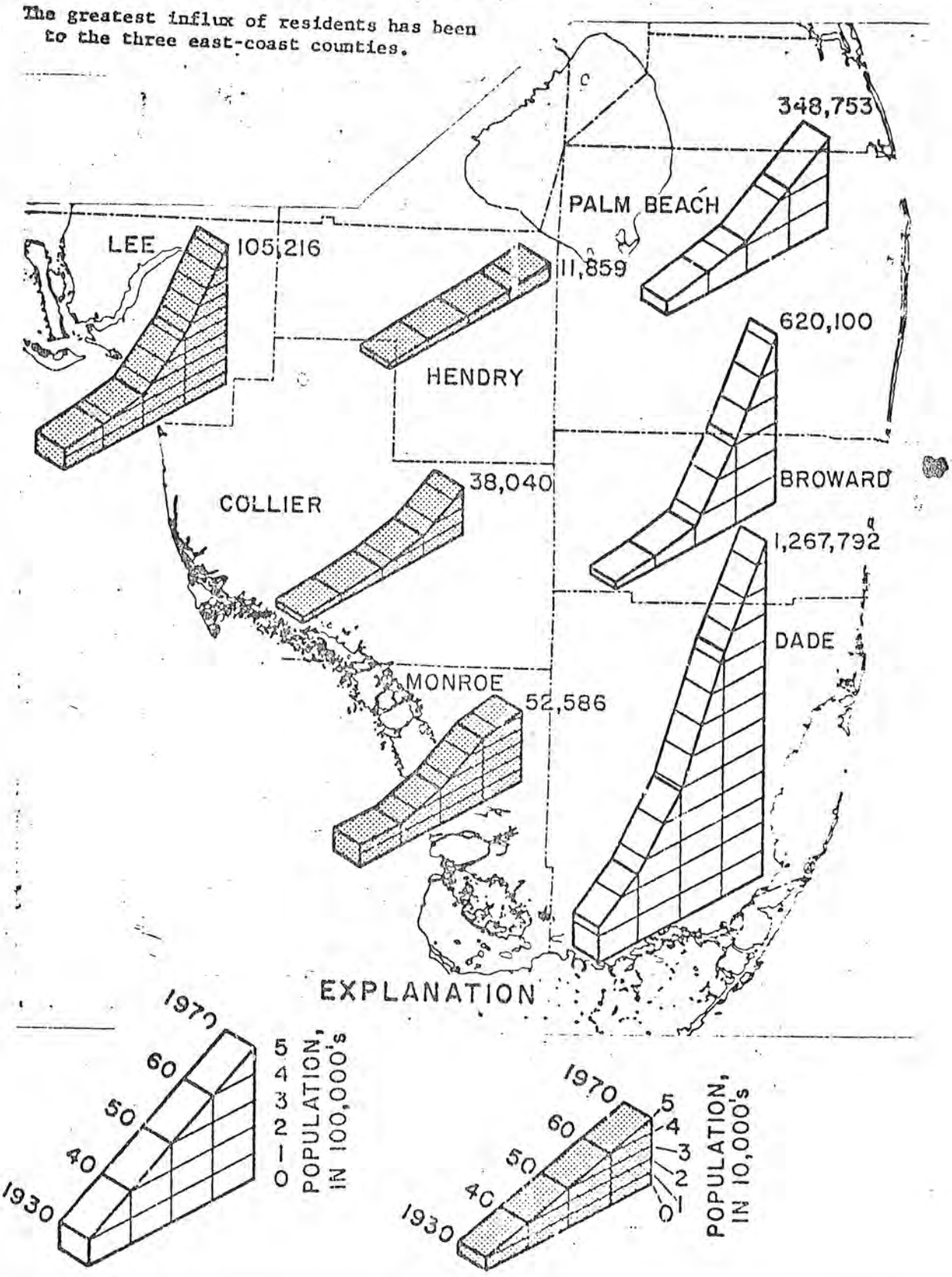
The greatest influx of residents has been to the three east-coast counties.



THE WATER CYCLE AND HOW MAN AFFECTS IT

The aquatic environment of south Florida is complex. How man affects it requires a thorough understanding of the water cycle--the endless movement of water from the atmosphere, to the earth, and back to the atmosphere.

All water in the lakes, canals, and aquifers in south Florida is from rain. Some infiltrates the soil or permeable rock and is retained as soil moisture. Part of the retained moisture either evaporates or is transpired by plants. The remainder infiltrates to ground-water reservoirs (aquifers), from whence it moves toward canals, the sea, or is pumped from wells.

Water that does not enter the ground is either intercepted by vegetation or ponds on saturated land. Because the land slopes are extremely gentle the ponded water runs off slowly, and evaporation is high. Of the average annual rainfall of 54 inches, 40 to 50 inches is evaporated and transpired. The remainder runs off or is used. Runoff ranges from about 10 inches along the southeast coast to near zero along the southwest coast.

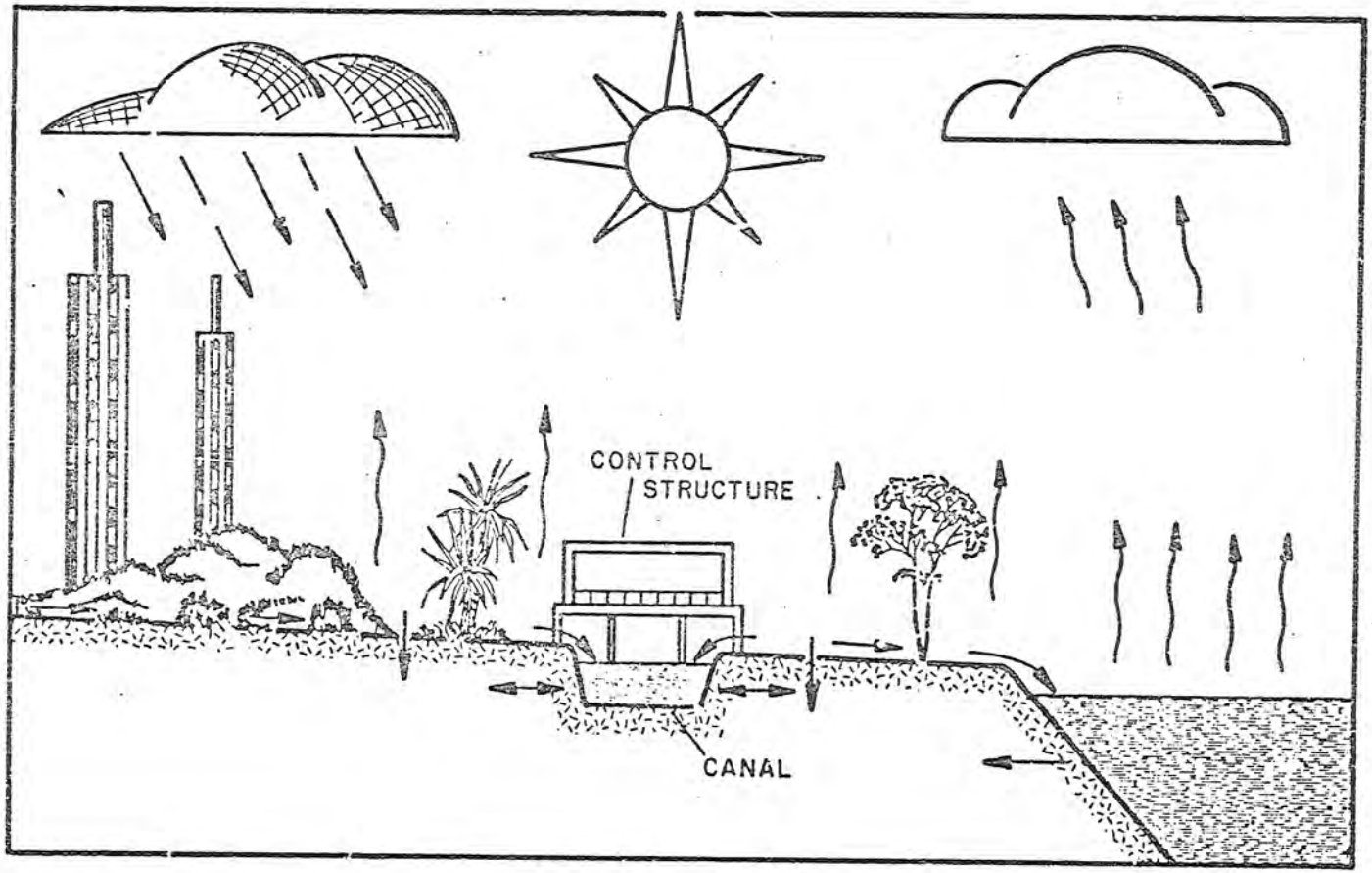
Man affects many elements of the water cycle. The extensive canal systems in south Florida obviously alter the cycle. The canals, consist of either deepened and widened natural channels or newly dug channels. They accelerate the movement of water from the interior to the coastal areas and to the sea during excessive rainfall. During dry periods, discharge is regulated by temporary storage. During wet periods, some water in the canals along the southeast coast is backpumped into the water conservation areas and into Lake Okeechobee, thus delaying and conserving runoff. The canals also drain land formerly inundated much of the year, reducing evapotranspiration. On the other hand, establishment of the three water conservation areas has increased evapotranspiration from large tracts.

Much of the fresh water used in south Florida is pumped from wells. The well water not consumed returns to surface-water bodies or to the ground.

Reforestation, deforestation, and agricultural and urban development change the nature of the land surface, which, in turn, affects the characteristics and rates of surface-water runoff, of infiltration, and of evaporation. Land clearing results in accelerated erosion and increased sediment loading of water bodies.

The discharge of waste at many points within the water cycle alters the distribution and quality of the water.

The sum total of man's effects on the water cycle results in changes in the quality, natural paths, and timing of water movement within the cycle.



The natural cyclical movement of water in the environment has been altered by man's activities.

CLIMATE

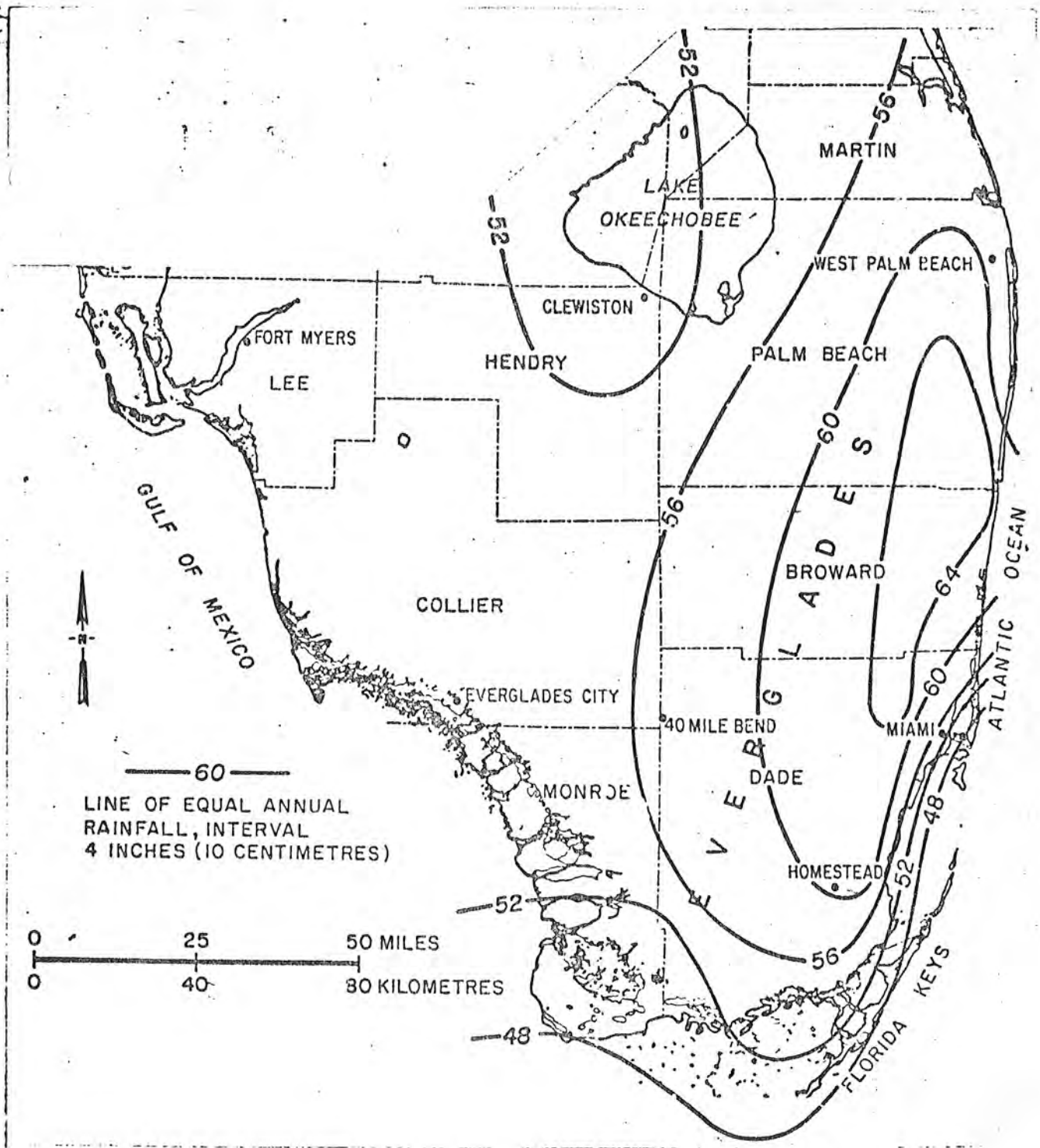
Annual Rainfall

Average annual rainfall within south Florida ranges from 40 to 65 inches. The east coast, from Homestead to Pompano Beach, usually receives the greatest amount, whereas the Florida Keys, the areas south of Lake Okeechobee, southwest Collier County, and an area just west of Fort Myers usually receive the least (Hughes, 1971).

Rainfall records, 1949-70, were used in the preparation of illustrations. The averages of these data are reasonably comparable with averages of long-term data available from several stations and are, therefore, considered to be representative of long-term trends. Although rainfall records for several areas are scant, notably large parts of the Everglades, lines of equal annual rainfall are reasonably well defined.

Variations in annual average rainfall for all of south Florida from 1949-1970 are illustrated. The average rainfall was 54 inches, and annual values ranged from 37 inches in 1956 to 72 inches in 1959.

In most areas of south Florida annual rainfall was greater than average in 1953-54, 1957-60, 1966, and 1968-69. Periods of excess rainfall are characterized by high recharge of the major aquifers and excessive surface discharge to the ocean. In 1950-52, 1955-56, 1961-65, 1967, and 1970, rainfall was below average. Extended rainfall deficiency often stresses the natural water systems. These stresses include low water levels, sea-water intrusion, fish kills, fires, depleted water supplies, and crop damage or loss.



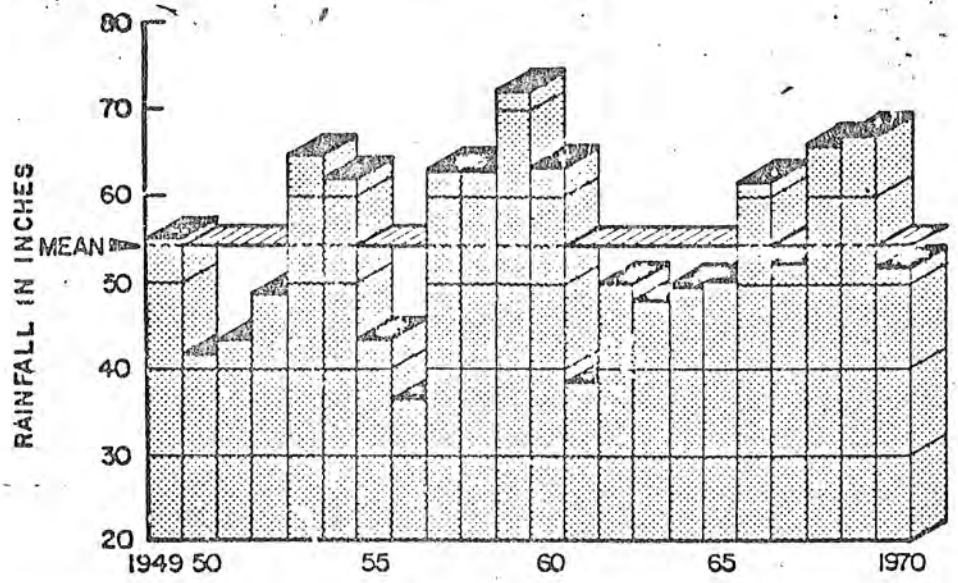
Rainfall is heaviest along the east coast (Data from National Weather Services).

Monthly and Seasonal Rainfall Distribution

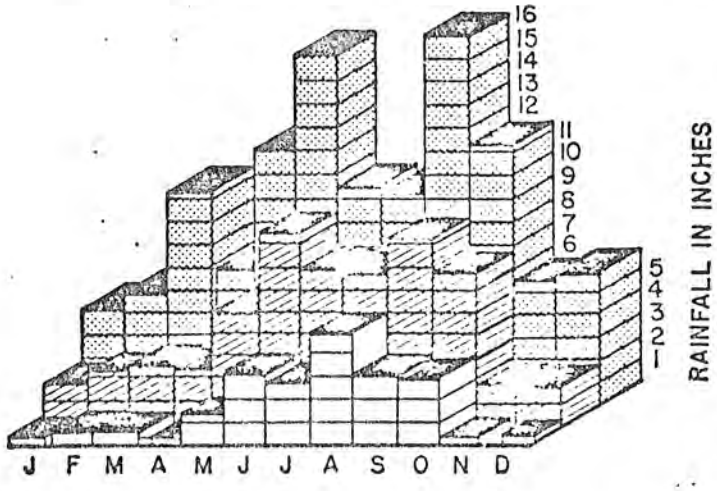
Seasonal variation in rainfall is pronounced. About three-fourths of the total annual rain in south Florida generally falls during the 5-month wet season, June through October. Because the wet season coincides with the period of high evapotranspiration, a nearly uniform moisture condition is maintained throughout the year (Ferguson, 1955).

Maximum monthly rainfall differs from place to place. On the southwest coast, in the vicinity of Ft. Myers, June and July are the rainiest months, whereas on the east coast September and October are the rainiest. The heavy June-July rainfall on the west coast probably reflects the activity of convectional, or airmass, storms over the Gulf. The high September-October rainfall on the east coast doubtless arises from the influence of the tropical storms that are particularly active in the early fall. (Ferguson, 1955).

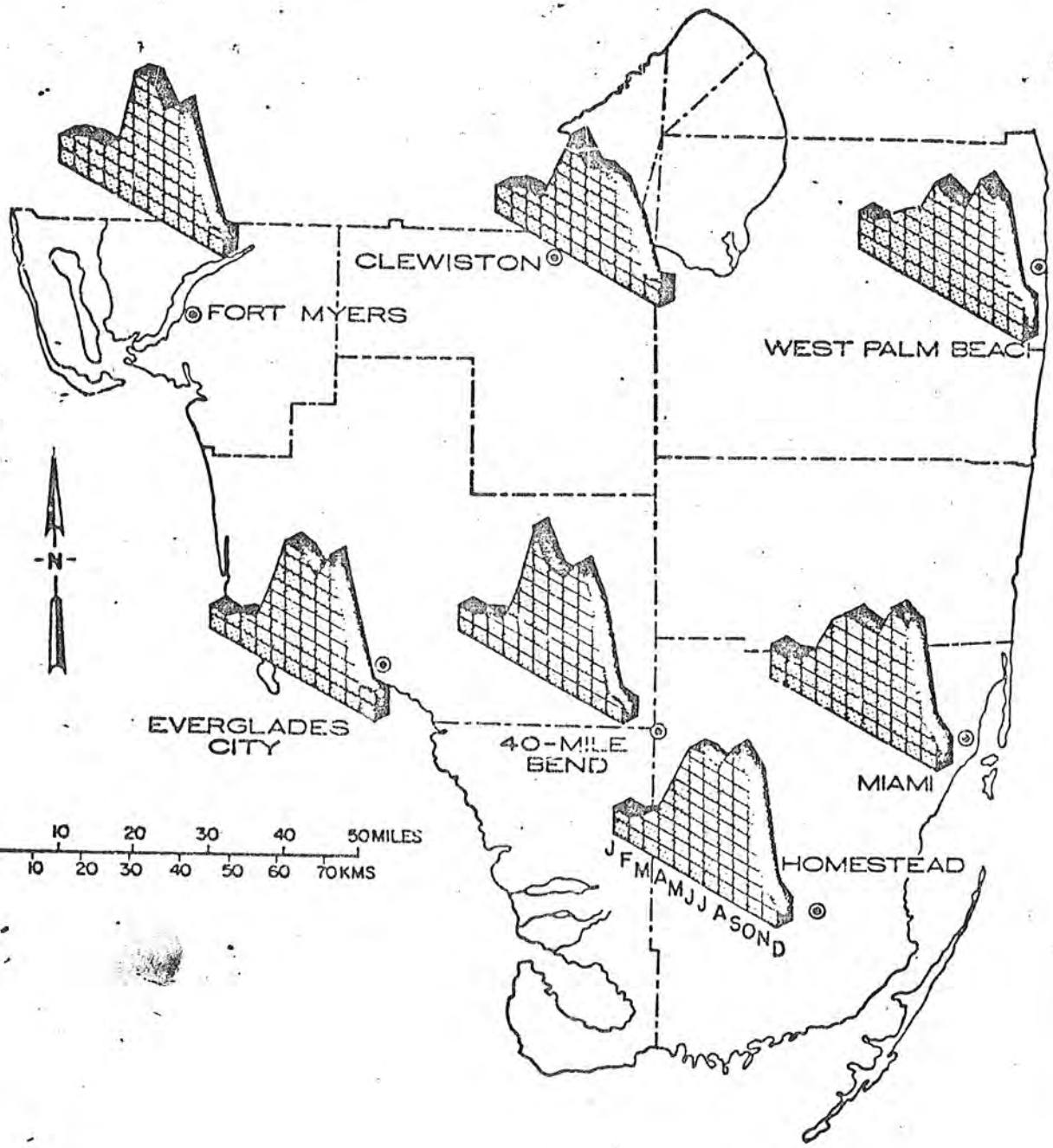
Except for tropical storms, most rain falls as local showers that are generally of high intensity but of short duration. Rainfall records from stations only a few miles apart frequently differ markedly. Daily differences can exceed 2 inches, and monthly differences often exceed 10 inches. In 1959 the difference in annual rainfall between Loxahatchee and West Palm Beach International Airport, only 10 miles apart, was more than 26 inches. This difference is about the same as the average annual rainfall in the conterminous United States.



Annual rainfall varies, but averages about 54 inches.



Monthly rainfall is also subject to large variations; the minimum, mean, and maximum during 1949-1970 are shown.



Along the west coast rainfall is heaviest early in the summer, but along the east coast it is heaviest in September.

Temperature

South Florida has a subtropical climate. Temperatures are generally moderate; average daily temperatures range from 68°F to 82°F. Frequent afternoon thundershowers and moderate breezes prevent extremely high temperatures during the summer.

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Evapotranspiration

Evapotranspiration is the combined process consisting of evaporation from land and water surfaces and transpiration by plants. It is the mechanism by which water returns to the atmosphere.

Evapotranspiration varies from place to place; it removes from south Florida as much as 70 percent of annual rainfall in urban areas and as much as 95 percent of rainfall in undeveloped areas, such as the Big Cypress and the Everglades. During dry years, evapotranspiration exceeds rainfall.

Although evapotranspiration data for large areas are scarce, several investigators have determined this loss for some areas within Florida by use of water-balance techniques. Evapotranspiration consumed about 70 percent of rainfall in the Snake Creek basin, an urbanized area north of Miami, during 1963-67 (Meyer 1971). Loss from the three water-conservation areas during 1963 and 1964 was about 80 percent of the annual rainfall (Leach and others, 1972). An analysis made for this report indicates that evapotranspiration averaged about 90 percent of the annual rainfall during 1968-70.

Evapotranspiration characteristics have changed over large parts of south Florida since the turn of the century. Changes have been greatest in the east part of south Florida, where extensive systems of canals and levees have been constructed. Drainage through these canals lowered water levels below land surface, with a resulting decrease in evapotranspiration. These canals, however, now provide a permanent water surface subject to evaporation.

Before the construction of the levees that surround the three conservation areas, the areas were generally inundated during and shortly after the wet season. Since construction of the levees they are inundated most of the time. The resulting increase in evapotranspiration is estimated to be 500,000 acre-feet per year.

In the west part of south Florida evapotranspiration has been reduced somewhat by drainage, but the amount of reduction is not known.

The changes in evapotranspiration discussed above affect each other to some degree, but the net effect of man's activities on evapotranspiration overall is not known quantitatively.

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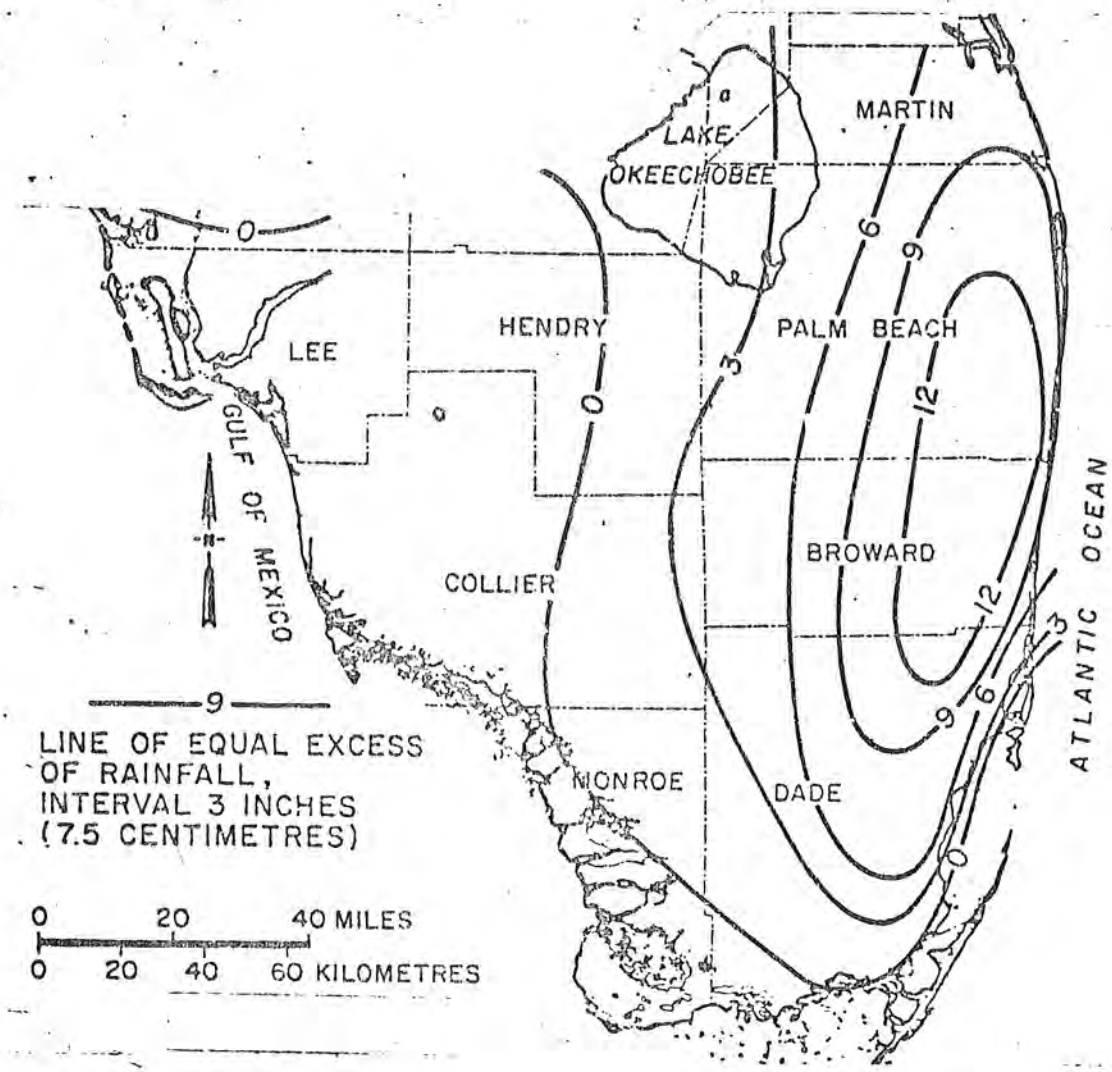


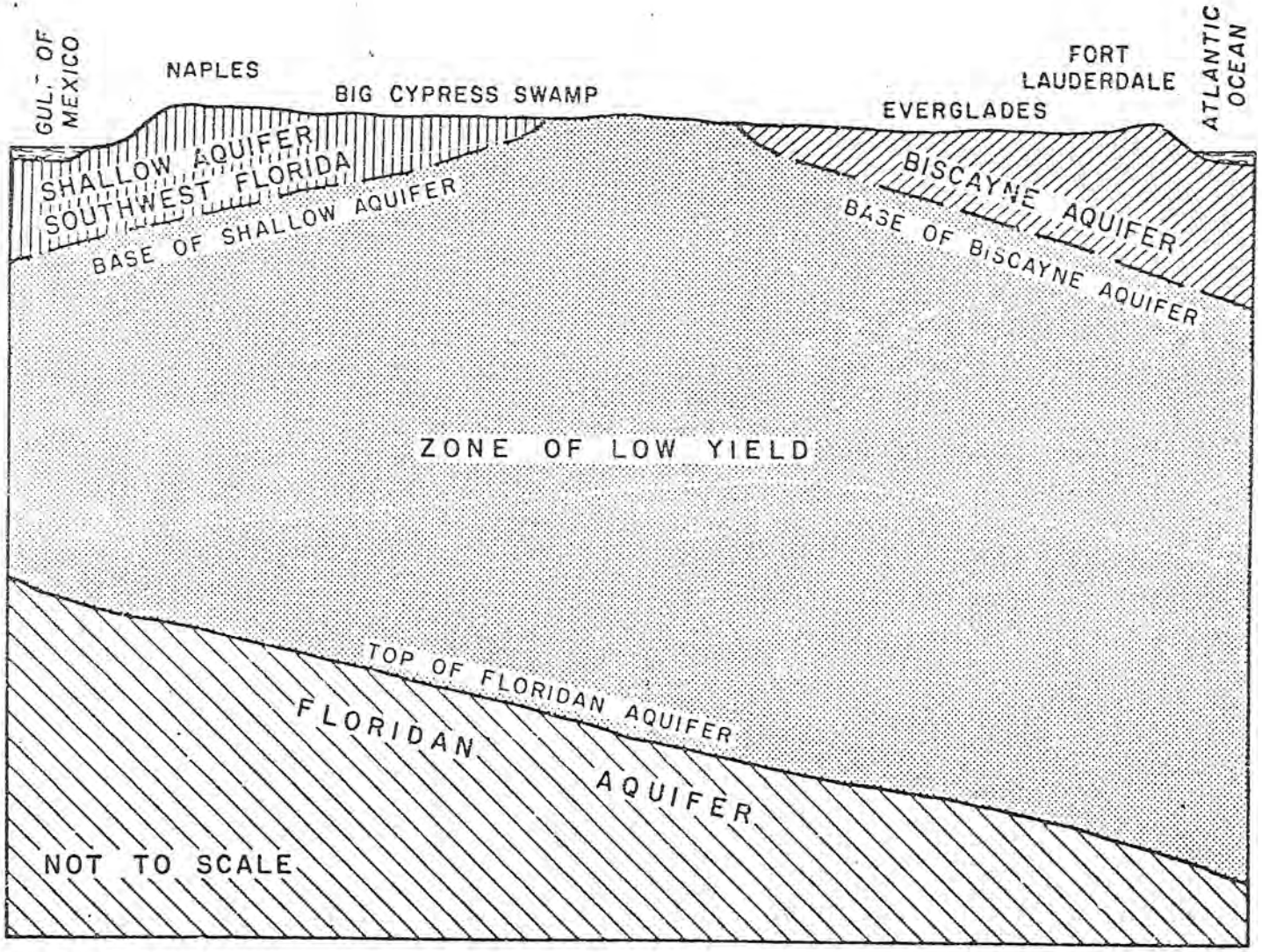
Along the west coast rainfall and lake evaporation are nearly equal; along the east coast rainfall exceeds lake evaporation as much as 12 inches.

34

WATER AND THE ENVIRONMENT

Aquifers and Ground-Water Characteristics

The upper 3,000 feet of rocks underlying south Florida are composed chiefly of limestone, dolomite, sand, clay, and shells. The major aquifers that yield potable and brackish water to wells are composed mainly of limestone. The primary shallow aquifers, which yield practically all the municipal and much of the irrigation water used in south Florida, are the Biscayne aquifer of southeast Florida, the shallow aquifer of southwest Florida, and the coastal aquifer of Palm Beach and Martin Counties. These shallow aquifers are underlain by a thick confining layer that overlies the permeable limestone of the Floridan aquifer. The Floridan aquifer in south Florida contains brackish water.



A thick zone of low yield separates the shallow aquifers from the Floridan aquifer.

Biscayne Aquifer

All municipal water supplies of the populous lower east coast from Boca Raton southward are obtained from the Biscayne aquifer. The Biscayne, a highly permeable nonartesian limestone aquifer more than 200 feet thick in coastal Broward County, wedges out 35 to 40 miles westward in the Everglades. It is chiefly composed of permeable limestone of the Miami Oolite, the Fort Thompson Formation, the Anastasia Formation of Pleistocene age, and a sandy limestone in the upper part of the Tamiami Formation of Miocene age. High yields are obtained from wells penetrating solution-riddled sections of the aquifer. For example, large-diameter wells in Miami's municipal system are capable of yielding 7,000 gallons per minute (10 million gallons per day), usually with less than 10 feet of drawdown.

Shallow Aquifer of Southwest Florida

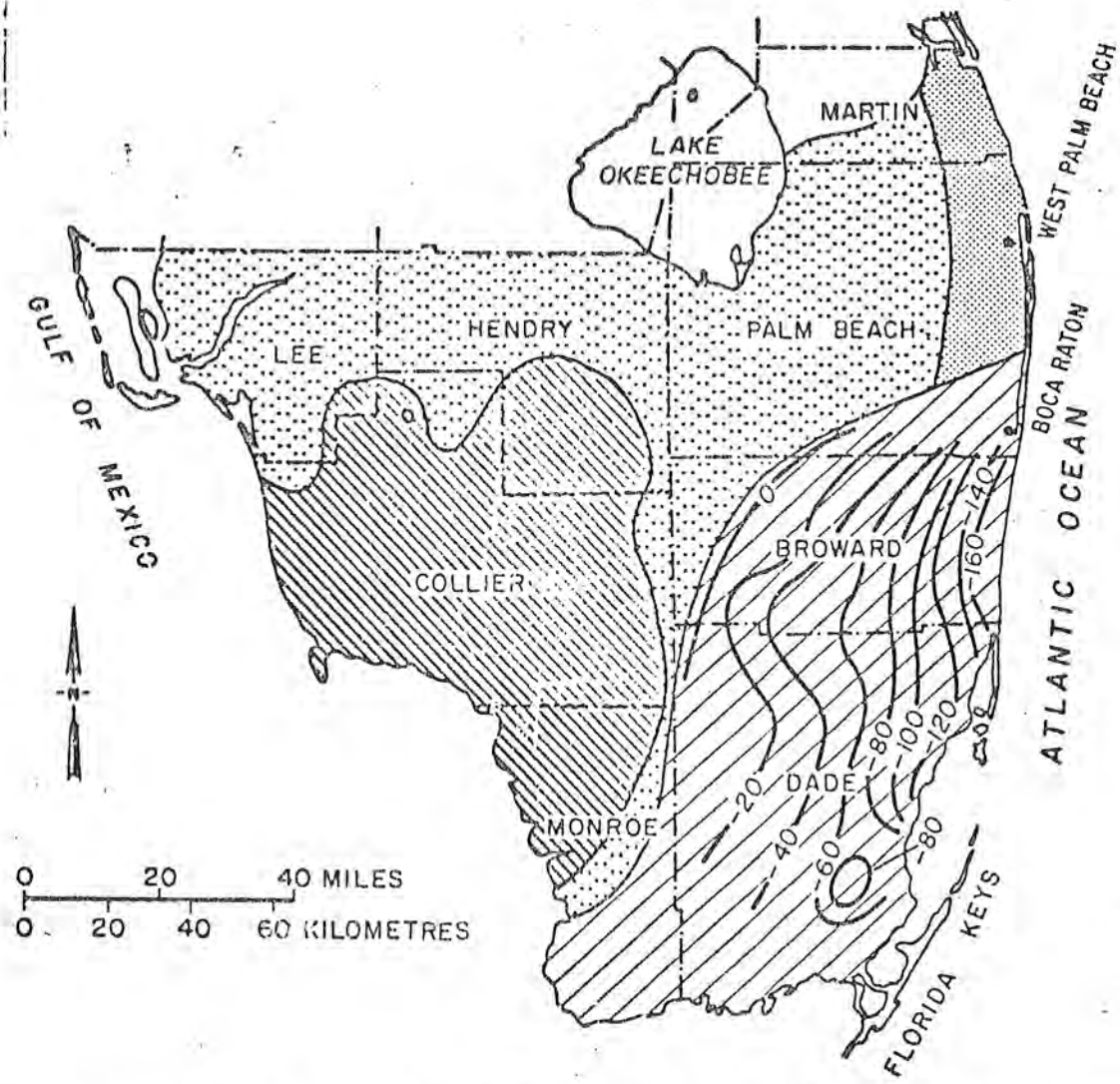
Important as the Biscayne aquifer is to southeast Florida, the shallow aquifer of southwest Florida is equally important to the urban lower Gulf Coast. The aquifer is about 130 feet thick near Naples, 60 to 80 feet thick in the central part of Collier County, and thins near the east edge of the county. Like the Biscayne aquifer, it is wedge shaped. It is composed mainly of limestone and sand of Miocene age and a thin section of sandy material and hard limestone of Pleistocene age. The most permeable part of the aquifer is a solution-riddled limestone of the Tamiami Formation.

The area of greatest potential for water supplies in all of southwest Florida is central and west-central Collier County, where the limestone is thick and extensive. Permeability of the aquifer decreases markedly within 10 miles of the Gulf.

Coastal Aquifer of Palm Beach and Martin Counties

Except for West Palm Beach, all coastal communities north of Boca Raton in Palm Beach County obtain water supplies from a non-artesian shallow aquifer. The aquifer is about 250 feet thick near the coast and becomes thinner inland. Discontinuous permeable limestone layers interbedded with thick sand sections characterize the aquifer. The limestone layers range in lithology from very sandy to coquinoid and contain sand-filled solution openings. The main component is the Anastasia Formation of Pleistocene age.

Water in the aquifer is generally fresh in a band as much as 10 miles wide extending inland from the coast. Farther inland, the mineral content increases and the yield of the aquifer decreases. Wells near the coast generally range in depth from 60 to 250 feet and those 10 miles inland from 50 to 125 feet. Six-inch diameter wells generally yield less than 500 gallons per minute, some less than 200 gallons per minute. The transmissive capabilities of this aquifer are much less than those of the Biscayne aquifer and the shallow aquifer of southwest Florida. The aquifer extends northward along the coast beyond Palm Beach County.



BISCAYNE AQUIFER, HIGH YIELD

SHALLOW AQUIFER OF SOUTHWEST FLORIDA, MODERATE TO HIGH YIELD

COASTAL AQUIFER OF PALM BEACH AND MARTIN COUNTIES, MODERATE YIELD

LOCAL, DISCONTINUOUS, WATERBEARING MATERIAL; LOW YIELD

—40— LINE OF EQUAL DEPTH OF BASE OF AQUIFER, FEET BELOW SEA LEVEL (EQUIDISTANCE -20 FEET = 6.1 METRES)

Shallow aquifers are the sources of most municipal water supplies.

Floridan Aquifer

The Floridan aquifer is extensive; it underlies all of Florida and parts of Alabama, Georgia, and South Carolina. Generally north of Lake Okeechobee, the aquifer yields fresh water except in some coastal areas. In south Florida, however, the aquifer contains mineralized water. There, water levels in wells penetrating the aquifer range from less than 20 feet to more than 50 feet above sea level. Most wells flow at the land surface. The top of the aquifer is about 400 feet deep at Naples and about 900 feet in coastal Dade County. A confining layer of fine sand, silt, and clay about 600 feet thick overlies the Floridan aquifer and prevents upward leakage to the shallow aquifers.

Water levels in the Floridan aquifer have not changed significantly in the last decade. Although the principal recharge to the aquifer is fresh water from central Florida the water in the aquifer in south Florida is brackish to saline.

The lower part of the Floridan aquifer is composed of cavernous dolomite and limestone known locally as the Boulder Zone and contains water almost as saline as sea water. The water temperature, 59°F in southeast Florida, is about 14°F cooler than water in the upper part of the aquifer. The cooling may be caused by water circulation and a direct connection between the aquifer and the ocean (Kohout, 1965).

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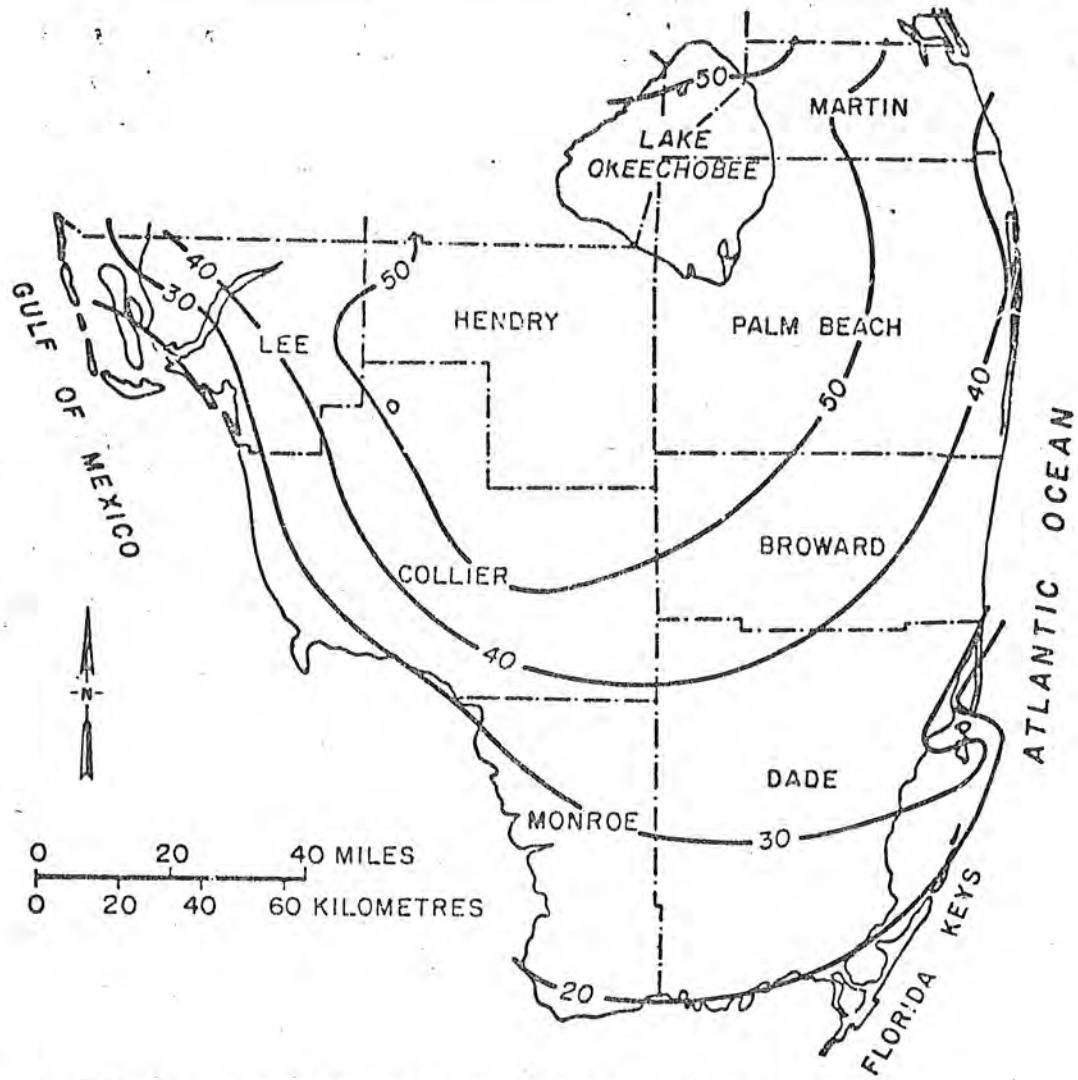
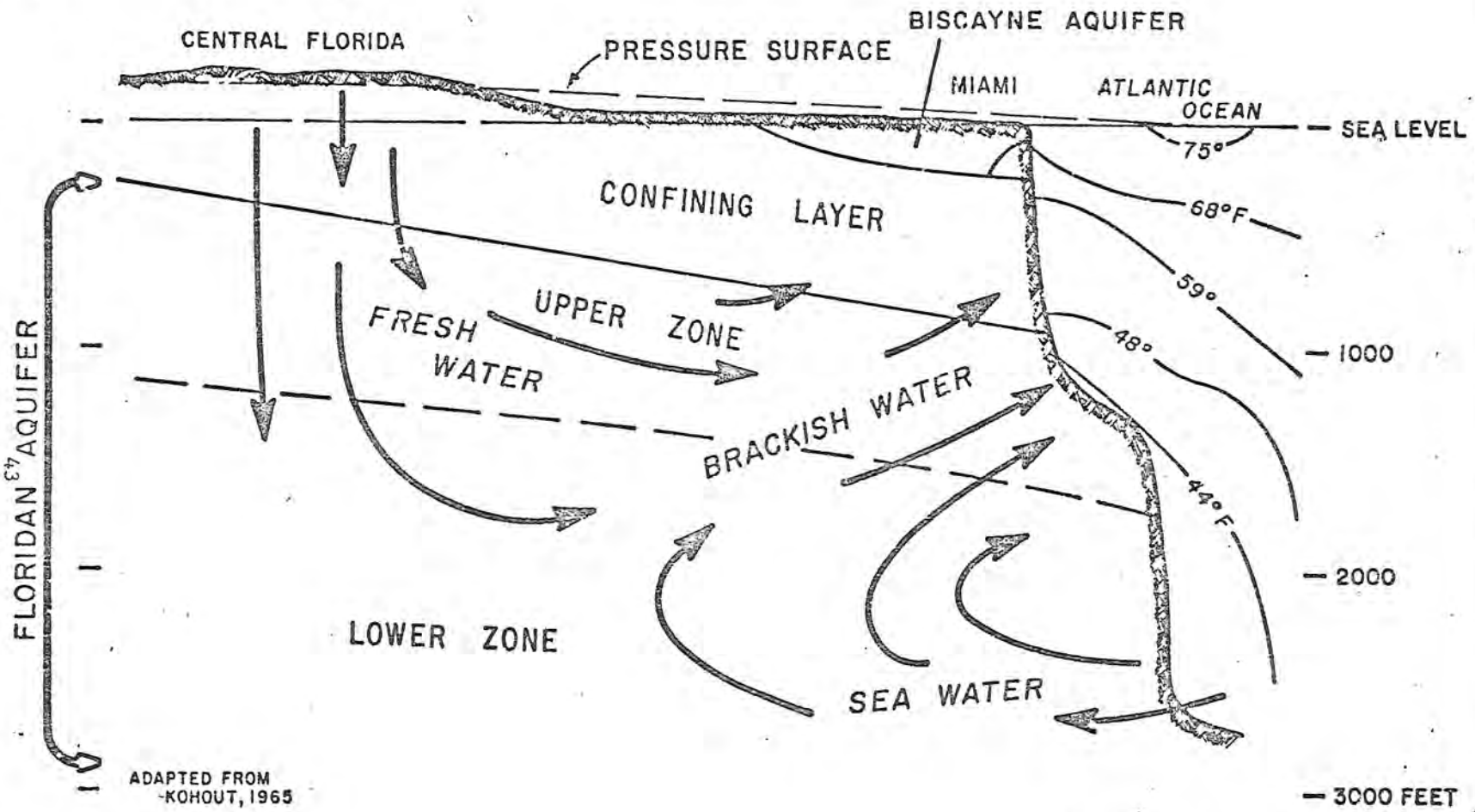


ALTITUDE TO WHICH WATER WILL RISE IN WELLS,
FEET ABOVE MEAN SEA LEVEL.
(10 FEET = 3.05 METRES)

Artesian pressures in 1961 ranged from about 20 feet to more than 50 feet above sea level; pressures in 1972 were about the same.



Circulation of cold ocean water near the southeast coast may explain cool water temperature in the lower part of the Floridan aquifer and mineralization of artesian water (Adapted from Kohout, 1965).

Surface Water

Rain falls in abundance on south Florida. Though much of the rain infiltrates the shallow aquifers, a great deal runs off or remains on the surface, where it forms prominent water features of the Florida landscape. Free-flowing streams in well-defined channels, such as are found in most other parts of the United States, are rare. During the wet season, most of the surface flow is in the form of overland sheet flow. Because the land slope is gentle, natural drainage is slow, especially within the Big Cypress and the Everglades. As a result, extensive areas are seasonally or perennially inundated.

Swamps, ponds, and sloughs cover most of the Big Cypress. Water moves through broad strands and sloughs, often miles wide and inches deep. Abundant but seasonal rainfall combined with sluggish drainage inundates as much as 90 percent of that part of the Big Cypress still in the natural state for as long as 4 months each year. With the onset of the dry season, water remains only in the deeper ponds and sloughs, only about 10 percent of the natural areas (Klein, 1970).

4

Drainage in the west part of the Big Cypress has been altered by canals that were built to protect residential areas from high water. These canals intercept flow from the strands and sloughs and convey it toward the Gulf. Since the 1920's, flow in the central part of the Big Cypress has been modified by the Barron River Canal. In the northeastern part of the Big Cypress the natural drainage toward Conservation Area 3A through the Kissimmee Billy and Godden Strands is aided by canals.

Land development and drainage have markedly reduced the swampland in south Florida. In the Everglades, south Florida's largest slough, agriculture and water-conservation areas have changed natural drainage patterns. Leveeing of Lake Okeechobee and subsequent control of its water level have significantly reduced the inundated areas south of the lake.

Lake Okeechobee, the second largest fresh-water lake wholly within the conterminous United States, has a surface area of about 700 square miles. Water levels in the saucerlike lake average about 15 feet above sea level. It is a major water-storage component in the overall water-management system in south Florida and acts as a retarding basin for runoff from Kissimmee River drainage on the north.

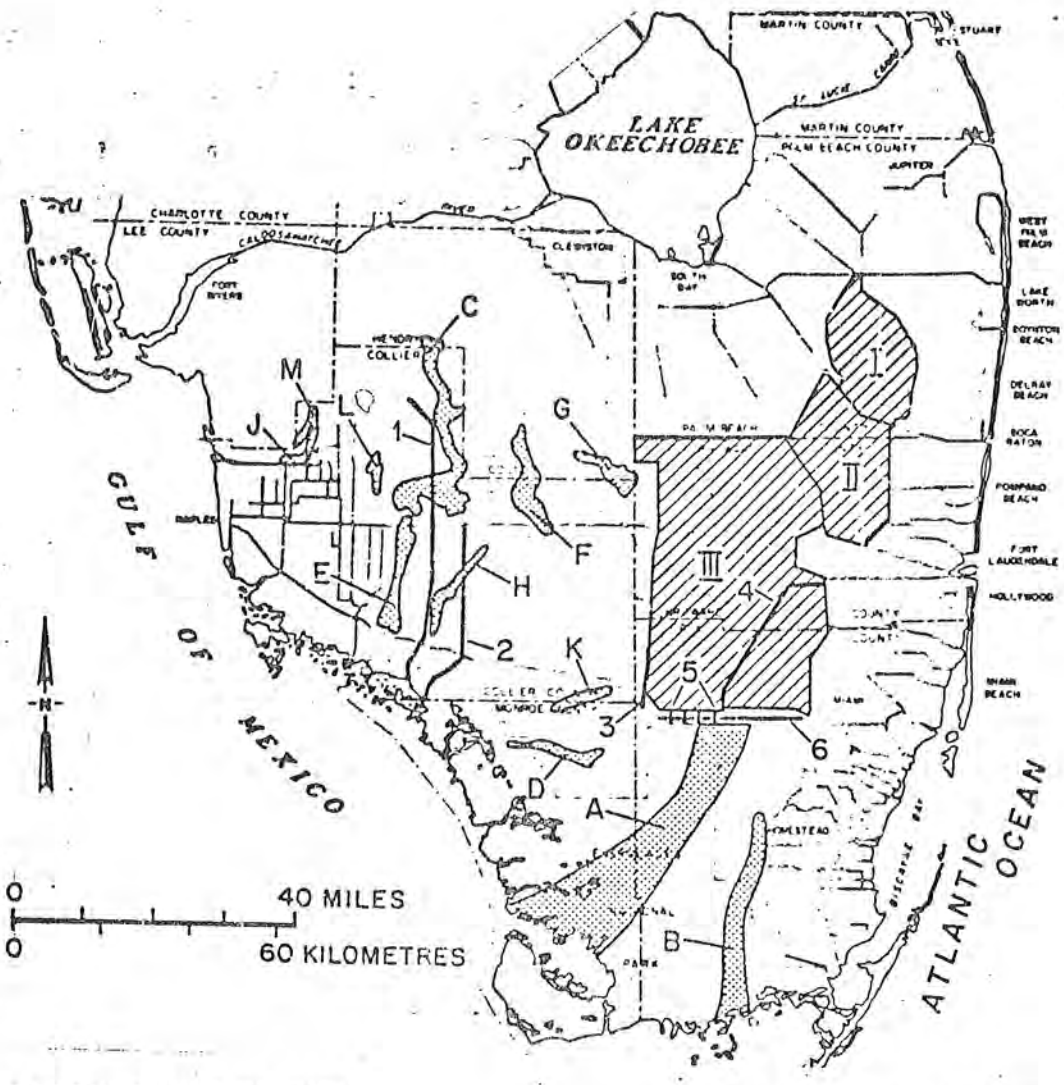
45

Shark River Slough, near the south end of the Everglades, is a major waterway through Everglades National Park. Part of the flow to Shark River Slough has been cut off by levees, and most of the flow is regulated by control structures along the south boundary of Conservation Area 3A.

Taylor Slough drains about 40 square miles, including agricultural land west of Homestead (Earle and Hartwell, 1972). It flows through the southeast part of the Everglades National Park and empties into Florida Bay.

In predevelopment days flow from the Everglades also reached the ocean through shallow sloughs called transverse glades, which cut through the Atlantic coastal ridge. Most of these transverse glades have been canalized to provide flood protection for the urbanized areas.

Canals are important in water management in south Florida. They are the means by which land is reclaimed, floods are controlled, and water is managed. However, a canal can be a protector or a destroyer, an asset or a liability. On one hand it may protect an urban area from flooding, but on the other it may destroy or change the environment by drying up wetlands. Managing the canal system for optimum benefit of the people and the environment is a major aspect of the overall water-management system.



A SHARK RIVER SLOUGH
B TAYLOR SLOUGH
C OKALOACOOCHEE SLOUGH
D GUM SLOUGH
E FAKAHATCHEE STRAND
F KISSIMMEE BILLY STRAND
G GODDENS STRAND
H DEEP LAKE STRAND
J BIRD ROOKERY STRAND
K ROBERTS LAKE STRAND
L CAMP KEAIS STRAND
M CORKSCREW SWAMP

1 BARRON RIVER CANAL
2 TURNER RIVER CANAL
3 L-28 CANAL
4 L-67 CANAL
5 S-12 SPILLWAY
6 LEVEE 29

CONSERVATION AREA

Strands and sloughs are numerous in the undeveloped areas, and canal systems are extensive in developed areas.

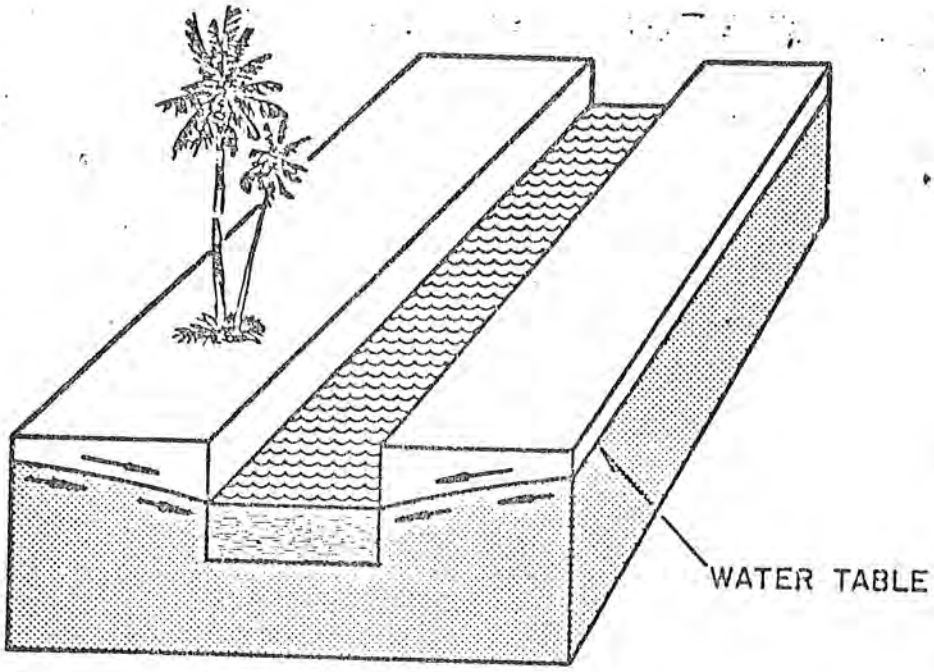
Ground Water and Surface Water are Related

The three primary shallow aquifers of south Florida are nonartesian; their upper surface is unconfined, and the water surface (the water table) is free to rise in response to recharge and to fall in response to discharge. The rate at which rainfall infiltrates a nonartesian aquifer is partly controlled by the material in the upper part of the aquifer. Silt and fine sand retard infiltration, and water levels rise slowly. On the other hand, medium or coarse sand or solution-riddled limestone do not slow infiltration to the same extent, and water levels rise almost immediately. Similarly, if the hydraulic connection between a canal and an aquifer is good, a rise in one is followed closely by a proportional rise in the other. In general, the hydraulic connection between shallow aquifers and surface-water bodies in south Florida is moderate to excellent.

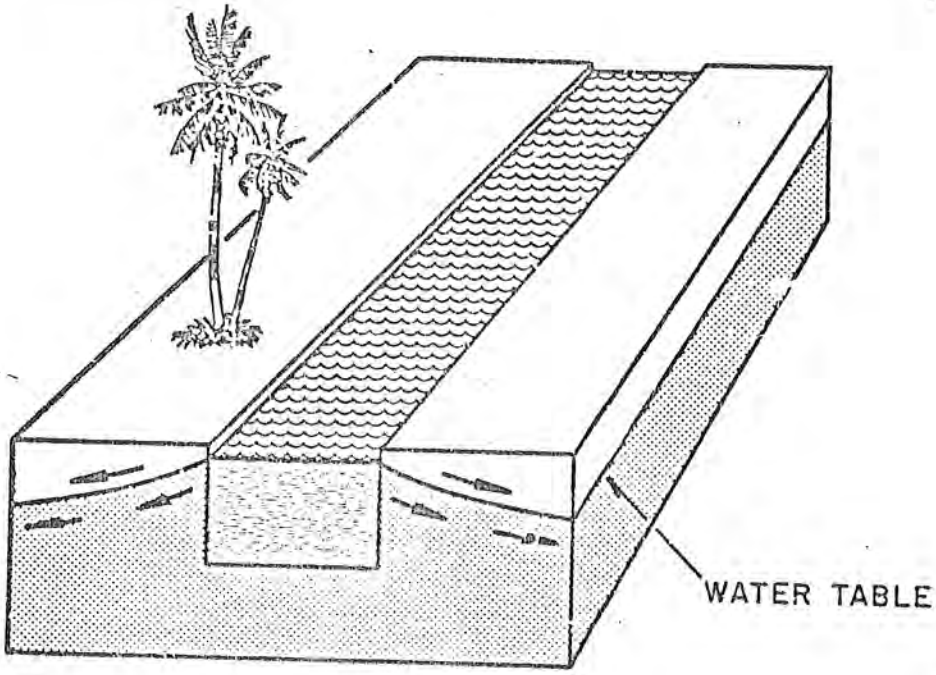
In addition to providing drainage, controlled canals provide a means for transferring water between ground-water and surface-water bodies in southeast Florida. When rainfall is heavy, ground water moves to canals that cut into the Biscayne aquifer and is discharged to tidewater, thereby lowering water levels and minimizing flooding. During drought, ground water continues to move to those same canals along their inland reaches and is transported to the controlled coastal reaches. There it recharges well fields and retards sea-water intrusion.

As needs for flood control expand, increased reliance is placed on the water-storage areas to provide water for aquifer replenishment. Canal systems aided by water-control structures are means by which storage is regulated in Lake Okeechobee, the water-conservation areas, and Everglades National Park. They are also the means by which water in some interior parts of Palm Beach and Broward Counties is pumped back inland to the water-conservation areas. Backpumping and storage regulation alleviate flooding, conserve water, preserve wildlife areas, and maintain wetlands.

49



When the water level in an aquifer is higher than that in a canal that penetrates it, water moves toward the canal.



When the water level in a canal is higher than that in the aquifer it penetrates, water moves into the aquifer.

WATER MANAGEMENT--ITS EFFECTS ON THE ENVIRONMENT

Because much of the land surface is flat and swamplike, it requires extensive drainage to prepare it for housing and for agriculture. Both land uses require that water levels be maintained at least a few feet below ground surface and that water be removed quickly from large areas during the wet season.

Impoundment of water is needed for flood control, water conservation, and protection against sea-water intrusion. The Central and Southern Florida Flood Control District (C&SFFCD) was established by the Florida Legislature in 1949. The water management system developed by this agency consists of canals, levees, impoundments, conservation areas, and many controls and pumping stations to manipulate and distribute water. Most of these facilities in southeast Florida were completed by 1968.

History of Canal and Levee Network

Historically, canals have been used for flood control and drainage. Canal construction in south Florida began in 1882, when the Caloosahatchee Canal was dredged to connect Lake Okeechobee with the Caloosahatchee River.

In 1905, the Florida Legislature passed the first drainage law, creating the Everglades Drainage District. Construction began on the tidal reaches of the North and South New Rivers in Broward County, and by 1913 both the North New River and Miami Canals were dug from Lake Okeechobee to the ocean. Land drainage and reclamation were continued with completion of the Hillsboro and West Palm Beach Canals. By 1921, these four major drainage arteries and hurricane gates at the lake end of each were completed.

The St. Lucie Canal, excavated between 1916 and 1924, was intended to be the main controlled outlet to regulate the water level of Lake Okeechobee. A severe storm in 1924 washed sediment into the canal, greatly reducing its efficiency. It was not until 1935 that the canal was restored to its design capacity, and from that time until 1946 it served its planned purpose.

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By 1924 a low muck levee was built along the south and east sides of Lake Okeechobee to protect lands south of the lake from flooding. Hurricane-driven storm waves in 1926 and 1928 overtopped and breached the levee. A higher levee was completed by 1938. This levee, with subsequent extensions, is now 85 miles long and begins just north of the Caloosahatchee Canal, extends along the south shore, and ends on the east side of the lake. Elevations on top of the levee range from 34 to 38 feet above sea level.

Several major canals along the lower east coast near Miami and in the Big Cypress were completed during the 1920's. The Barron River Canal, completed in 1926, provided the source of material to construct State Road 29 from Everglades to Immokalee. It was the first major drainage canal in the Big Cypress. The Tamiami Canal also resulted from road construction, providing fill for the Tamiami Trail (U.S. Hwy. 41). The Tamiami Canal, completed in 1928, intercepts and distributes southward flow from both the Big Cypress and the Everglades.

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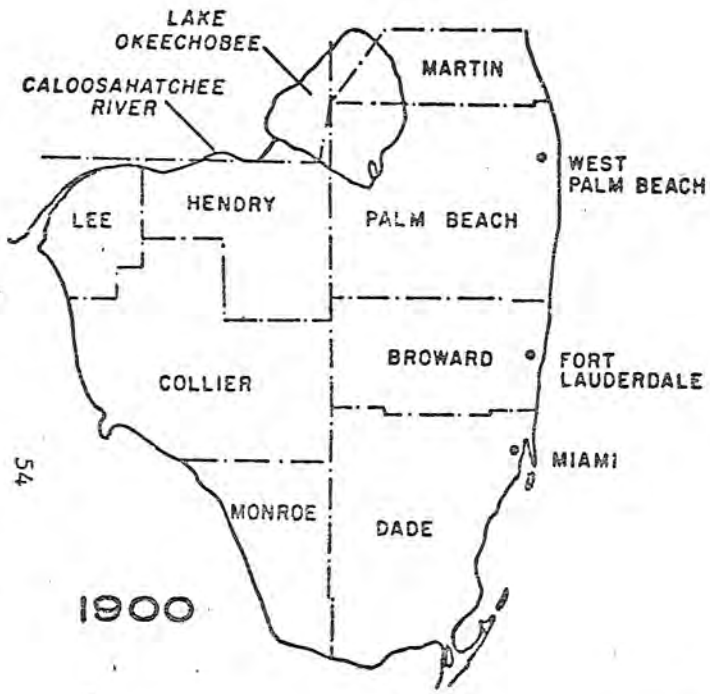
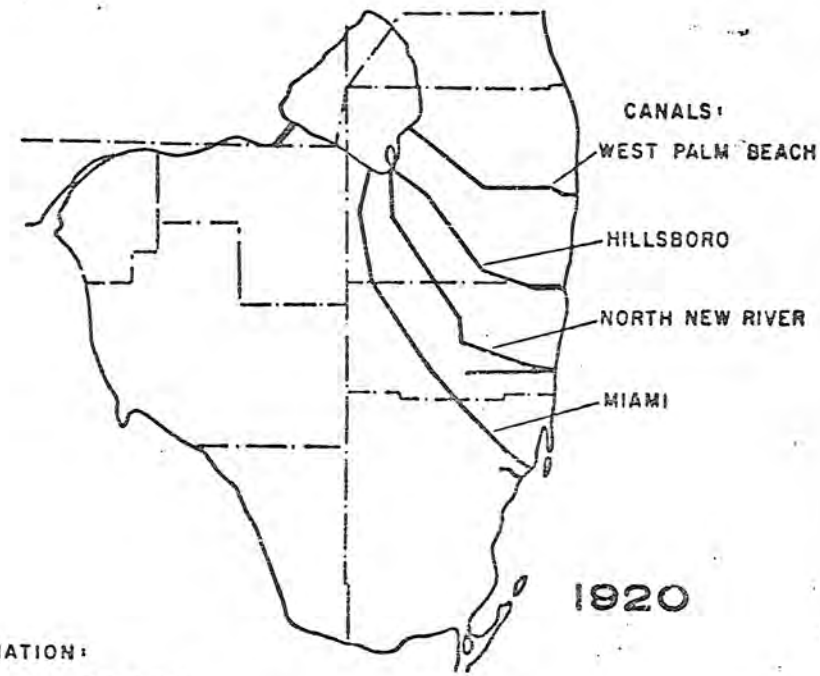




EXPLANATION:

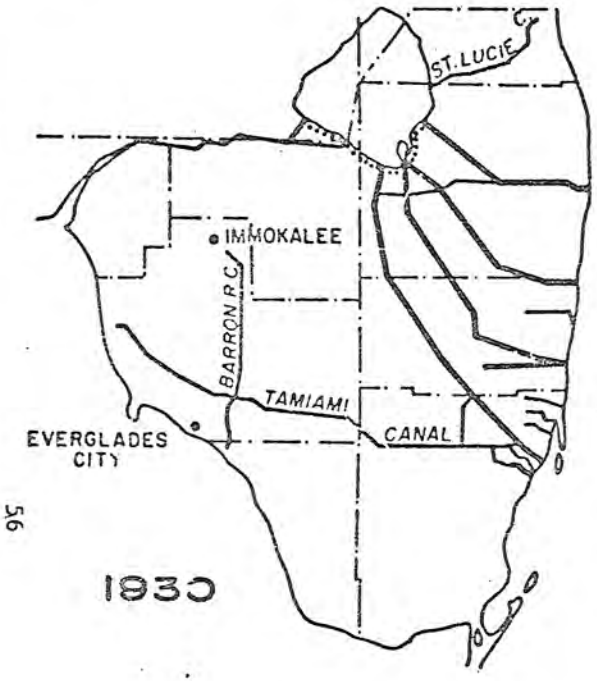
MAJOR CANAL EXISTING AT GIVEN DATE

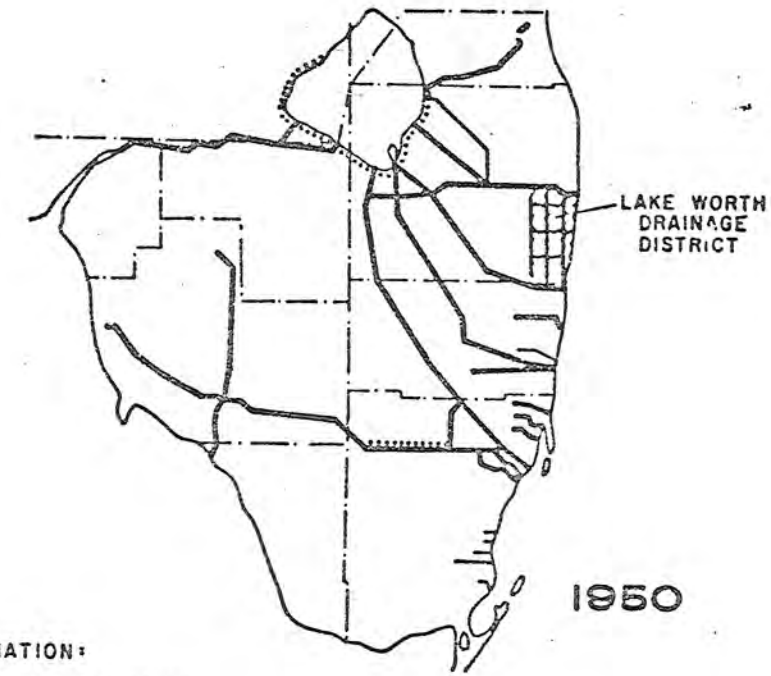
NEW CANAL SINCE LAST DATE

Much of south Florida was seasonally inundated in predevelopment times. To provide flood protection to cities and farms, extensive canal and levee network were constructed.

The Lake Worth Drainage District in Palm Beach County began operations in the 1930's. The District comprises about 200 square miles of agricultural land extending from the latitude of West Palm Beach southward to the Broward County boundary and from the west side of the urban coastal ridge inland nearly to Conservation Area 1. The area is dissected by 50 shallow lateral canals (east-west) and 4 equalizing canals (north-south). The network is connected to three primary canals that discharge flood water. Through inland connection with the West Palm Beach and Hillsboro canals, the system also provides irrigation water during dry seasons. The irrigation water is diverted from the system into shallow ditches and supplies such varied users as citrus groves, commercial flower farms, truck farms, dairy farms, and ranchland. Water levels throughout are regulated by control structures and pumps.

Many canals along south Florida's east coast were completed by 1930, providing rapid removal of storm water to the ocean. Because most of the canals were uncontrolled, they continued to drain the aquifer during dry seasons. This lowered water levels and invited the intrusion of sea water into both the canals and aquifer.





EXPLANATION:

MAJOR CANAL EXISTING AT GIVEN DATE

NEW CANAL SINCE LAST DATE

MAJOR LEVEE

The drought of 1943-45 brought into focus the need for control structures on the canals near the coast. Such structures allow discharge of flood water during rainy seasons and reduce or prevent flow during dry seasons. By regulation of flow, the structures maintain high water levels to retard sea-water intrusion during droughts and permit normal discharge of flood water. The structures do not permit passage of boats.

A new era in water management in south Florida began with the formation of the Central and Southern Florida Flood Control District. A system of levees, completed in 1953, along the east edge of the Everglades was the start of what eventually became the three conservation areas. The enclosure of Conservation Areas 1 and 2 and the south side of Conservation Area 3 enabled regulation of flow to Everglades National Park. These enclosures were completed by 1960 and 1962, respectively. By 1967 Conservation Area 3 was enclosed except for a 7.1-mile gap along its west boundary.

A flood-control plan was implemented for south Dade County as an aftermath of Hurricane Donna in 1960. The plan called for several primary canals and control structures, nearly all of which have been completed.

During the 1960's, extensive water-control works were also built to drain a large tract in the west part of the Big Cypress. The Golden Gate Canal system drains the west part of the tract, and the Fahka Union Canal system drains the south part; a series of weirs prevents overdrainage of the shallow aquifer (McCoy 1973).

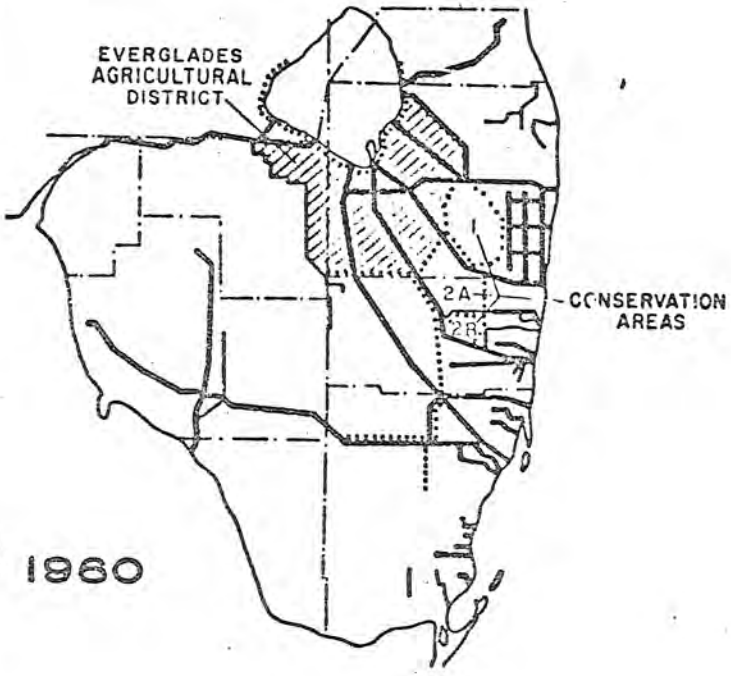
Currently, in southeast Florida, the following C&SFFCD water-management and control measures are in operation:

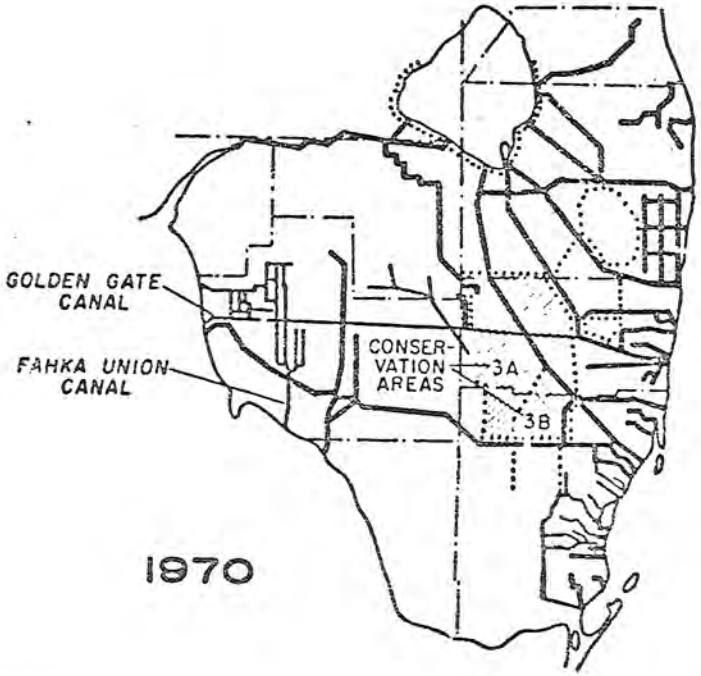
(1) Gated control structures in all canals, as near the coast as is feasible, block the inland flow of sea water. Secondary structures in inland reaches of certain canals regulate flow to downstream reaches and maintain fresh-water levels as high as possible in inland areas.

(2) A continuous levee system along the east edge of the Everglades, extending from mid Palm Beach County southward to south Dade County, forms the east boundary of the water-conservation areas and prevents the eastward flow of flood water from the Everglades.

(3) The three water-conservation areas store flood water for recharging the Biscayne aquifer along the coast and for supplying water to Everglades National Park. They also provide recreation and wildlife refuges.

(4) Improved and extended major canals control flooding in inland urban and farm areas during the rainy season. They also convey water, stored in the conservation areas, to the urban coastal area during drought.





EXPLANATION:

MAJOR CANAL EXISTING AT GIVEN DATE

NEW CANAL SINCE LAST DATE

MAJOR LEVEE

(5) high-capacity pumping stations at the north and south sides of the Everglades agricultural area control water levels for crop protection.

(6) A higher levee around Lake Okeechobee increases its storage capacity.

(7) A modified Kissimmee River channel and a system of water-storage pools increase potential replenishment to Lake Okeechobee.

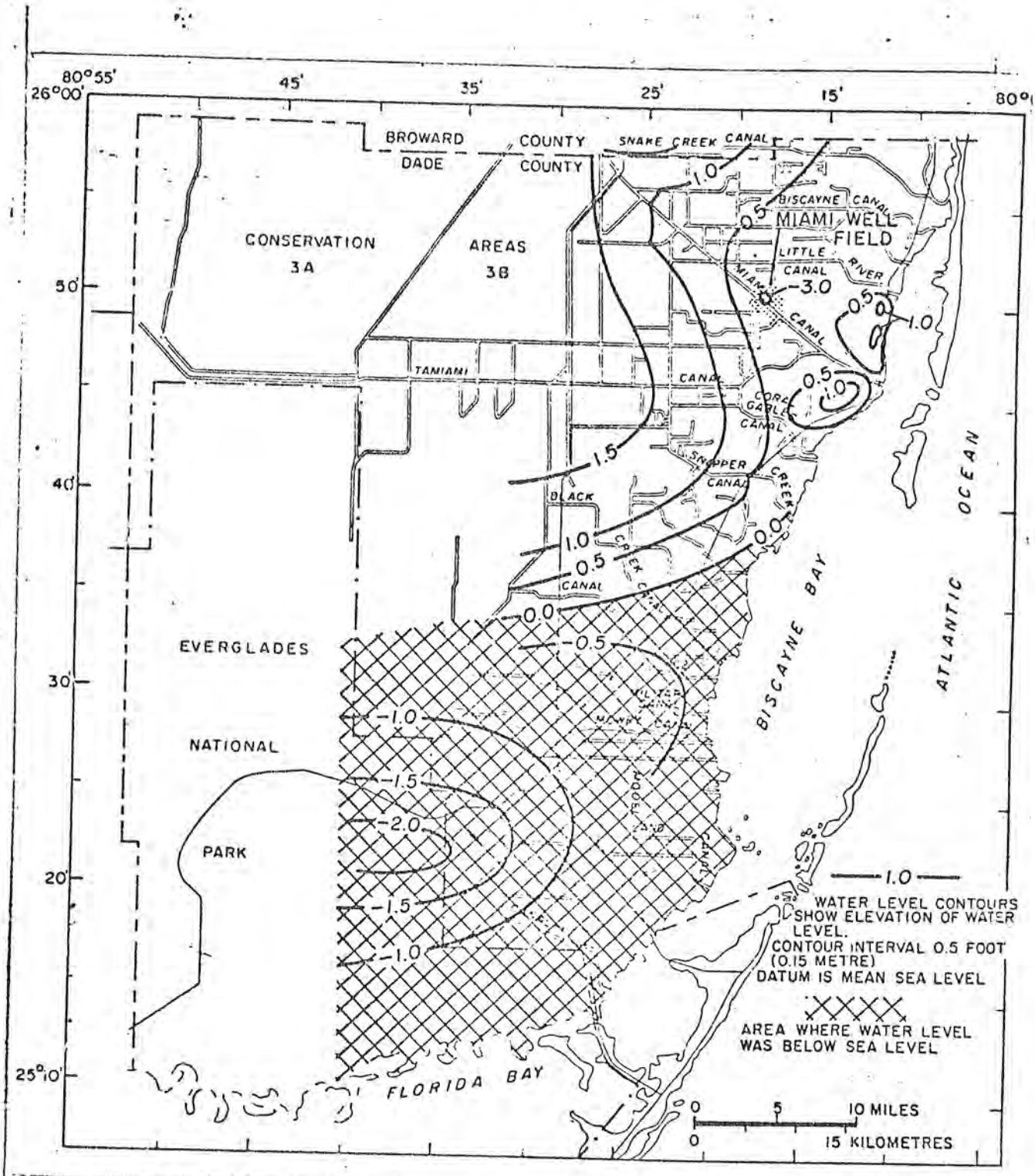
(8) An integrated network of canals moves water from Lake Okeechobee to Dade and Broward Counties. During the waning days of the prolonged drought of 1971, this network made water available to recharge the municipal well fields of Miami and Fort Lauderdale, preventing sea-water contamination.

History of Water Levels

Water levels in south Florida are usually highest in September or October and lowest near the end of May. Before any canals were constructed most of south Florida was inundated during the rainy season. Construction of the Caloosahatchee and St. Lucie Canals, the levees around Lake Okeechobee, and the primary drainage canals through the Everglades to the ocean caused water levels in southeast Florida to decline 5 to 6 feet (Parker, and others, 1955). The decline in water levels resulting from uncontrolled drainage was the prime cause of sea-water intrusion along the lower east coast and land subsidence in the Everglades agricultural areas. In the 1930's and 40's conditions worsened.

Water levels were record low at the end of the 1944-45 dry season. At that time: (1) across the north part of Dade County the hydraulic gradient was seaward but only 1.5 feet in 18 miles; (2) in the south part of Dade County water levels were below sea-level and the hydraulic gradient was inland; and (3) in the Miami well field, adjacent to the Miami Canal sea water was contaminating the municipal water supply. In 1946 salinity-control structures were placed in all primary canals in Dade County--the real beginning of water control and conservation in most of southeast Florida and the end of emphasis on land reclamation.

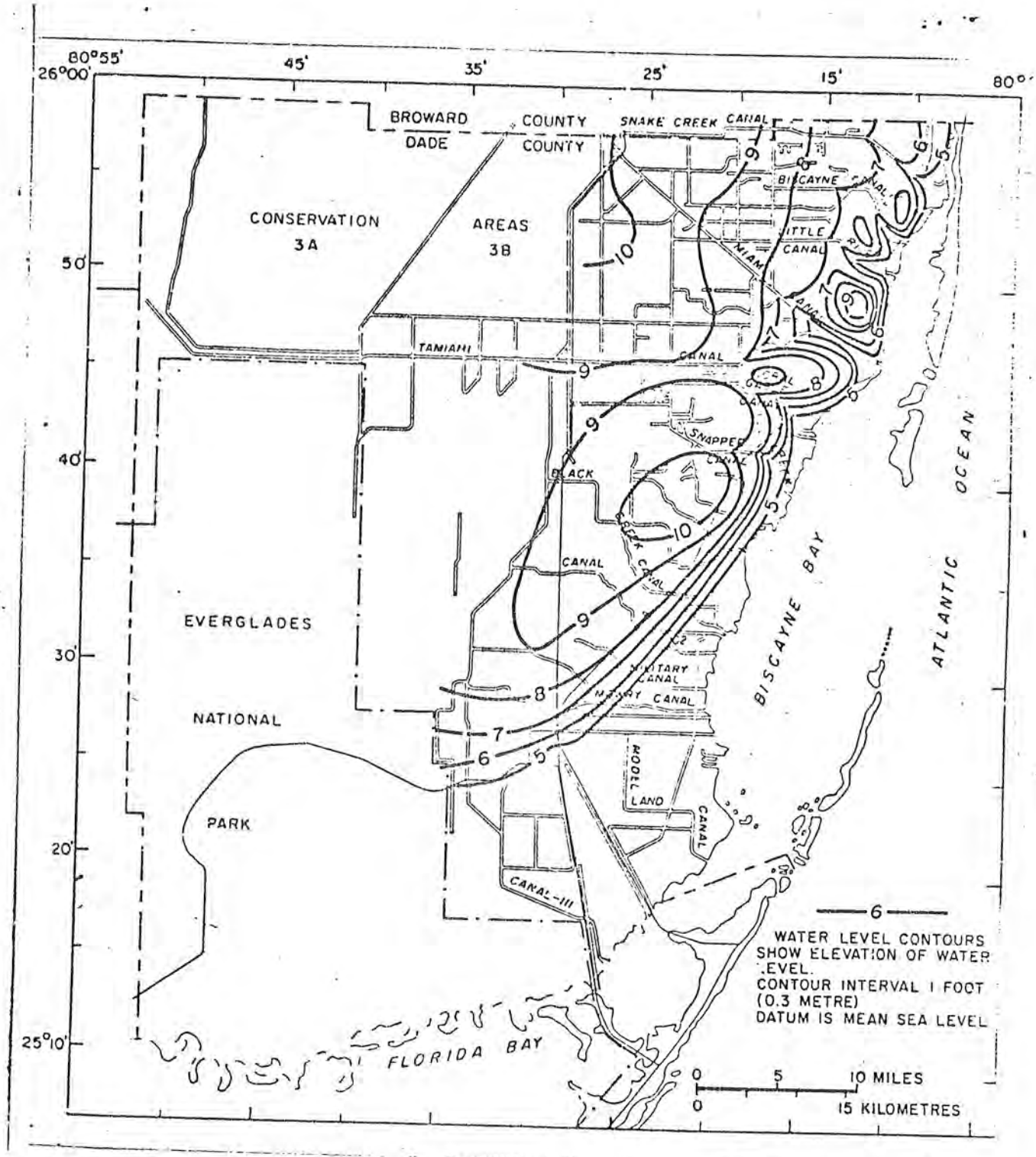
62



Ground-water levels during May-June 1945 were below sea level in much of Dade County. The absence of salinity control structures in most canals resulted in the inland migration of salt water.

Flooding was widespread in October 1947. All but the high sections of the Atlantic coastal ridge were flooded for several days to a few weeks. Particularly hard hit were the downtown and suburban areas of Miami and Fort Lauderdale, and in the south Dade area water levels were more than 10 feet above sea level. The canals in existence at that time were not able to accommodate the eastward overflow from the Everglades.

Before the Central and Southern Florida Flood Control District was established in 1949, water-level data outside of Dade County were sparse. Before that time data from a few gaging stations recorded large seasonal changes, ranging from flood to prolonged drought. The Everglades was flooded annually, but, because of drainage, it was inundated for shorter periods than during predrainage. This shortening promoted the dessication of the peat soil and decreased southward flow to Florida Bay and to what is now Everglades National Park.



Record high water in October 1947 flooded interior and south parts of Dade County and much of downtown Miami.

The Big Cypress, most of which is still in a natural state, is inundated several months each year. Early in the rainy season surface water recharges the shallow nonartesian aquifer in southwest Florida. Later in the rainy season the aquifer becomes saturated, and the surplus surface water flows slowly southward through large strands and sloughs and the Barron River Canal. After the rainy season both flow and inundation gradually diminish, and, except in the major sloughs, water levels decline below the land surface. In the western part of the Big Cypress, the period of inundation began to decrease after 1960. Water-level characteristics in the east part of the Big Cypress have changed but little.

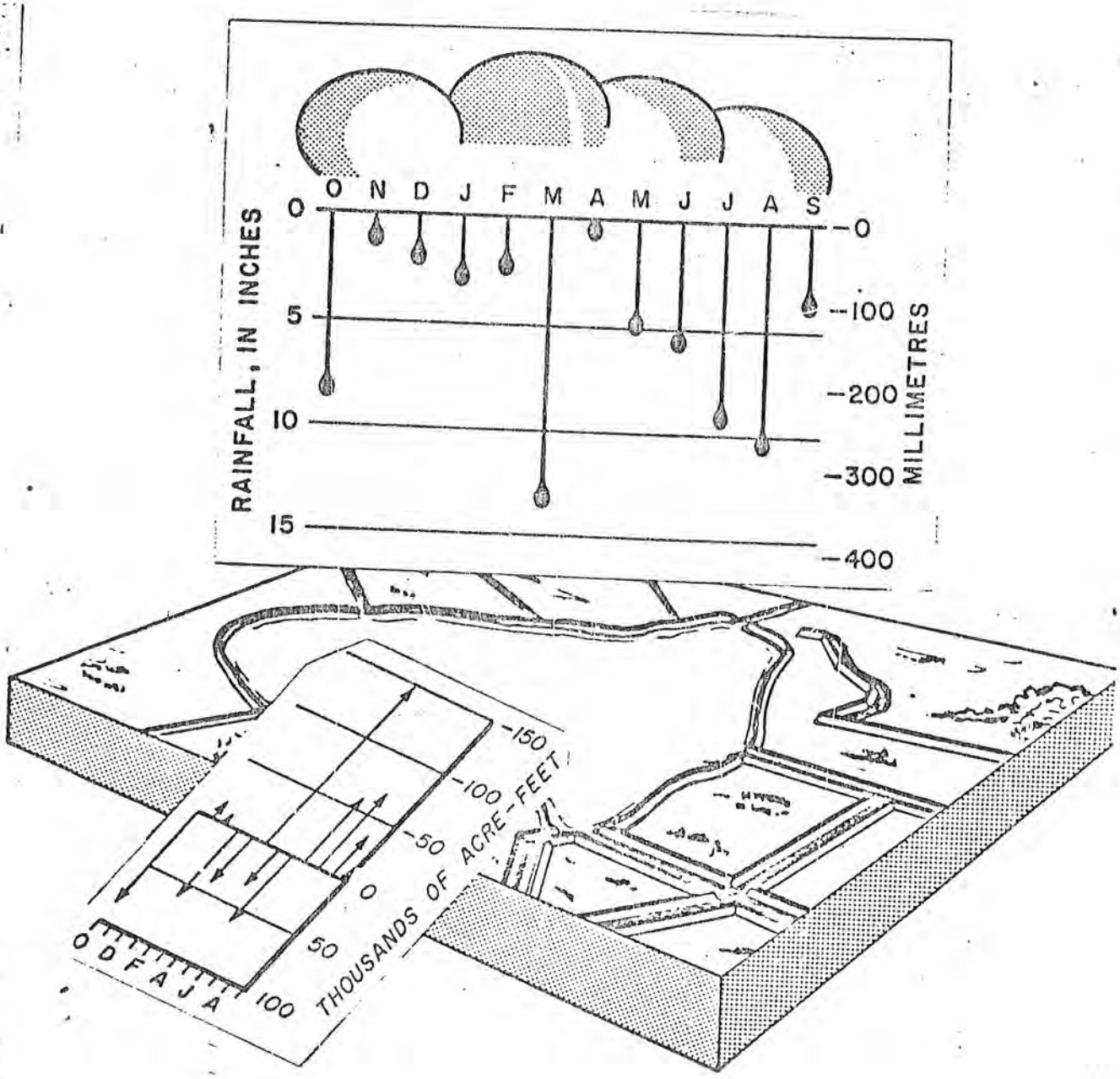
Impoundment

Before intensive development began in the northern Everglades, flow was continuous through the Everglades to Florida Bay during the rainy season and for several months afterward. Damage from the 1928 hurricane indicated that if parts of the Everglades were to be developed, Lake Okeechobee had to be controlled. By 1938 a levee along the south shore of the lake was completed to prevent recurrence of the flood damage caused by lake overflow. Thus, the initial purpose of impoundment in the lake was to protect adjacent lands from flooding. Its level was regulated by releases of water eastward through the St. Lucie Canal and westward through the Caloosahatchee River.

With the establishment of the C&SFFCD, the emphasis on land reclamation began to change to water control and conservation. Lake Okeechobee became the prime unit for surface-water storage in the water system of southeast Florida, supplemented by the three water-conservation areas to the south. Water from the lake is also used to irrigate the surrounding areas and to maintain water levels in the West Palm Beach Canal basin. The conservation areas serve as replenishment sources for lower east coast municipalities and agriculture by releases into canals and by underseepage through the Biscayne aquifer.

Lake Okeechobee is fed from the north chiefly by the Kissimmee River. It is fed from the south by a system of pumping stations along its south shore, which removes surplus water from the north part of the Everglades agricultural area.

Nearly all surface flow into and out of Lake Okeechobee is controlled. Generally during dry periods, water is released from the lake to sustain the highly productive agricultural areas just south of the lake and to supply water to the urban areas along the lower east coast. During wet periods, water is pumped into the lake from the agricultural areas to prevent flooding. Thus, the volume of downstream flow, in a general way, is inversely proportional to rainfall. For instance, during the 1970 water year (October 1, 1969, to September 30, 1970,) a wet year, pumpage into the lake from these canals was greater than the flow to the canals from the lake. Long-term averages show that flow out of Lake Okeechobee through the West Palm Beach, Hillsboro, North New River, and Miami Canals is only slightly more than pumpage into the lake from these canals.

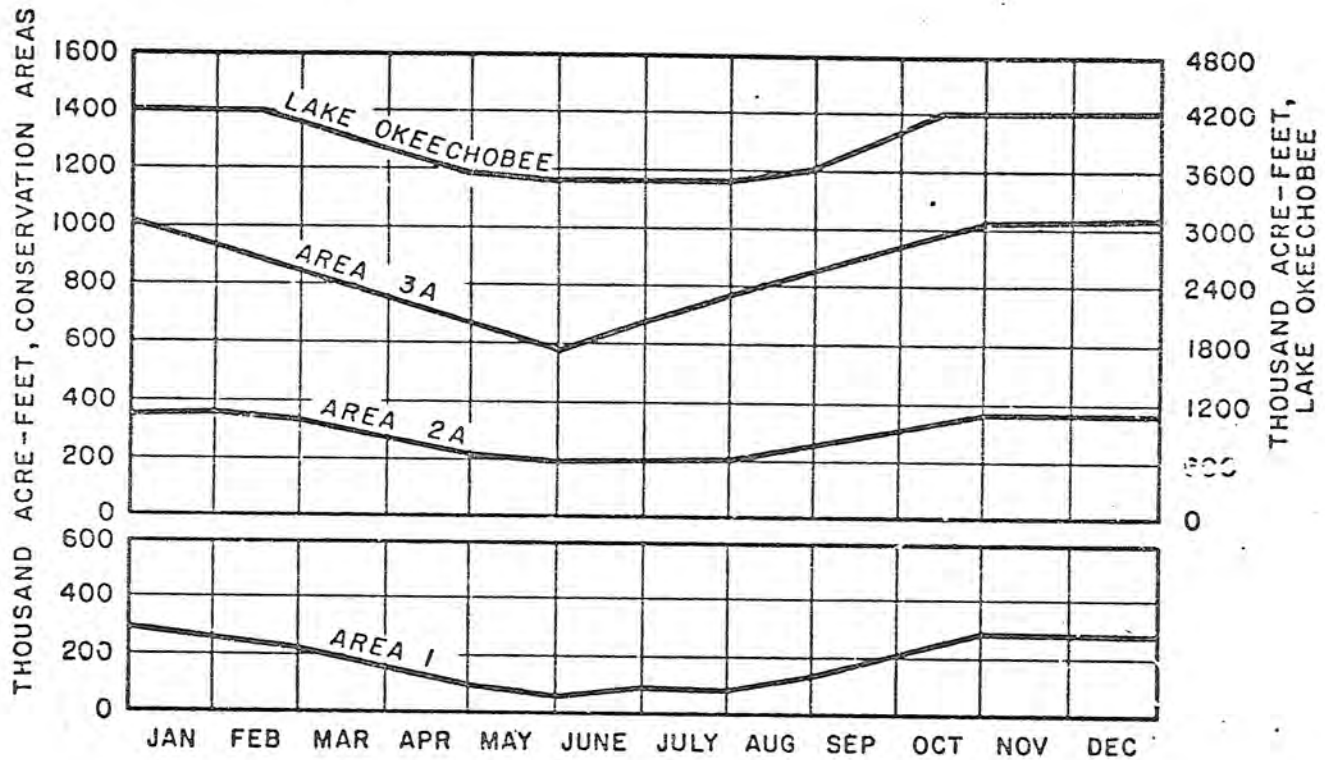


Arrows represent total monthly flow into or out of Lake Okeechobee by way of the West Palm Beach, Hillsboro, North New River and Miami Canals during the 1970 water year. Net flow was into the lake.

The three water-conservation areas are connected by spillway structures that enable water to be transferred directly from Lake Okeechobee through Conservation Area 3 and thence to the Miami area during drought. The water-conservation areas are replenished by rainfall and in addition by: (1) pumping of excess water from the south part of the Everglades agricultural areas into Areas 2 and 3; (2) pumping of excess water from interior parts of Palm Beach County into Area 1; (3) water moving from eastern Collier County to Area 3; and (4) pumping of excess water in the inland parts of south Broward County westward into Area 3 (backpumping).

Control structures throughout the system are operated to effect the storage schedules shown in the graphs of desired water levels for the four reservoirs. During times of extreme rainfall the storage schedules are exceeded for short periods until releases can be made to return the storage to schedules. On the other hand, during prolonged drought, storage may be below schedule for several months.

The scheduled level for Lake Okeechobee ranges from 14.0 to 15.5 feet above sea level. When the perimeter levees are raised in the near future, the operating levels will range from 15.5 to 17.5 feet, adding approximately 900,000 acre-feet to storage for use during dry seasons. The partly dry and partly wet character of regulation of the conservation areas is designed to preserve or enhance the vegetation and the fish and wildlife in the areas.



A schedule of desired water storage for the conservation areas and Lake Okeechobee is maintained as closely as possible (Adapted from Corps. of Engineers, 1968).

The use of the impoundment system not only minimizes flooding in urban and agricultural areas, but it also conserves water by delaying the runoff. The impoundment of water constitutes an attempt to remedy the effects of overdrainage in the Everglades by attempting to duplicate artificially the natural storage capacity that prevailed during predrainage times.

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Water Budgeting for the Conservation Areas

The three water-conservation areas make up a major part of the southeastern water-management system. Levees surround their nearly 1,400 square miles, making them shallow lakes capable of storing large volumes of water temporarily. From the water-conservation areas the water is conveyed to Everglades National Park, to the urban areas along the lower east coast, or is evaporated.

The water budget is a popular method of accounting for water entering and leaving a hydrologic system. A balance sheet is set up that lists receipts, disbursements, and water on hand. The receipts include rainfall and surface-water inflow. The disbursements are surface-water outflow, seepage through the boundaries, and evapotranspiration. Water on hand is the water in storage (surface or underground).

Because the three water-conservation areas constitute such an important element in the water-management system, a water budget was developed for them. Only the controlled parts of the conservation areas--about 1,200 of the total 1,400 square miles--were used in the development.

The accounting period for the purpose of this investigation is the runoff year, beginning April 1 and ending the following March 31. For example, the 1968 runoff year begins April 1, 1968, and ends March 31, 1969. The runoff year was selected because, normally, flow in the Everglades begins in April and stops by the end of March. The drought of 1970-71, one of the most severe droughts, was included in one accounting period.

Entries are made in the water-budget balance sheet according to the equation:

Evapotranspiration = Inflow - Outflow + Change in Storage.

Flows were computed for all surface-water inflow and outflow points except that through a 7.1-mile opening along the west boundary of Conservation Area 3A, where the inflow was estimated. Seepage losses were estimated from the difference in water levels on either side of a levee.

A comparison of the receipts and disbursements for the 1969 runoff year with those for the 1968 runoff year shows that more water flowed into and out of the conservation areas in 1969 (an above-average rainfall year) than in 1968 (a year of normal rainfall). In the 1970 runoff year (below-average rainfall) recipts and disbursements, except for evapotranspiration, were generally smaller than in 1968. This indicates less movement in the system.

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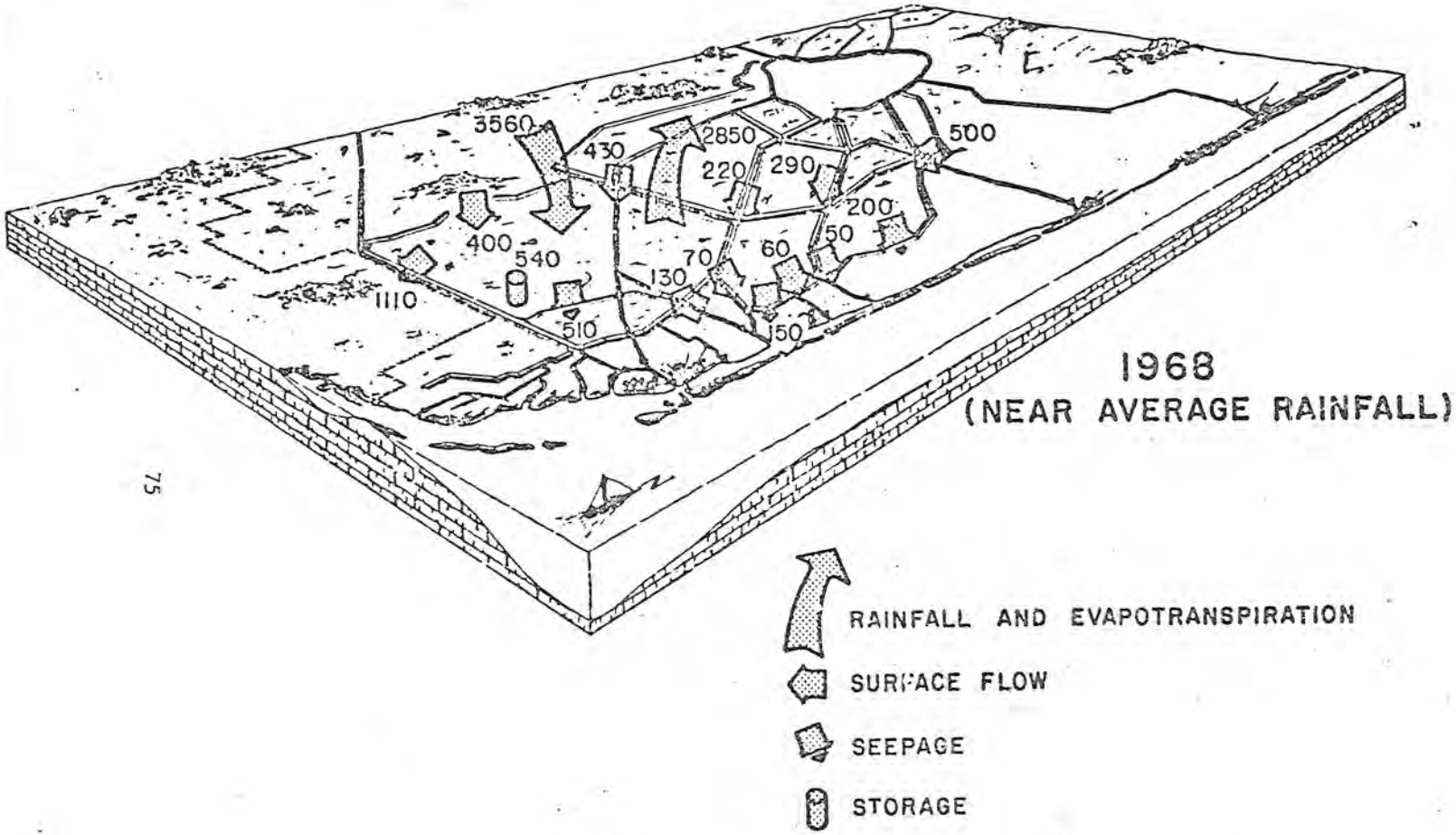
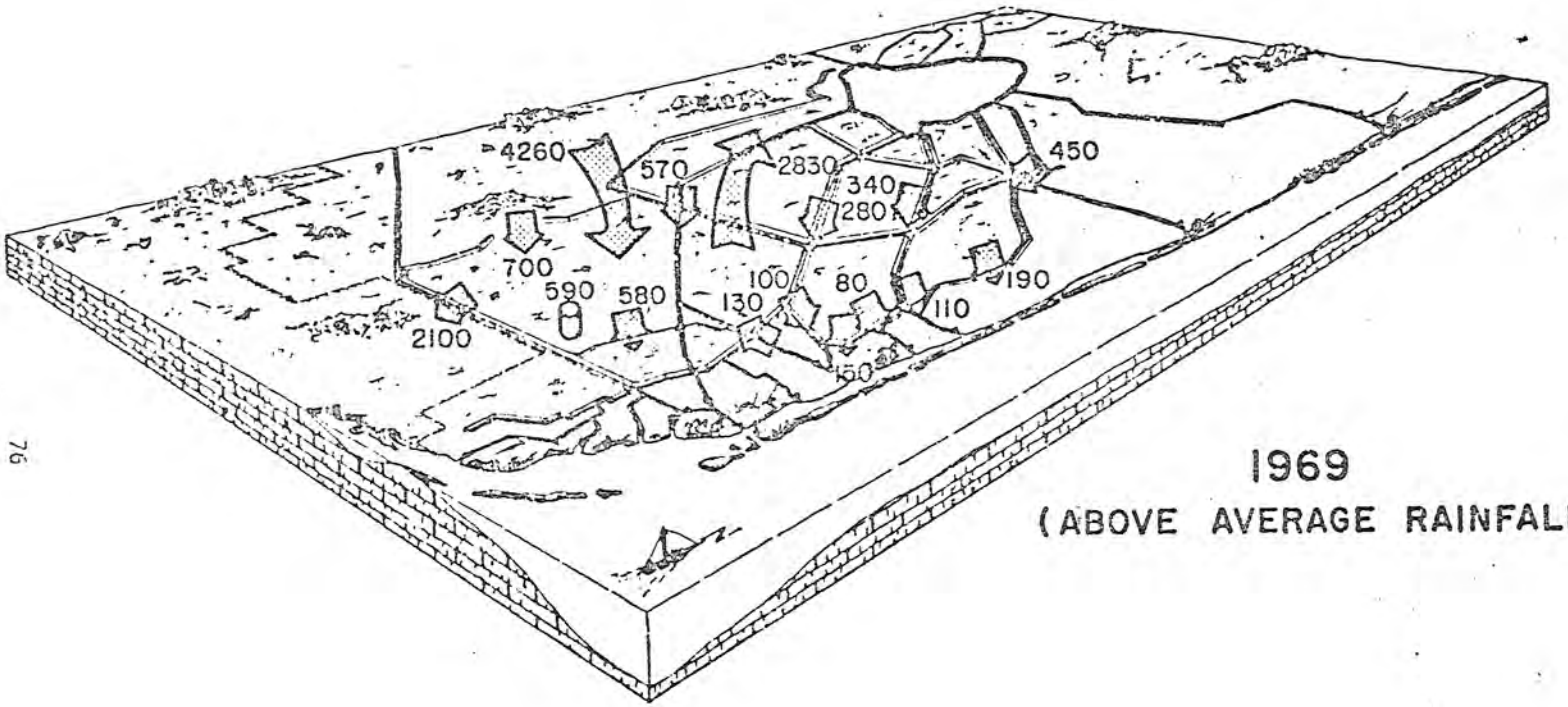
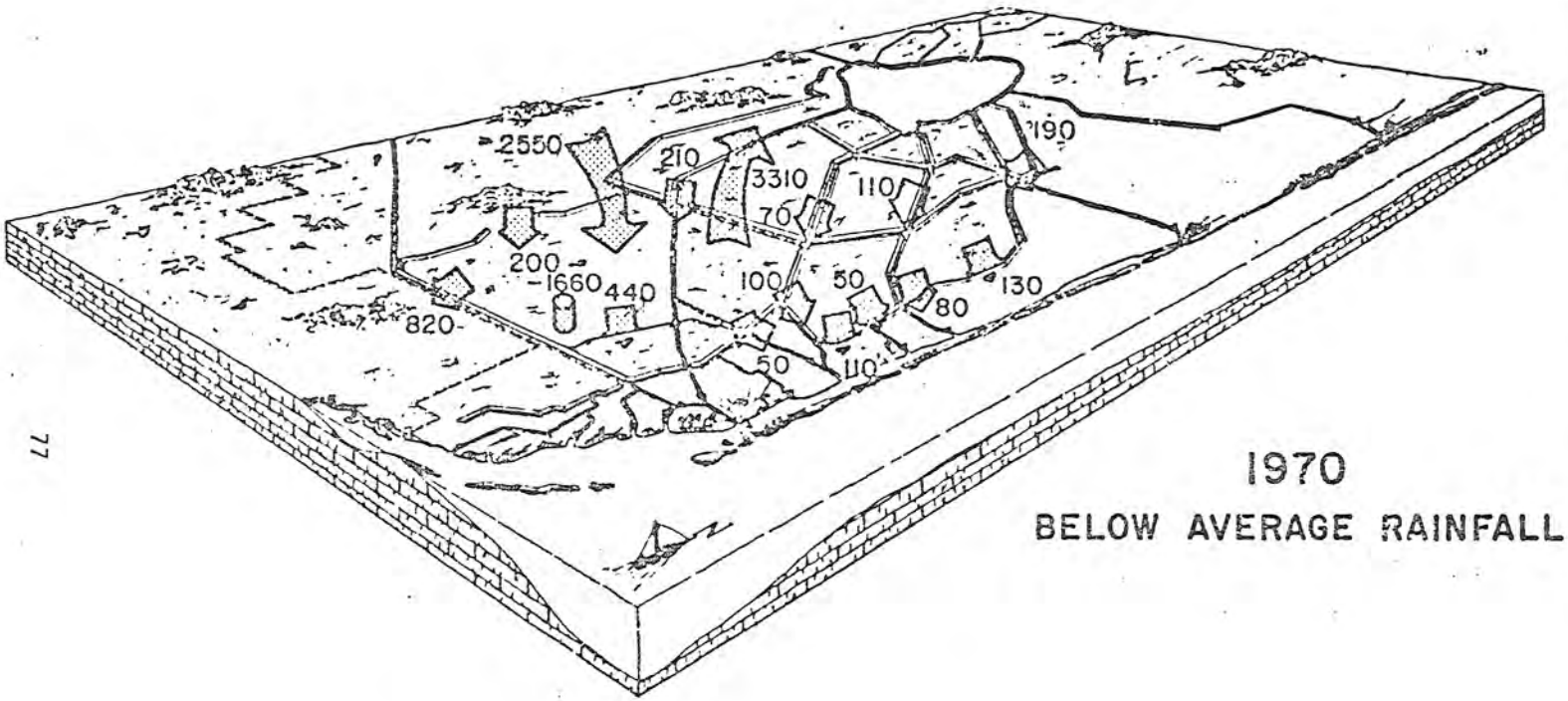


Inflow and outflow were generally smaller in 1970 than in 1968. Evapotranspiration was greater in 1970 than in either of the two other years.

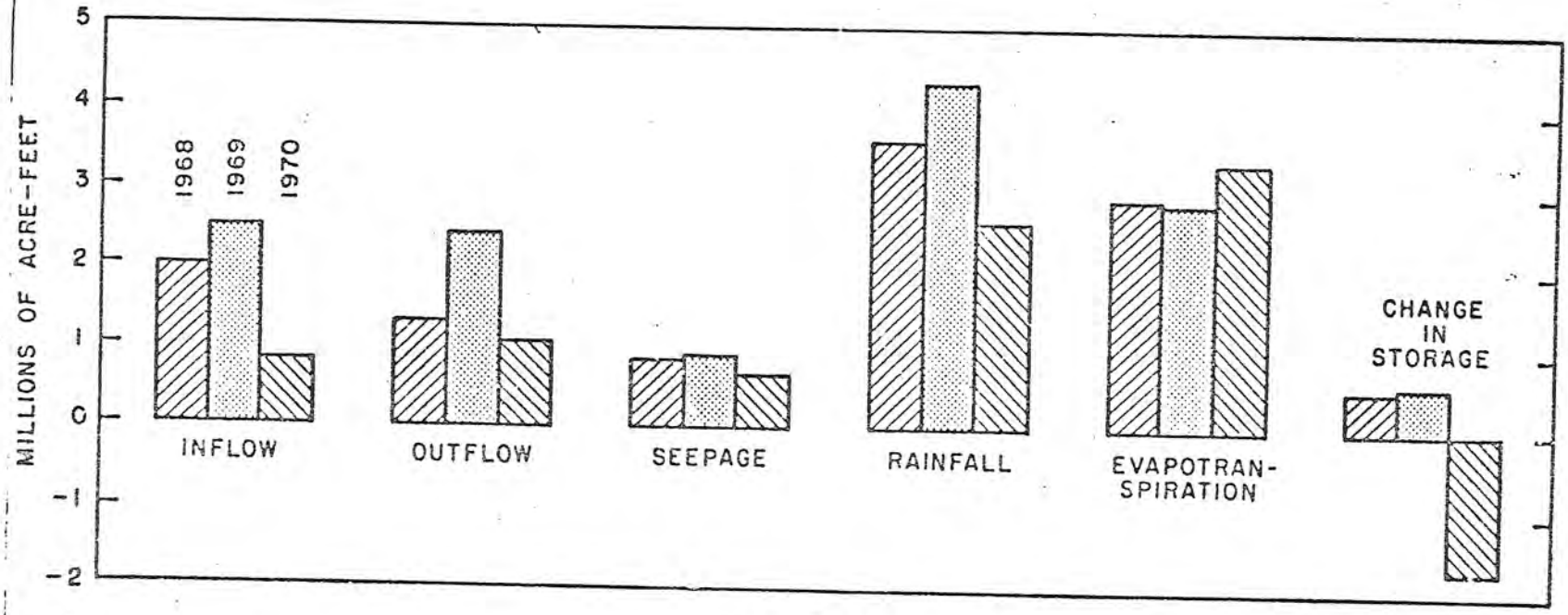


1969
(ABOVE AVERAGE RAINFALL)



1970

BELOW AVERAGE RAINFALL


MILLIONS OF ACRE-FEET
5
4
3
2
1
0
-1
-2
1968
1969
1970
INFLOW
OUTFLOW
SEEPAGE
RAINFALL
EVAPOTRAN-
SPIRATION
CHANGE
IN
STORAGE

SUMMARY

Evapotranspiration usually averages 75 to 95 percent of rainfall. For the 3 years of the investigation, the average was about 90 percent. Note that in 1970 evapotranspiration exceeded rainfall by 30 percent, a usual condition when rainfall is significantly less than normal. The 1970 drought also decreased storage in the impounded areas about one and a half times the amounts of the combined increase of the 2 previous years.

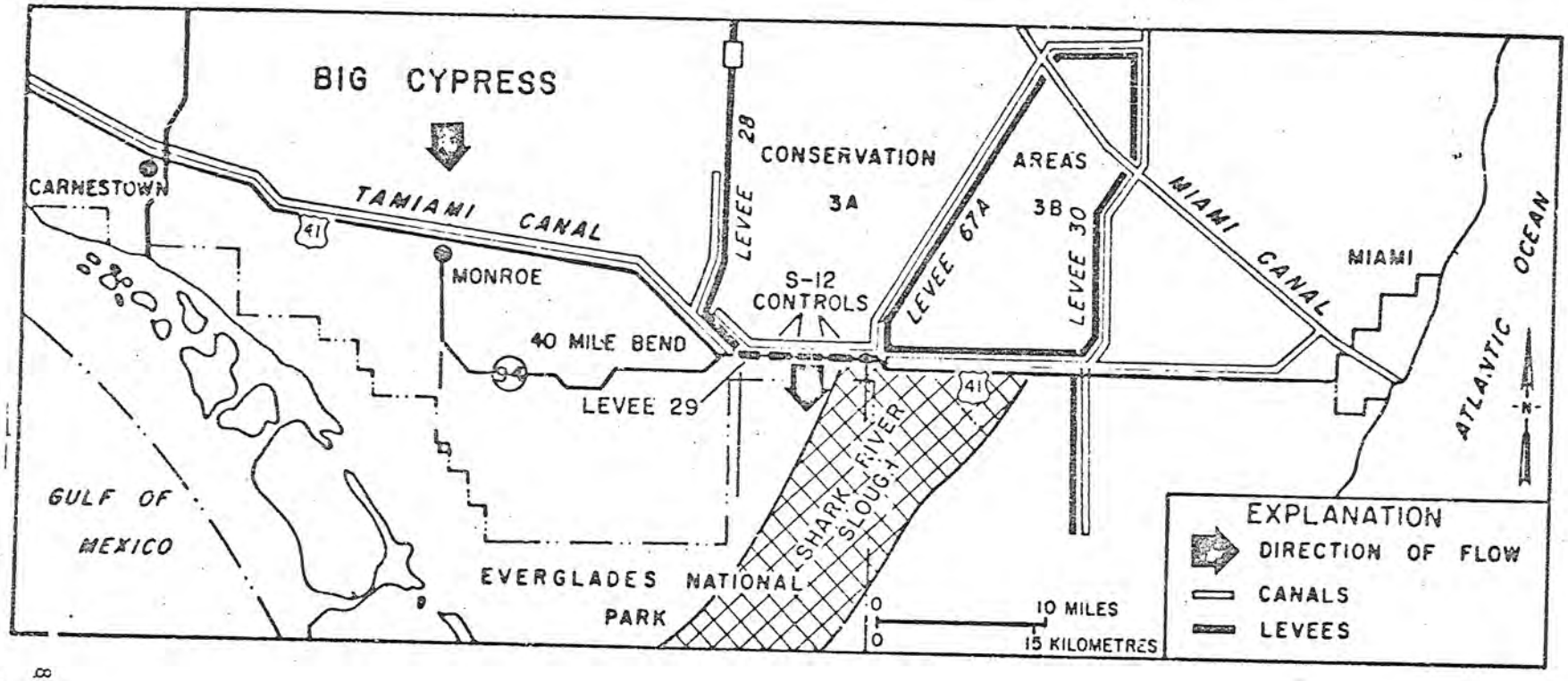
An important factor to consider in the evaluation of the effects of the dry period near the end of the 1970 runoff year is that most inflow and outflow occurred early in the year. Excess water was carried over from the previous year (1969) and was released early in the year to prepare for the wet season. Although the surface-water inflows and outflows reflect a reduction in water movement, they do not adequately reflect the severity of the water shortage in the latter part of the year. Water levels declined rapidly as rainfall became more deficient. The effects of this drought would have been much more severe had the 1970 runoff year not been preceeded by a period of excessive rainfall.

Flow to Everglades National Park

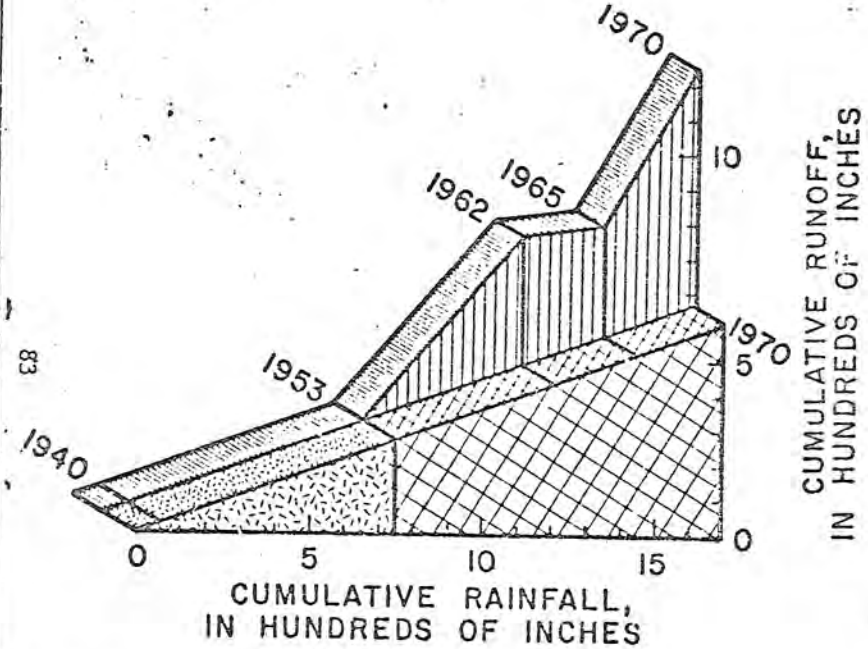
Everglades National Park is a unique widespread lowland swamp area with a highly water-oriented environment. Water flowing south into this area helps to sustain its typically moist condition. Historically, water flowed to Everglades National Park from the Big Cypress, from the Everglades through Shark River Slough, and from the south part of the coastal ridge by way of Taylor Slough. Since 1962, flow into Shark River Slough has been regulated by control structures in the south boundary of Conservation Area 3A.

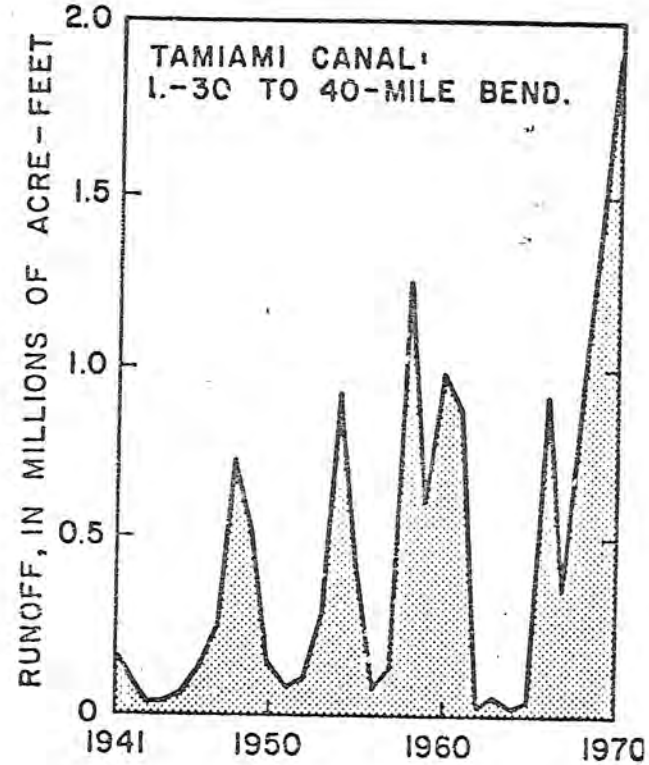
Flow to the Park is of two types--natural and regulated. Flow from the Big Cypress and Taylor Slough is natural, and flow into Shark River Slough is regulated. Hydrologic data for several index stations from 1941 to 1971 illustrate flow characteristics before and after construction of water-management facilities. Other short-term records were extended to the 1941-71 period by use of correlation techniques.

Natural flow originating in the Big Cypress (through outlets in Tamiami Canal from 40-Mile Bend to Monroe) averaged 541,000 acre-feet per year (1941-62) and 637,500 acre-feet per year since then (1963-70). The difference reflects the variation and distribution of rainfall.



Flow to Everglades National Park from Conservation Area 3 is regulated; flow from the Big Cypress is not regulated.





Cumulative runoff under natural conditions.

Projected cumulative runoff had no water-control facilities been built.

Actual cumulative runoff.

Southward flow to Everglades National Park from Conservation Area 3 has increased since the completion of water-control facilities north of the park. Since 1962 flow has been controlled.

A different and independent analysis made for this investigation yielded similar results. This analysis, known as a double-mass curve analysis, removes the effects of rainfall variations. Cumulative annual runoff is plotted against cumulative annual rainfall. In this analysis, significant departure from a straight line indicates a change in hydrologic relations. Completion of the eastern levee system in 1953 and Levees 29 and 67A in 1962 are each reflected by sharp breaks in the double-mass curve. Note also that the double-mass curve for natural flow from the Big Cypress is a straight line, which indicates that conditions affecting the rainfall-runoff relation have not been altered.

Inflow of 315,000 acre-feet per year has been considered to be the total annual water requirement for the Park, excluding inflow from the Big Cypress. Of this total, 260,000 acre-feet per year, as reported by Leopold (1969), is widely cited as the average annual inflow needed for the Park from Conservation Area 3A. The remaining 55,000 acre-feet per year is made up of inflow from Taylor Slough, 26,000 acre-feet per year, and from the panhandle area at the east edge of the Park, 29,000 acre-feet per year. These figures were based on available data for a 10-year index period ending in 1962. Inflows presented in this report are based on historic flows during 1940-62, before control of releases from the Everglades southward across Tamiami Trail. Therefore, differences exist.

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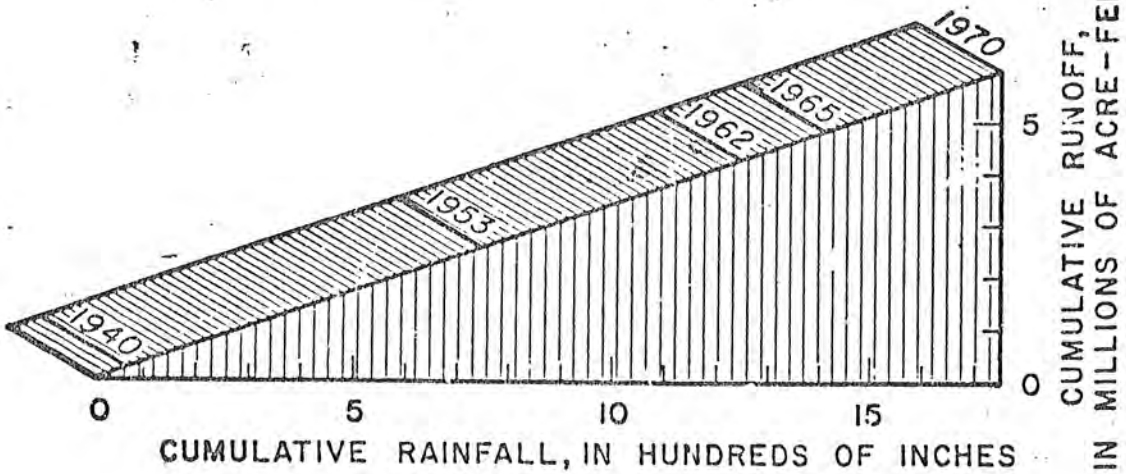
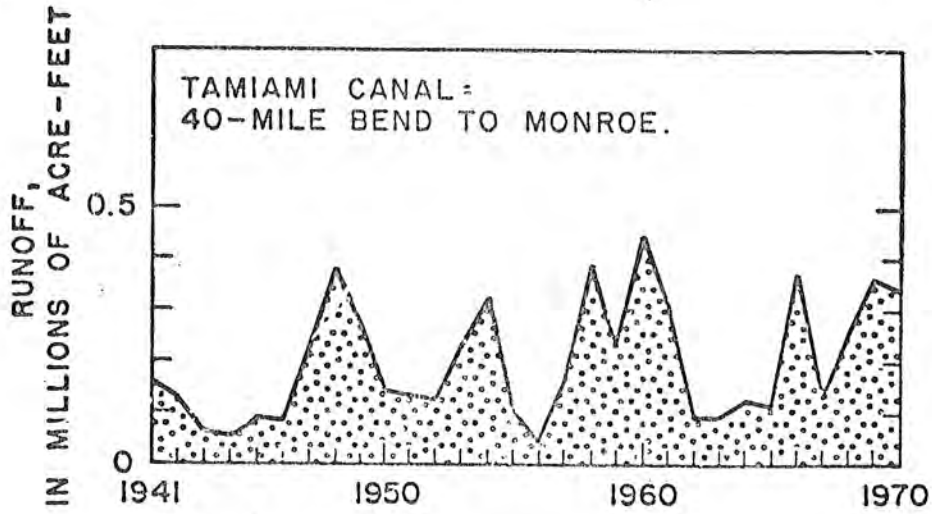


Cumulative runoff to the park under natural conditions.



Southward flow to the park from the Big Cypress has remained uncontrolled. Variation in this flow results from variation in rainfall.

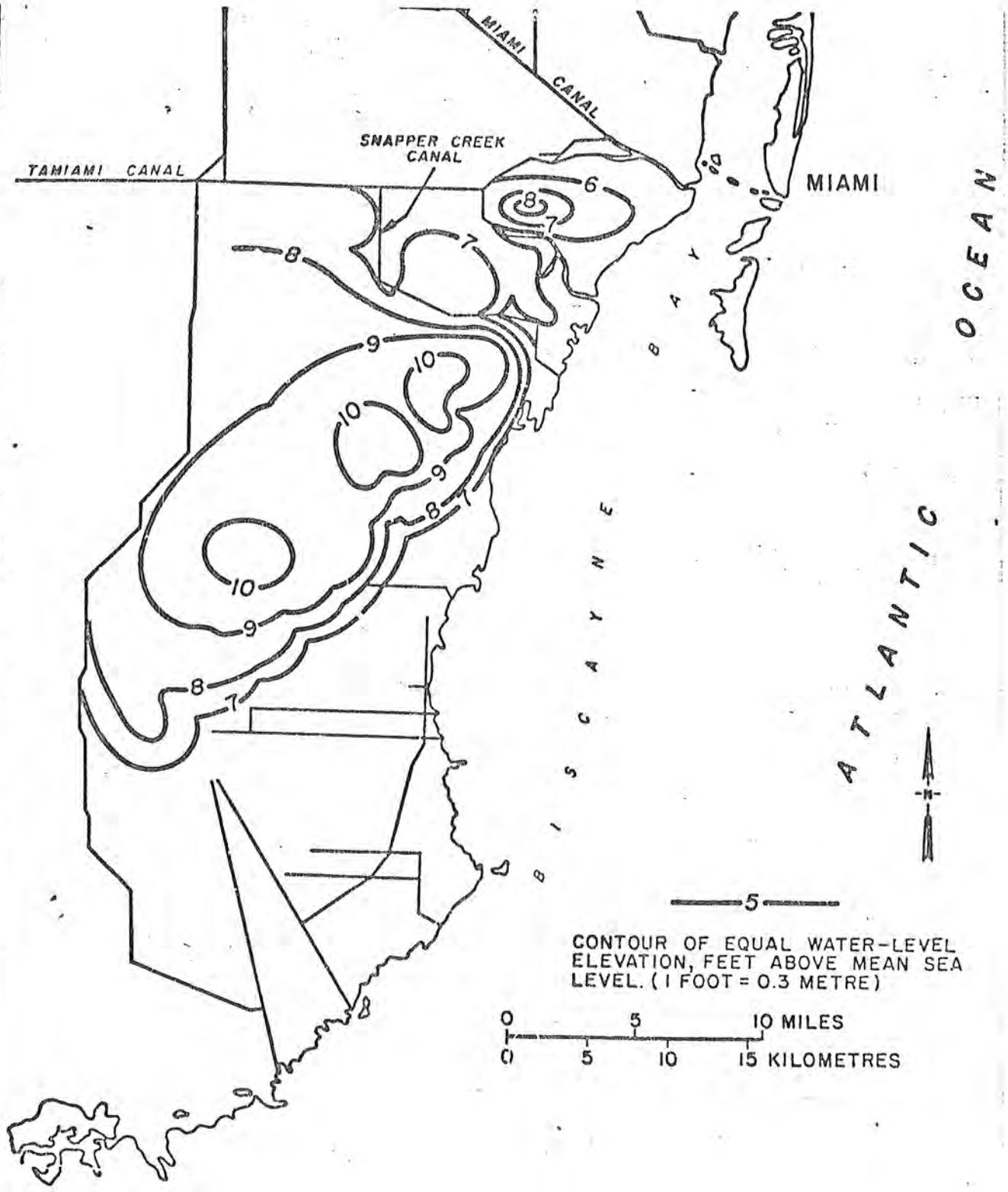
On the basis of long-term data and short-term data extended to the longer period, the total average annual inflow to the park was 947,600 acre-feet before construction of controls (1941-62) and 1,284,800 acre-feet after construction (1963-70). About 250,000 acre-feet per year of this increase was caused by the levee-canal network. The remainder of the increase is due to higher than average rainfall. It is emphasized that the figures of inflow from the Big Cypress and Taylor Slough are only indicators and are considered to be conservative. Big Cypress discharge does not include any flow originating in the area between the Tamiami Canal (where the flow is measured) and the park boundary. Inflow from Taylor Slough is measured near Royal Palm Hammock (inside the park) but is considered to be a representative index. These flows do not reflect the total quantity of water needed to sustain the environment in the park. Replenishment of water supplies by rainfall within the park is an important factor. Rainfall allows some areas of the park to be independent of external inflow for their water supply.

The ecosystems within the park depend not only on a minimum quantity of water but also on the seasonal distribution of inflow. Large variations within or between annual cycles can be as destructive as insufficient inflow.

Improved Drainage

Because of a large population influx during 1950-70, work on drainage and water-management improvements was continued along the urban coastal ridge of southeast Florida to minimize flooding in urban and agricultural areas. During the 1950's, flooding in southeast Florida was greatly reduced by canal improvements and regulation of water levels in canals and in the shallow aquifer. During the wet years of 1959-60, however, developed areas were flooded, particularly north Broward County, parts of Palm Beach County, and south Dade County, where drainage was as yet unimproved.

The extreme rainfall related to Hurricanes Donna and Florence, in September 1960, caused fairly widespread flooding in south Dade County, the area of heaviest rainfall. All but the high areas of the coastal ridge south of the Snapper Creek Canal were flooded for a few days to several weeks. The high-water levels in south Dade County equaled those of 1947.

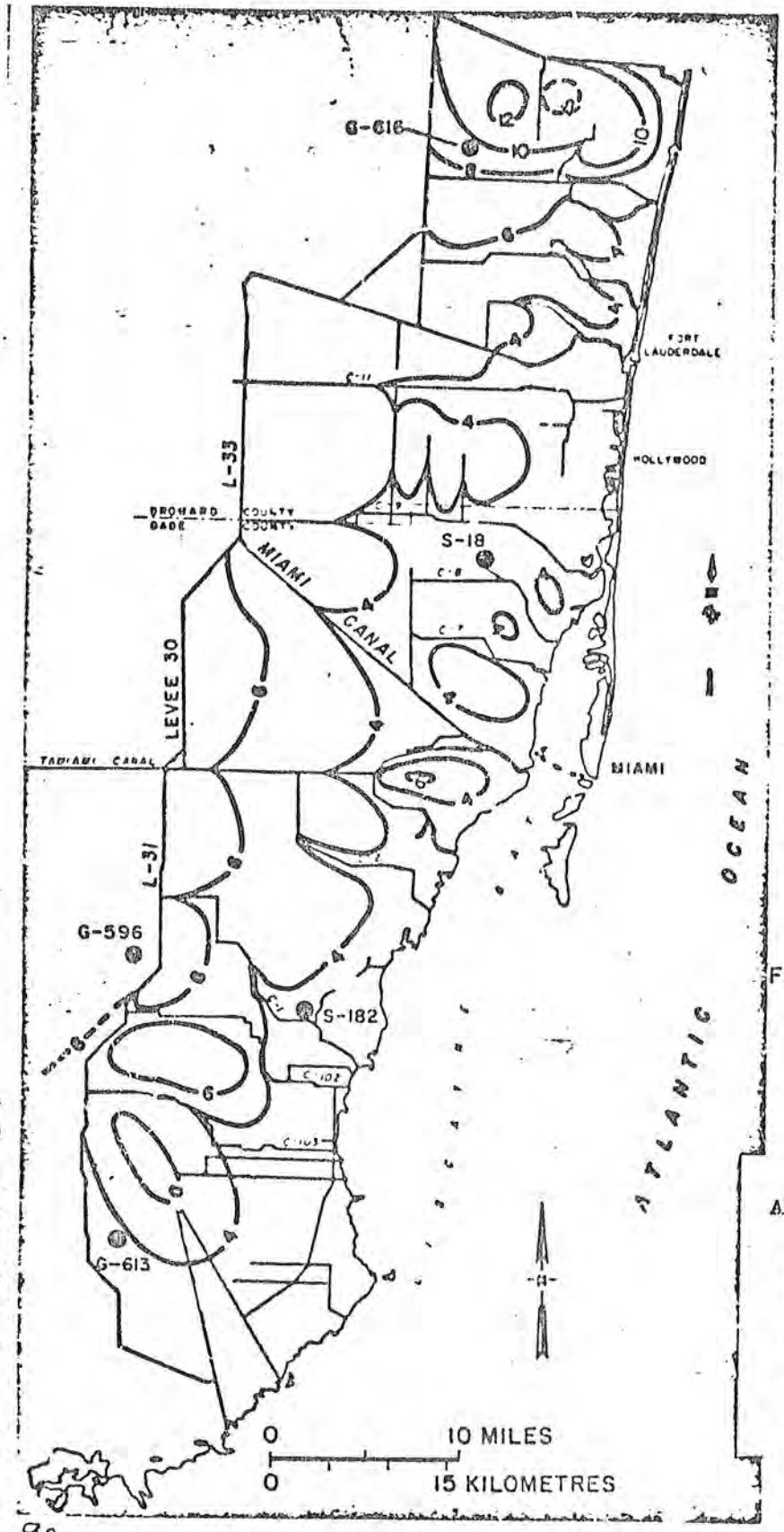


Heavy rainfall in September 1960 caused widespread flooding in south Dade County.

South Florida Water Management District Library

Plans for a drainage system for south Dade County thus received impetus. Such a system was virtually completed by the end of 1968. The effectiveness of the new system, after rainfall of nearly 16 inches in May and more than 15 inches in June near Homestead, is shown by the map of southeast Florida showing water-level contours near the end of June 1968. when water levels were high within most of the urban and agricultural area. Flood-control resulted in local ground-water mounds in the intercanal areas rather than in a single elongate mound in south Dade County, as in September 1960. By draining during potential flood periods, build-up of high ground-water levels is prevented and flooding is minimized. There were no floods during May-June 1968, although the rainfall volume exceeded that of the 1960 storms (28 inches during August and September 1960).

The short-period hydrographs of well S-182, in south Dade County near Canal 1, compare the rates of recession of the water table before and after construction of Canal 1.
The increase in the rate of recession on the September 1965 graph shows how effectively the canal drains ground water when control structures are opened during the rainy season.



EXPLANATION

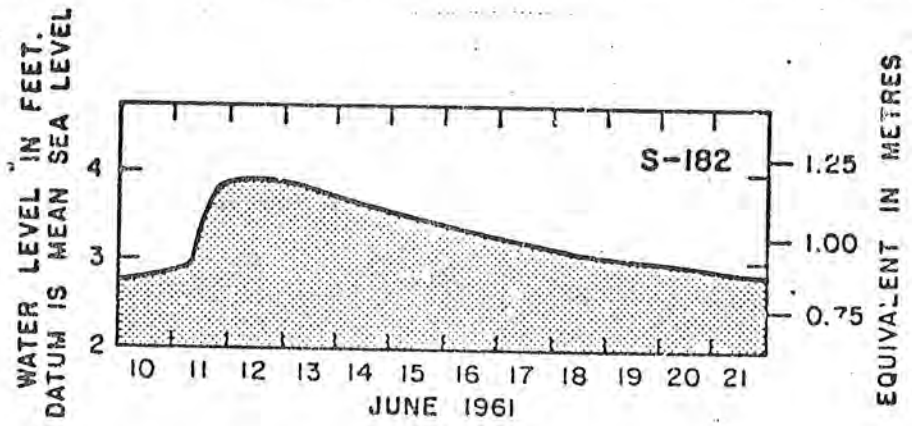
G-616

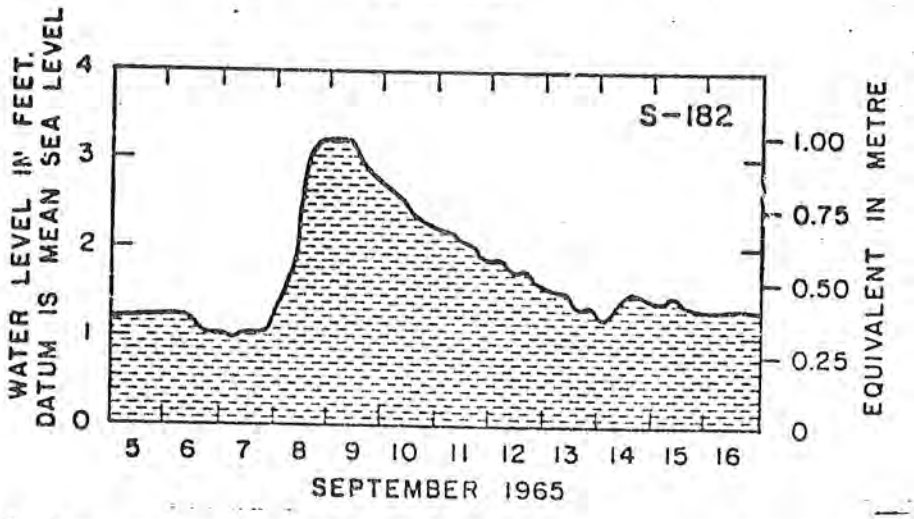
OBSERVATION WELL

4

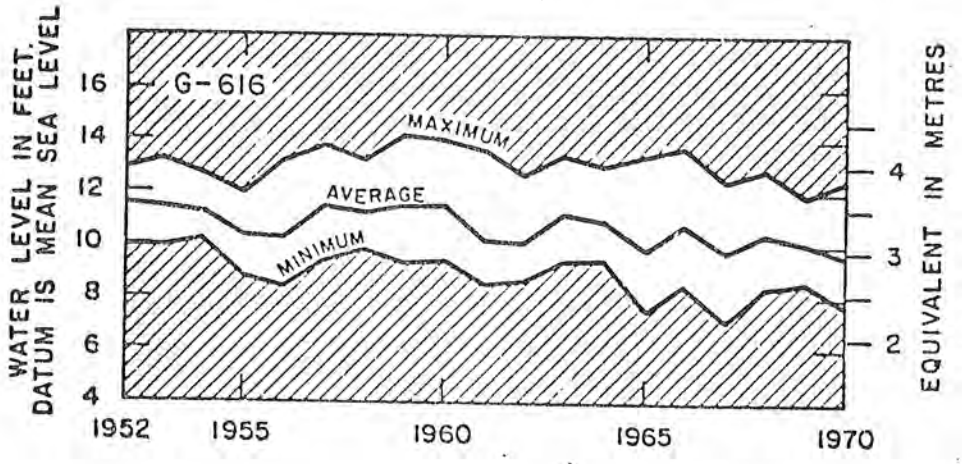
CONTOUR OF EQUAL WATER-LEVEL ELEVATION, FEET ABOVE MEAN SEA LEVEL. (1 FOOT = 0.3 METRE)

Although rainfall during May-June 1968 exceeded that of the September 1960 storms, flooding was minimized because of new drainage canals (Leach and others, 1972).





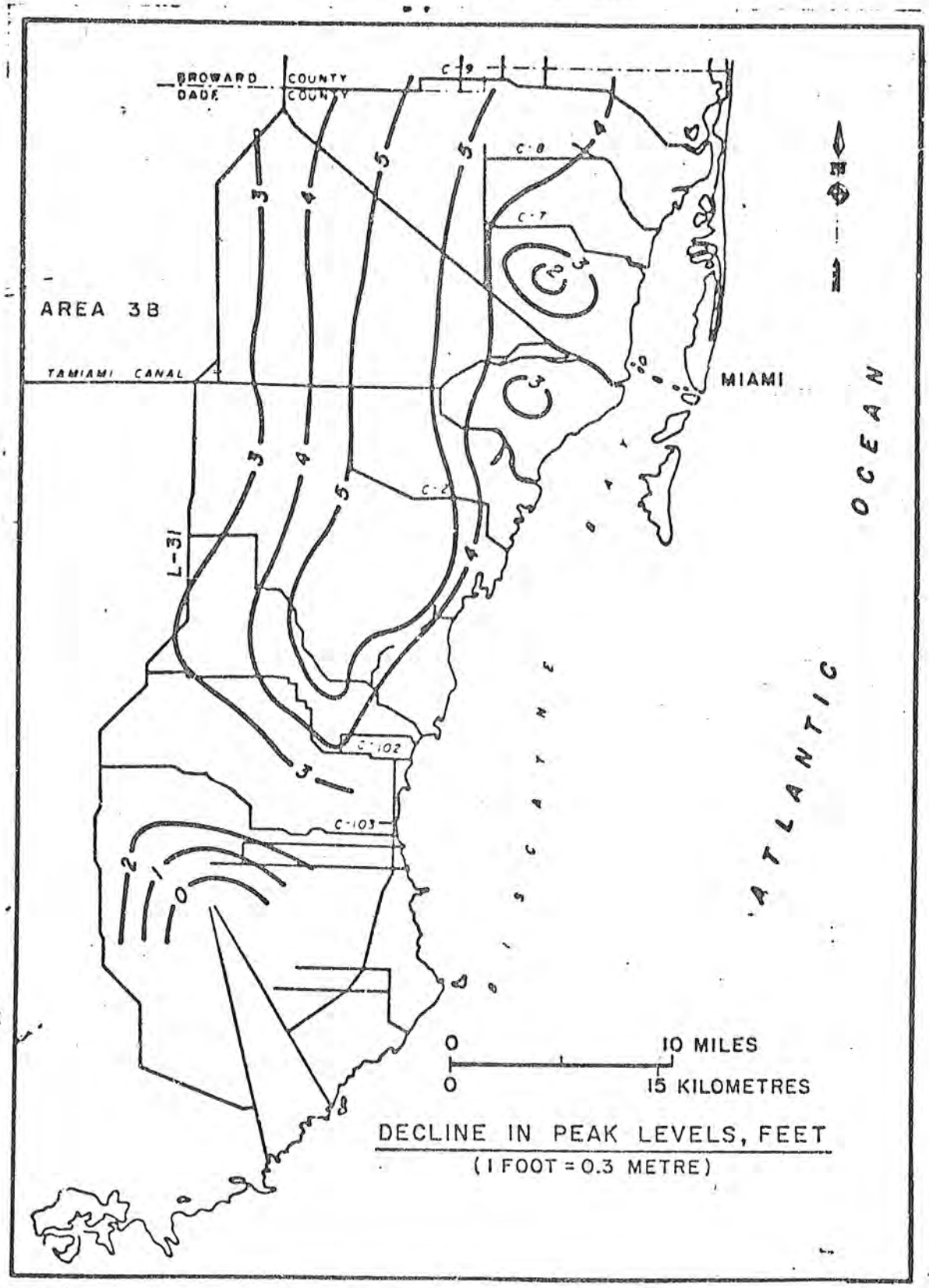
Peak water levels in south Dade County decline quicker after canals are constructed than before.



Because of improved drainage in north Broward County, the difference between high and low water levels (range) in a well there has increased. The average and minimum levels have declined.

The patterns on the map of Dade County represent the amount that peak water levels were reduced from 1947 (premanagement conditions) to 1968, when virtually complete management was in effect. Peak levels were lowered, as much as 5 feet, and reached a maximum along the west edge of the urbanized ridge area in north Dade County and along and adjacent to the ridge area southwest of Miami.

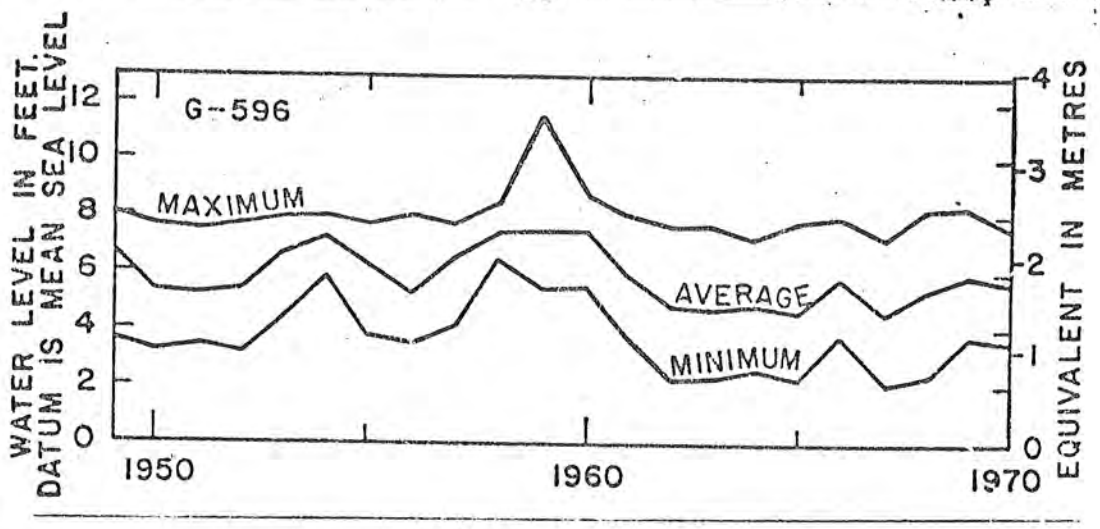
Long-term records of water-levels are indices of the effect that flood control and water management have had on the water resources of southeast Florida. Some records span the period of land reclamation through the present period of water management. The long-term hydrographs of wells show the effects that the water-management works of the C&SFFCD have had on water levels in Broward and Dade Counties.



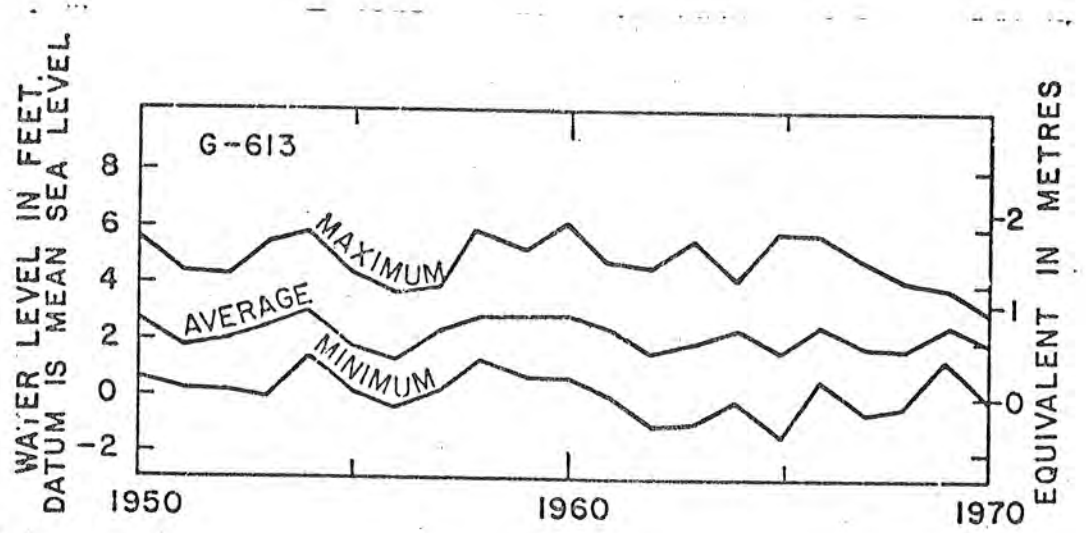
93 Contours show the difference in peak water levels from 1947 to 1968.

Water-level data in interior parts of areas under water control indicate results of that control. The hydrograph of well G-616 west of Pompano Beach, in Broward County, shows that the range in water-level fluctuations has increased, the annual minimums have been lowered, and the average levels have been lowered through a 20-year span, as flood-control measures were adopted. A similar increase in amplitude of fluctuations and decline in average levels were recorded at observation well G-596, more than 20 miles southwest of Miami and west of Levee 31. Changes in levels in that area were greatest after 1961, as a result of the digging of Canal 1, which extended from the coast to Levee 31, and the completion (1962) of the levee on the south side of Conservation Area 3B. The levee prevents southward overland flow from Conservation Area 3B. The lowering of annual minimum levels was caused by the continuous drainage of ground water along the inland reaches of the canal, enabling the opening of new farmlands throughout the inland part of the Canal 1 basin.

As a result of the drainage-canal system of south Dade County (completed 1968), lowering of water levels and an increase in amplitude of fluctuations were reflected in areas south of Homestead. These changes are shown in the hydrograph of well G-613, 4 miles southwest of Homestead. This hydrograph shows that levels in the vicinity of Homestead fell below sea level only twice during 1950-61, but were below sea level during 8 of the 10 years (1961-70), when the program of flood control was in effect in south Dade County.

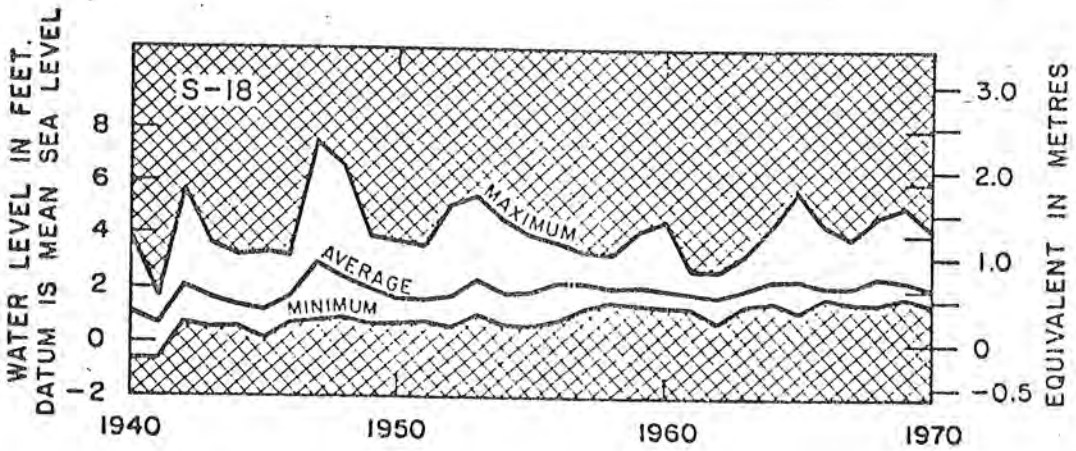


Similar water-level fluctuations were recorded in a well 20 miles southwest of Miami after construction of Canal C-1 in 1961.

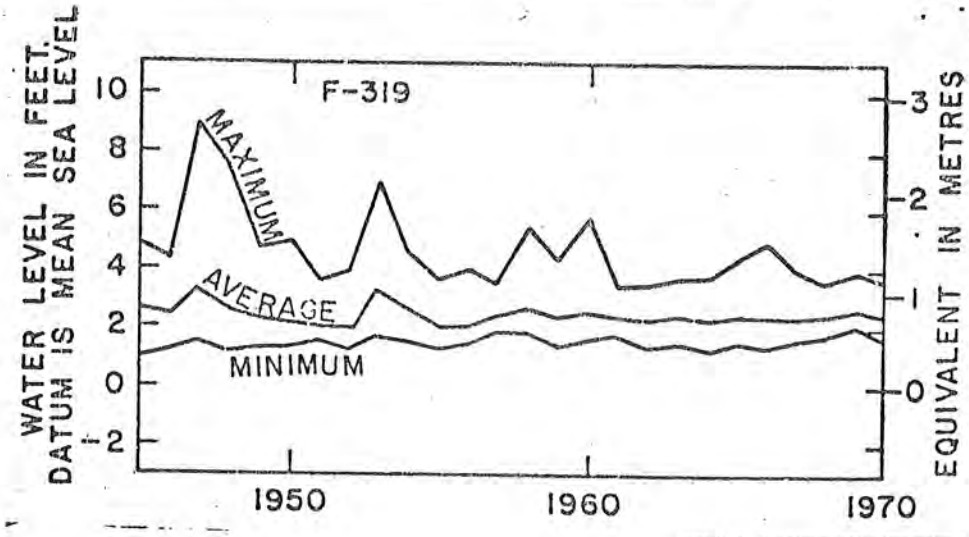


In inland areas of south Dade County water levels dipped below sea level during 8 of 10 years (1961-70) as a result of flood-control practices.

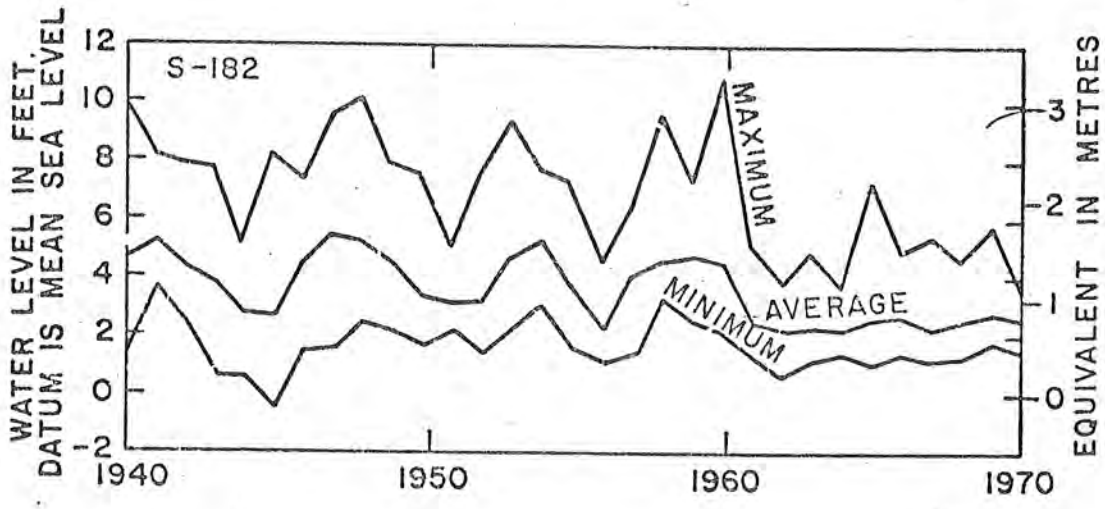
Long-term water level trends in coastal parts of Dade County can be used to show how past flood-control and water-management practices affect drainage and sea-water intrusion. The relation between changes in coastal areas with those inland indicate the modifications in hydraulic gradients that have taken place. The coastal trends are represented by the hydrographs of well S-18, in north Dade County, well F-319, south of Miami adjacent to Canal 2, and well S-182, adjacent to Canal 1 in south Dade County. In contrast to the hydrographs of the inland wells, each of these three hydrographs shows a decrease in the amplitude of water-level fluctuations during the last 10 to 15 years. Annual peaks have been lowered markedly, and peak aquifer storage in the coastal areas has been reduced as much as 3 feet in south Dade County. However, the annual minimum levels rose about 1 foot in recent years in north Dade and less than 1 foot in mid-coastal Dade County. The upward trend in minimum levels is the result of the following influences: (1) The primary canals in north and central Dade County can pick up ground water under relatively high head in the interior and move it seaward, thereby maintaining high levels at the coastal control structures to retard sea-water intrusion; (2) Improved management practices brought about by increased experience in control operations have resulted in overall decreases in dry season losses from aquifer storage along the coast in middle and north Dade County.



Minimum and average water levels have increased in north Dade County in recent years as a result of water management. Fluctuations have decreased.



Water levels in a well south of Miami, adjacent to Canal C-2, show similar trends. Reduction of peak levels and maintenance of minimum levels is accomplished by operation of the control structure in Canal C-2.



The decline in average water levels in a well in coastal south Dade County, adjacent to Canal C-1, shows that aquifer storage has been reduced.

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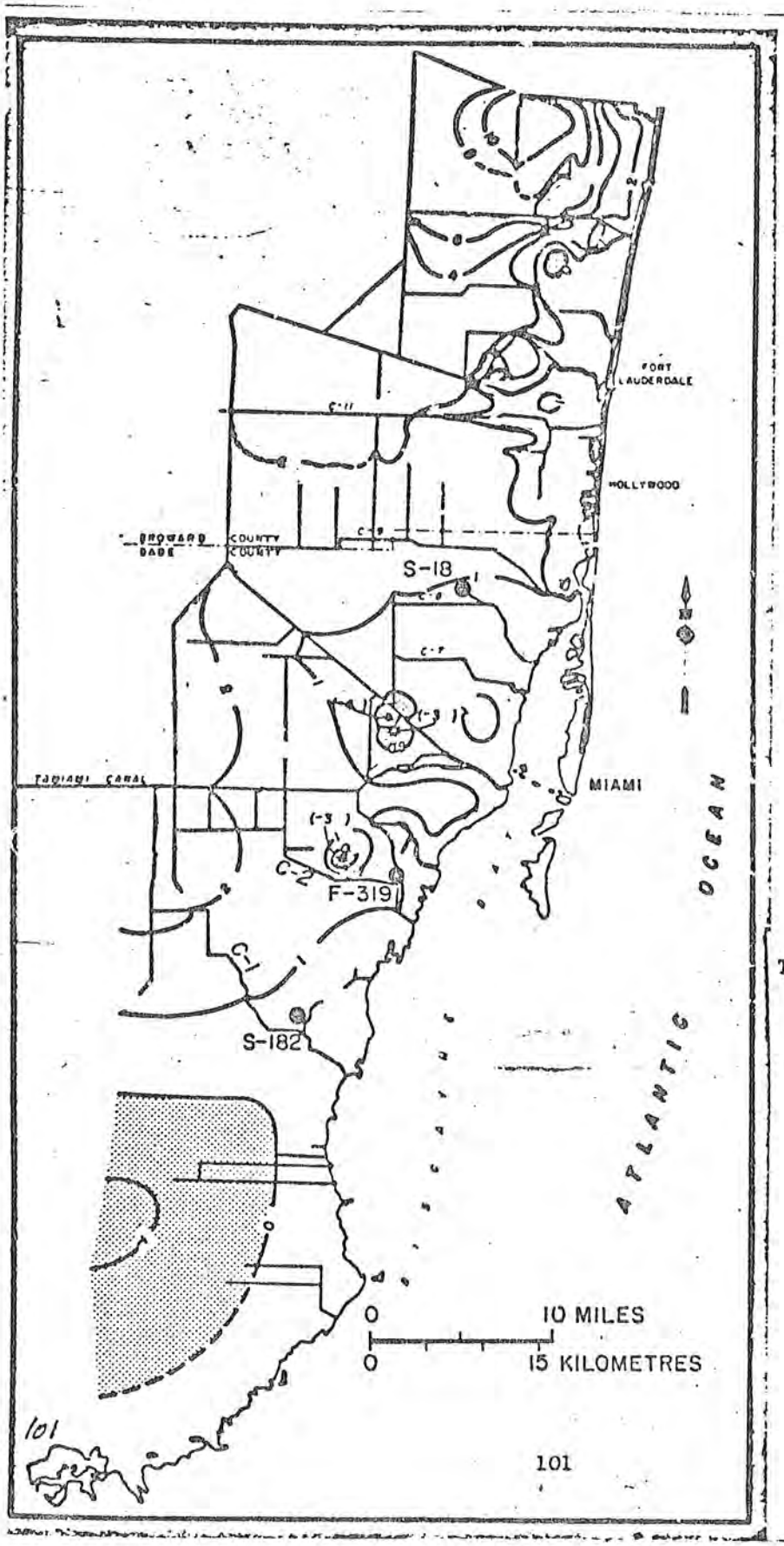
The long-term hydrograph of well S-182, adjacent to Canal 1 in south Dade County, shows a decrease both in annual peak levels and in the range of fluctuations, as do those of wells S-18 and F 319 but, also shows a slight decline in annual minimum levels since water control was started in south Dade County. This decrease in the minimum levels may, during prolonged droughts, result in a readvance of sea-water intrusion in that area. The levels declined because not enough water is available in the interior part of the Canal 1 basin to maintain water levels in the lower reach, particularly at the salinity-control structure. In contrast, the interior parts of the basins drained by the northern canals are replenished by underseepage from Conservation Area 3, where levels are perennially high. Unless higher levels can be maintained in the Canal 1, Canal 102, and Canal 103 basins, equally low water levels will recur in south Dade County during dry seasons, and salt water will advance slowly into the lower part of the aquifer to a relatively stable position farther inland from its position in 1971.

Analysis of the water-level contour map of the southeast coastal area for May 1962, one of the lowest water-level periods of record, gives further reason for the low levels in south Dade County and the inability to maintain adequate water levels at the coastal control structure in Canal 1. The contours show that in May 1962 levels south of Canal 1 declined below sea level. Water picked up by the upper reach of Canal 1 moves downstream toward the control structure; however, part of that water is lost by outseepage to the south along the lower reach. Thus, much of the water that would normally move to the control structure to maintain the required water level, instead moved downgradient to recharge the area of low-water levels to the south.

The general magnitude of water-level fluctuation and the areas where fluctuation has been greatest after 10 years of water management in southeast Florida have been determined. The patterns on the map of the protected area of the C&SFFCD indicate these, and represent the difference between the extreme drought ending in May 1962 and the high-water conditions of June 1968. The differences were greatest in south Dade County in the vicinity of Homestead and in the west part of the area under flood protection in Dade County, as a result of flood-control works, and in the Prospect and Pompano Beach well-field areas in middle and northern coastal Broward County, as a result of large increases in pumping.



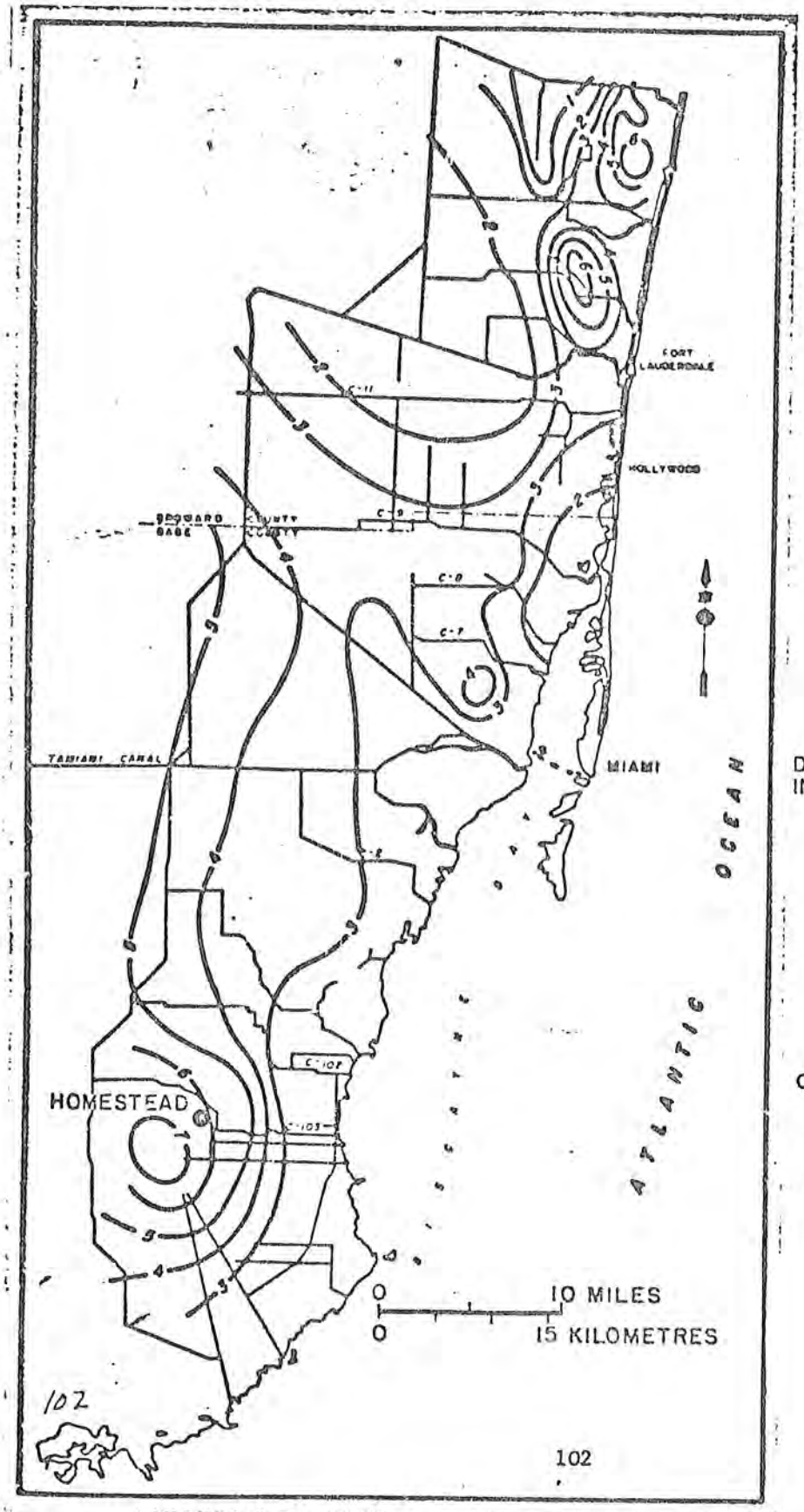
EXPLANATION

6

CONTOUR OF EQUAL WATER ELEVATION, IN FEET (1 FOOT = 0.3 METRE)

AREA WHERE WATER LEVEL IS BELOW SEA LEVEL

The dry season that ended in May 1962 caused water levels to decline below sea level in south Dade County.



EXPLANATION

—6—

DIFFERENCE IN WATER LEVEL IN FEET. (1 FOOT = 0.3 METRE)

Contours indicate the differences between highest and lowest water levels since water management began. The highest was in June 1968, and the lowest was in May 1962.

Changes have also been major in southwest Florida, as a result of flood-control works to accomodate urban development. Changes there thus far, have been restricted to the western one-third of the Big Cypress and western Lee County. As indicated previously, drainage in the Big Cypress began with the early digging of the Barron River and the Turner River Canals in the central part of the Big Cypress. These canals had relatively minor effect on water resources because they were shallow and did not generally penetrate the highly permeable limestone of the shallow aquifer.

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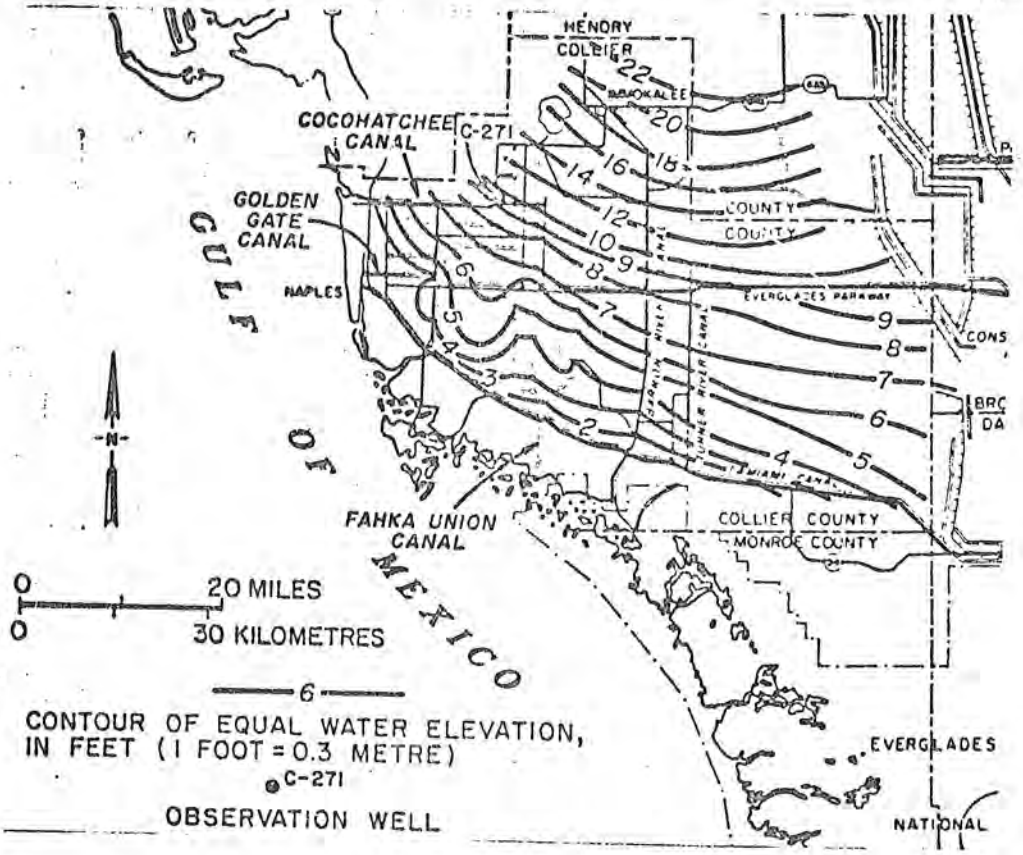
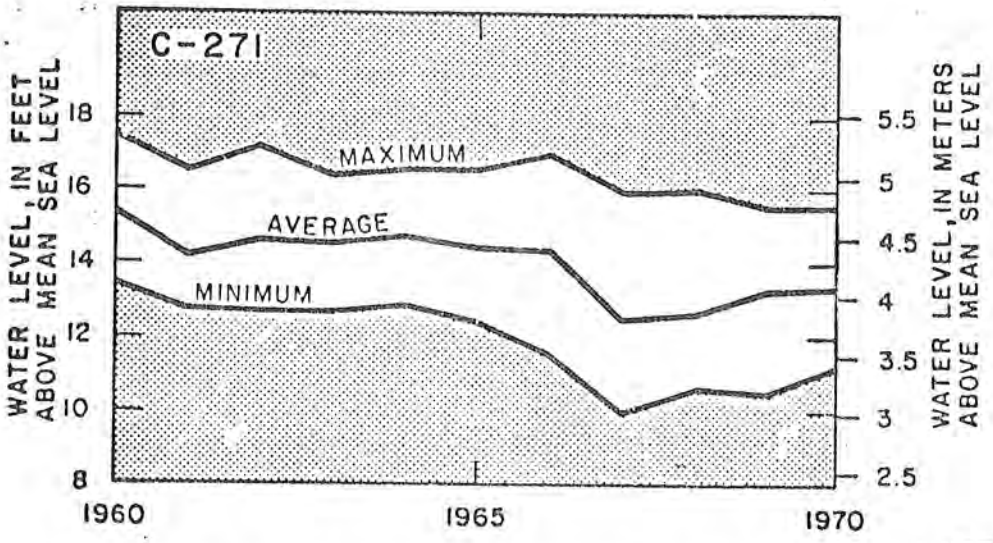
Extensive water control and land-value enhancement for urban development began in the 1960's with the Cocohatchee River Canal, the Golden Gate Canal, and, in 1969, the Fahka Union Canal. The inland reaches of the Golden Gate and Fahka Union Canals penetrate permeable limestone and, therefore, they have lowered water levels enough to permit land development to begin east of Naples. The hydrograph of well C-271, about 15 miles northeast of Naples, shows a decline of annual minimum levels and an increase in the amplitude of fluctuations beginning in 1966, about the time that the Golden Gate Canal system was extended inland. The decline was 2.5 to 3.0 feet. The inland reach of the canal was draining water from the aquifer and recharging the aquifer adjacent to the downstream reach; thus water levels in the interior were lowered to maintain high water levels at the control structure near Naples to retard salt-water intrusion. Similar lowering of water levels in the inland part of the Fahka Union Canal basin can be expected as a result of the completion of that canal.

104



The effect of drainage by the Golden Gate and Fahka Union canals is greater than that of the Barron River and Turner River canals.

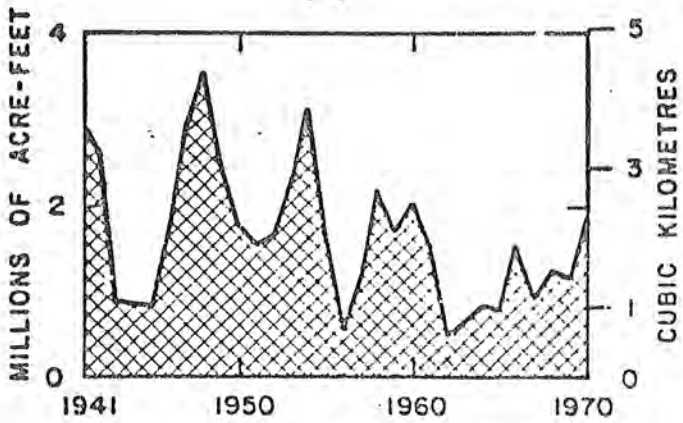


Minimum water levels in a well northeast of Naples began to decline sharply in 1966, about the time that the Golden Gate Canal system was extended inland.

The water-level contour map of the Big Cypress shows the hydrologic conditions near the end of the dry season of 1970-71. The contours show that during low water the Barron River and the Turner River Canals do not drain the aquifer and that the Fahka Union and Golden Gate Canals do. Overdrainage in the latter two canals is prevented by weirs placed throughout their upstream reaches.

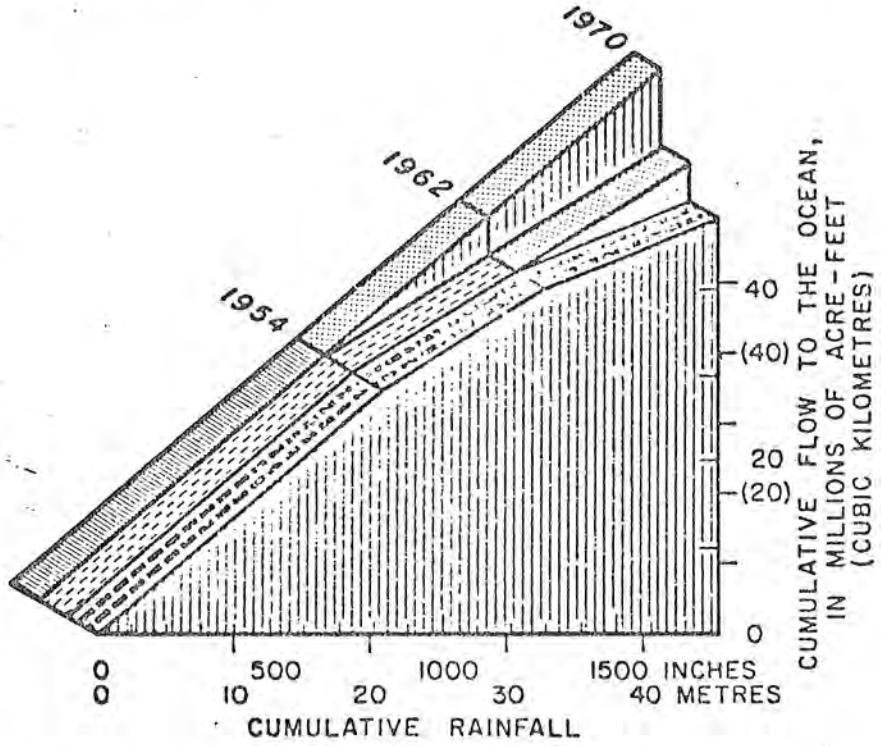
Reduction of Flow to the Ocean

A way to assure an adequate fresh-water supply along the east coast is to minimize canal flow to the ocean. Fresh-water discharge to the ocean is, for the most part, lost for immediate practical use. Water management by the C&SFFCD has gradually reduced flow to the ocean. At first the drainage canals were uncontrolled. Later, when water-control structures were built near the coast and in the interior, flow to the ocean was reduced. The reduction is demonstrated by a double-mass curve of rainfall and the combined flow to the ocean from the four major canals that transect the Everglades and the coastal ridge. Annual discharge from these canals--West Palm Beach, Hillsboro, North New River, and Miami--is an indicator of past hydrologic conditions and effects of subsequent water management. Long-term discharge records are available for each of these canals.



Flow to the ocean from the West Palm Beach, Hillsboro, North New River and Miami Canals.

Total flow to the ocean from the West Palm Beach, Hillsboro, North New River and Miami canals has been decreased by the construction and operatio of water-management facilities.



Cumulative flow to the ocean—had no water-control facilities been built

Cumulative flow to the ocean—had only the north-south levee been built

Actual cumulative flow to the ocean

Projections

The curve of cumulative runoff against cumulative rainfall for the four canals shows two changes in slope, each change representing a reduction in runoff. The first occurred between 1954 and 1955, about when the levee system east of Conservation Areas 1,2, and 3 and several control structures that regulate flow to the coastal reaches of the canals were completed. The levee, which generally follows the east edge of the Everglades, was designed to relieve flooding along the urban coastal area and the adjacent farmlands during wet seasons by intercepting eastward sheet flow from the Everglades and diverting it southward. The second reduction occurred about 1962, when most of the control structures south of Lake Okeechobee and Conservation Areas 1, 2, and 3 were virtually completed. About 7.3 million acre-feet of fresh water was prevented from flowing to the ocean between 1954 and 1970. An additional 4.7 million acre-feet was conserved from 1962 to 1970. The total reduction in eastward flow, thus, was about 12 million acre-feet, or about 750,000 acre-feet per year. The reduction is more than twice the total municipal pumpage for Dade, Broward, and Palm Beach Counties, and about six times the waste water presently discharged to the ocean from these counties.

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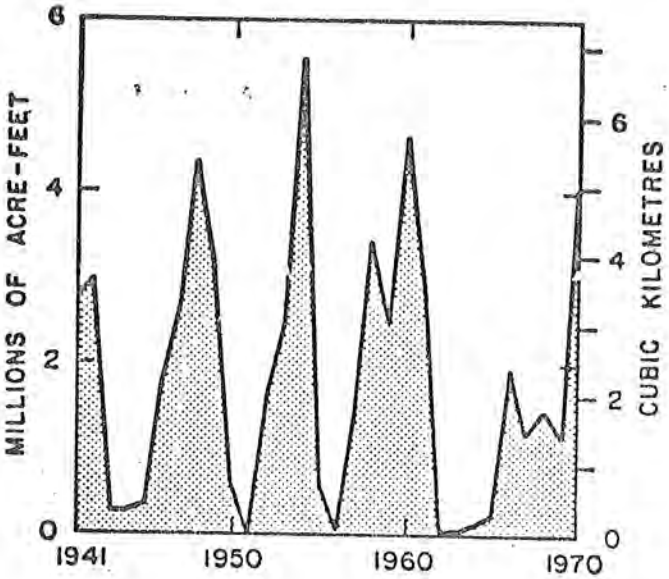
Two other major canals, the St. Lucie and the Caloosahatchee, discharge water to the ocean to regulate water levels in Lake Okeechobee. Each is equipped with locks, thus providing for cross-State navigation. Flow in the canals is controlled similarly. The cumulative combined flow of the canals against cumulative rainfall indicates virtually no change during the last 30 years. The best-fit curve had more scatter, however, than that of the other four canals, probably caused by temporary adjustments necessitated by local levee construction and dredging.

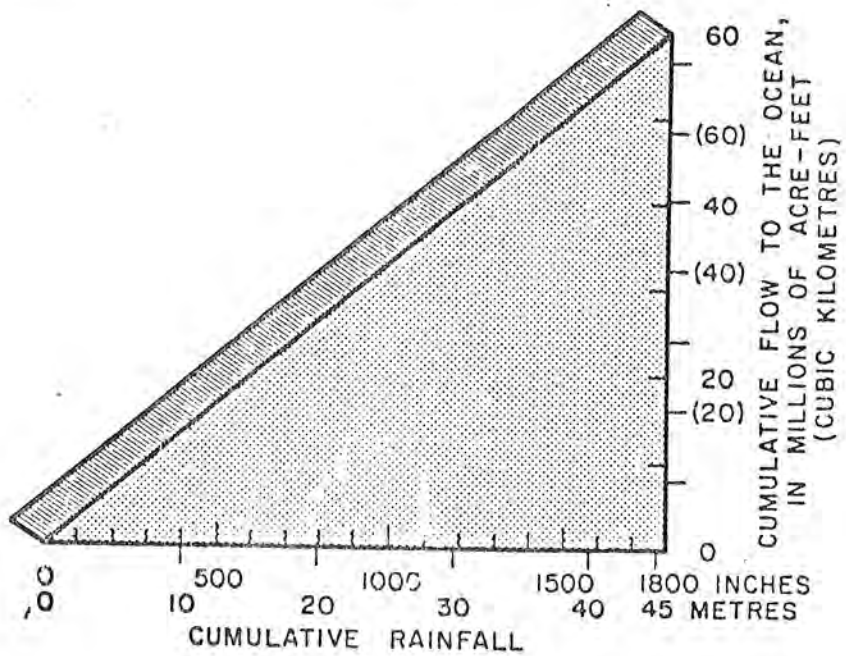
Flow to the ocean is not restricted to these six canals. Many smaller canals drain the urban and agricultural areas of Palm Beach, Broward, and Dade Counties. Canals that drain developing areas along the west coast also add to the total flow to the ocean.

In summary, water management has reduced flow to the ocean from the West Palm Beach, Hillsboro, North New River, and Miami canals, and flow to the ocean from the Caloosahatchee River and St. Lucie Canals has remained virtually unchanged.



Flow to the ocean from the St. Lucie and Caloosahatchee River canals.

Hydrograph of flow to the ocean from the St. Lucie and Caloosahatchee River canals indicates that regulation of flow in the two canals has remained virtually uncharged since 1940.



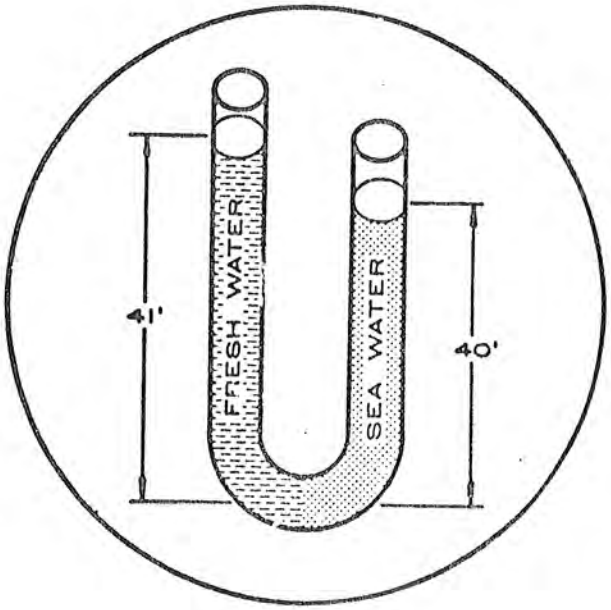
How Sea Water Intrudes

Residents of south Florida are becoming increasingly aware that protection of fresh-water supplies from contamination by sea water has high priority. Most communities along south Florida's coast obtain municipal water supplies from ground-water sources near the coast.

Sea-water intrudes silently, persistently. In its unseen spread, it can and does contaminate domestic wells, destroy city water supplies, kill crops, and render soil unusable for agriculture. Sea-water intrusion has affected south Florida's water resources chiefly in Dade and Broward Counties over the past several decades.

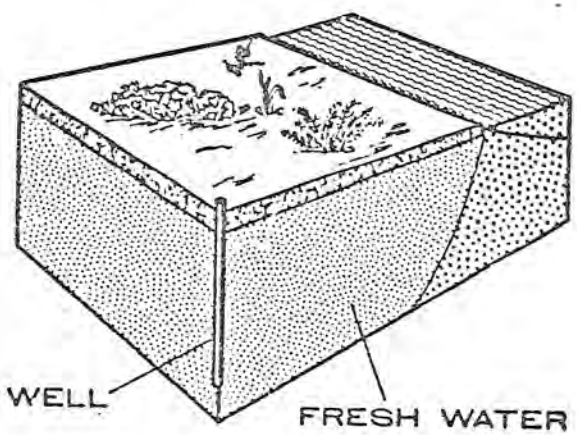
Sea-water is 2.5 percent heavier than fresh water. A 41-foot column of fresh water is required to balance a 40-foot column of sea water. Based on this relation, within a reasonable distance from the ocean, each foot of fresh water above sea level theoretically indicates the presence of 40 feet of fresh water in the aquifer below sea level. The constant threat of sea water moving inland requires that fresh-water levels remain or be maintained as high as practicable above sea level.

A 41-foot column of fresh water is required to balance a 40-foot column of sea water.

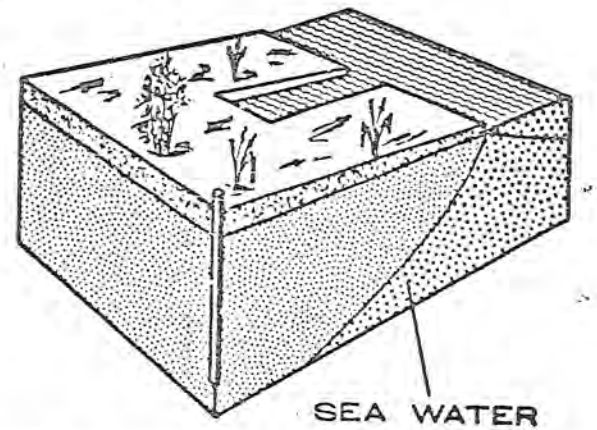


Sea water moves inland in aquifers and along canals as a wedge. When streamflow and water levels are high, sea water is prevented from moving inland. When streamflow and water levels are low, sea water moves inland up tidal streams and into adjacent aquifers.

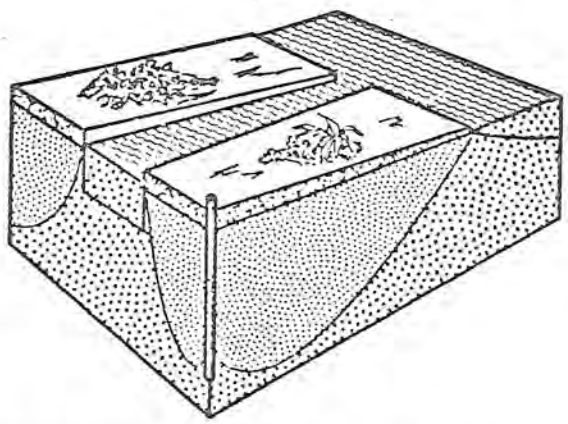
Man adversely affects the natural processes that tend to retard sea-water intrusion when he constructs canals and pumps large volumes of water from aquifers near the coast. Uncontrolled canals constructed from inland areas to the ocean affect the position of the salt-fresh water contact by lowering freshwater levels, thus reducing the opposition to inland movement of salt water; they also provide channels to convey sea water inland. The salt front in the aquifer then shifts inland laterally from the canals. Salinity-control structures have been built near the coast in southeast Florida on all primary coastal canals to raise freshwater levels and to prevent inland movement of sea water.



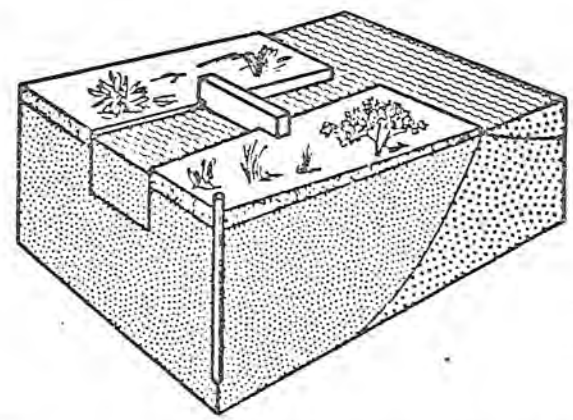
The fresh water - sea water interface was nearly stable before coastal canals were built.



Uncontrolled tidal canals cause sea-water intrusion by lowering fresh-water levels and providing open channels to the sea. The interface in the aquifer shifts inland adjacent to the canal.



An uncontrolled canal that extends into an area of heavy pumping can convey sea water inland to contaminate fresh-water supplies.



In contrast, a controlled canal can provide a perennial supply of fresh water to prevent sea-water intrusion and to recharge a well field by bringing in fresh water from upgradient areas.

The position of the salt-fresh water contact can also be affected when large volumes of fresh water are pumped from wells in an aquifer. As the wells are pumped, ground water moves toward the pumping area. If the wells are near the coast, salt water moves toward the wells also. If an uncontrolled tidal canal is nearby, the combined effect of the pumping and the proximity of the canal causes sea water from the canal to move toward the well field. Some municipal well fields were abandoned for this reason. Most of the first wells drilled in south Florida were an appreciable distance from the coast and from canals. Continued inland urban growth, however, necessitated more canals for drainage. Some canals passed near well fields, which became contaminated. Subsequently, water-control structures were built near large well fields to provide higher water levels, which facilitate recharge to well fields and prevent sea-water intrusion (Sherwood, 1966).

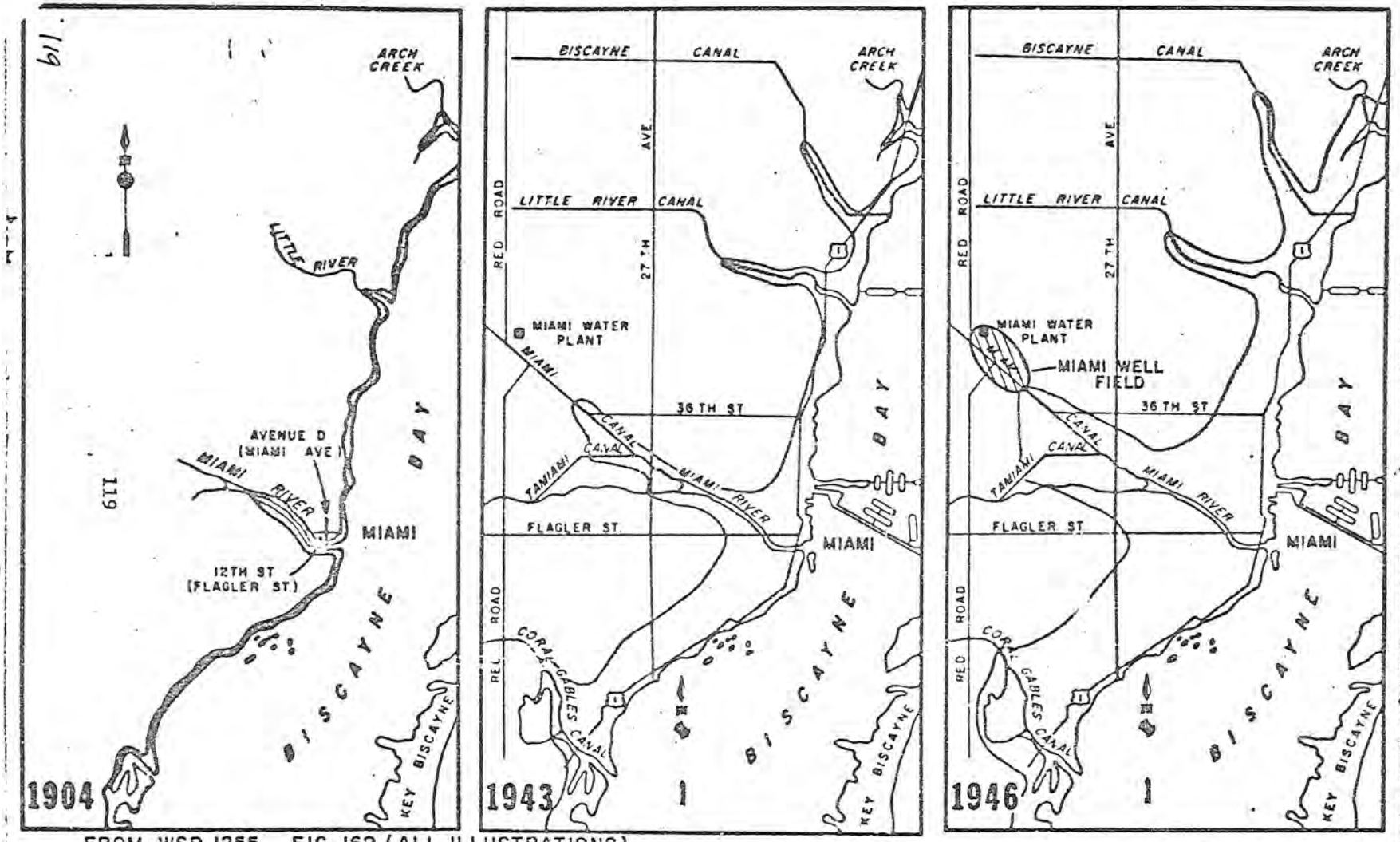
Sea-Water Intrusion--East Coast

Canal flow in southeast Florida was virtually uncontrolled before 1945, but the drought of 1944-45, which clearly showed the need to control sea-water intrusion, marked the end of uncontrolled canal drainage. Temporary sheet-steel pile control structures were thereafter installed in primary canals. The piles were pulled during rainy seasons to release flood water, then replaced at the beginning of dry seasons to prevent overdrainage and to conserve water. The C&SFFCD then began a high-priority project to replace sheet-pile controls with more efficient, easier operated concrete controls on all primary canals. Benefits of the new structures were quickly realized. Losses of fresh water to the ocean were reduced although large areas, rapidly being developed for housing, had to be protected from flooding by lowering water levels. Further inland movement of sea water also was prevented. In some areas salt water was moved seaward. Maintenance of high fresh-water levels upstream from the structures insured continued protection against sea-water intrusion and decreased the threat in municipal well-field areas. The high levels also permitted at least a three-fold increase in withdrawals from well fields because of the increased water available for aquifer replenishment by infiltration from canals.

The sequential maps of the Miami area show the inland extent of salt water at the bottom of the Biscayne aquifer from 1904 to 1971. Inland movement of salt water was greatest before 1946, before water control. The pattern shows that lowering water levels along canals facilitated sea-water intrusion, as indicated by the tongues of salt water along canals. The 1946 pattern shows the threat to the Miami well field along the Miami Canal near the water plant.

The inland spread of sea-water intrusion was halted during subsequent years in most areas, and its inland extent was reduced markedly in some areas as a result of installing the sheet-pile control structures. In particular, water in the aquifer freshened along the Little River and Biscayne Canals and, to some degree, along the Miami Canal. The extent of intrusion along the Coral Gables and Tamiami Canals, however, did not decrease because control structures in those canals were too far inland to be effective.

Movement of salt water in the aquifer was stabilized during the 1950's and 60's in Dade County, except in the northern part of the county and near the Miami well-field area. Continued movement there resulted from increased withdrawals from the North Miami Beach, the North Miami, and Miami well fields. A new control structure installed in 1971 in the Tamiami Canal near its confluence with the Miami Canal is expected to reduce the threat of sea-water intrusion to the Miami well field.



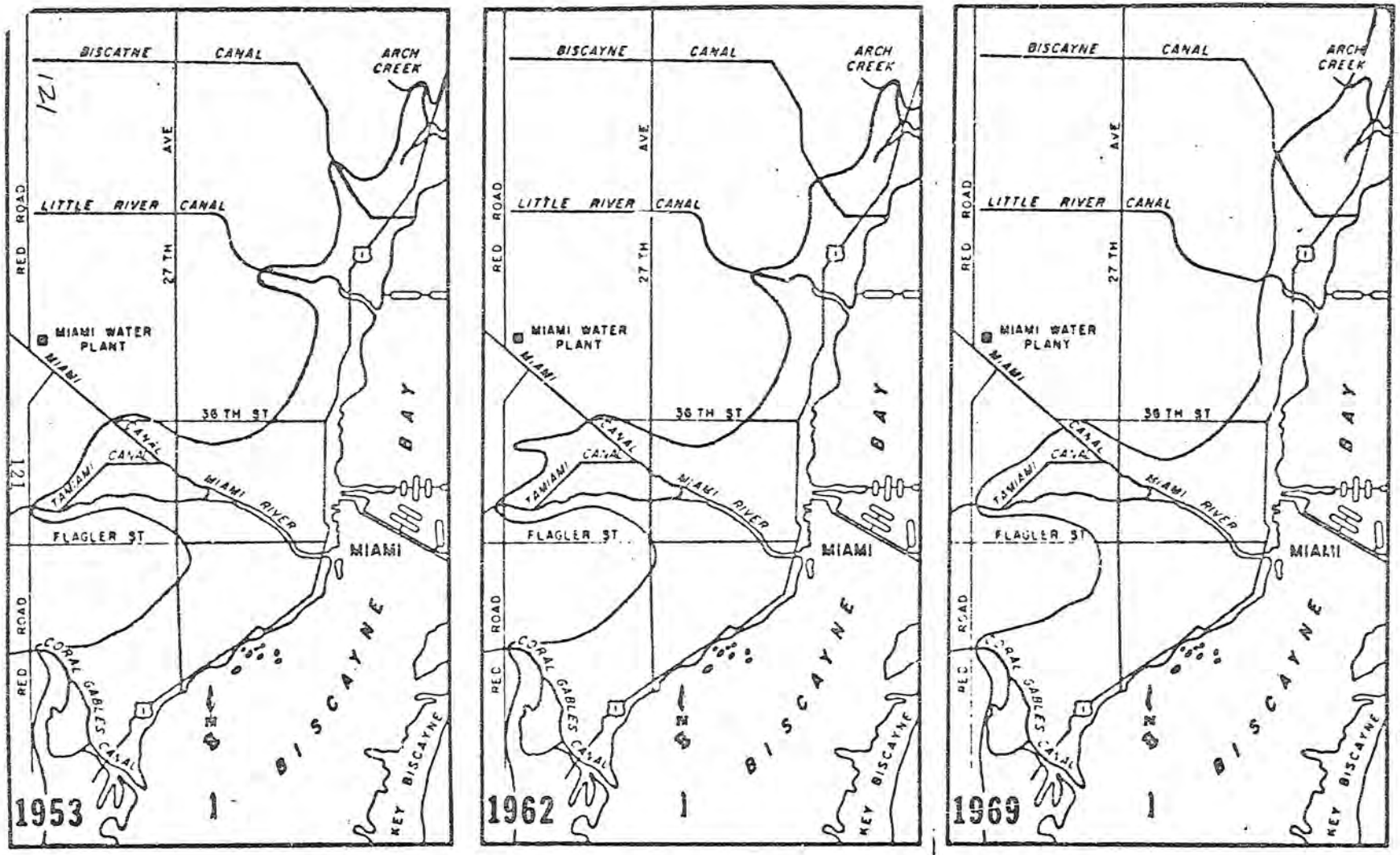
FROM WSP 1255 FIG 169 (ALL ILLUSTRATIONS)

0 5 MILES

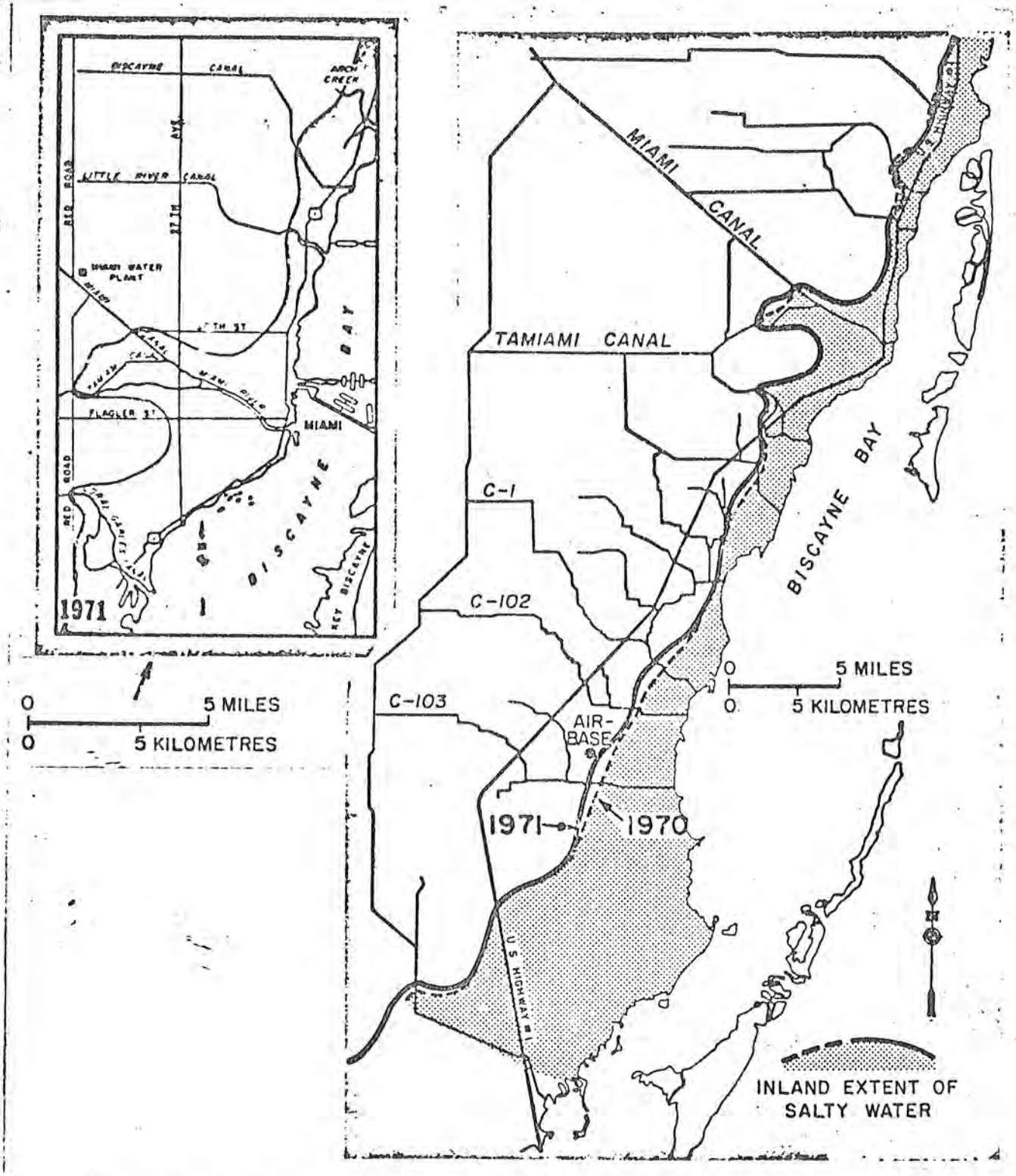
0 5 KILOMETRES

Since 1953, the fresh water - salt water interface in the aquifer in the Miami area has been generally stabilized, except in the North Miami area.

In May 1971 at the end of the prolonged drought, water levels were as much as 1.5 feet below sea level in south Dade County and 8 feet below sea level in the center of the Miami well field. The greatest inland migration of salt water during 1970-71 in Dade County was 0.75 mile in the southeast part of the county and 0.6 mile at the south edge of the Miami well field. The source of salt water south of the well field was tidal water from the Tamiami Canal. Near the end of the drought, salt water in the aquifer in southeast Dade County was moving slowly inland and upward in response to the below-sea-level water levels in the interior. It intersected the bottoms of the controlled reaches of Canals 1, 102, and 103 upstream from their coastal control structures, contaminating those reaches and threatening the well field of the Homestead Air Force Base near Canal 103.



0 5 MILES
0 5 KILOMETRES



The inland migration of salty water at the bottom of the aquifer in Dade County was generally held in check, even during the severe drought of 1970-71.

Similarly, sea-water intrusion in Broward County resulted from overdrainage by major canals, as urbanization and agriculture grew. The major area of intrusion is the coastal section of central Broward County (Fort Lauderdale and vicinity). The Dixie and Prospect well fields of Fort Lauderdale are affected (See p. 57). The reasons for the intrusion are threefold: (1) land in the western suburbs of Fort Lauderdale was comparatively inexpensive, which encouraged urbanization and its accompanying drainage to prevent flooding ; (2) the area is extensively dissected by real-estate finger canals for recreation (these are connected to tidal canals, which provide entry for salt water); and (3) the inland positions of the salinity-control structures in the North New River Canal and in Canals 11, 12, and 13. The control for the North New River Canal is nearly 8 miles from the coast.

Near the end of the dry season of 1961-62, pumpage from Fort Lauderdale's Prospect well field was in excess of 30 mgd, and water levels in the field were more than 2 feet below sea level. The highest water level between the well field and the coast was 0.5 foot above sea level. Because of the low levels, salt water beneath the uncontrolled North Fork of the New River moved inland to contaminate two municipal supply wells. Pumping from those wells was curtailed, and the bulk of the pumping was shifted to wells farther inland. Since then, a controlled feeder canal has been dug that connects with the controlled reach of Canal 13. As a result of the modification, water levels have been raised in that critical area, and additional recharge was furnished to the well field to reduce the threat of intrusion. Improvement is indicated by the fact that salt water did not advance in the area during the 1970-71 drought although pumpage from the well field increased to 40 mgd.

Sea-water intrusion in north Broward County and Palm Beach County is not yet a problem except at Boca Raton, in southeast Palm Beach County, and in north coastal Palm Beach County. Municipal well fields in those areas have already been affected by sea-water intrusion. Obtaining additional water supplies will necessitate pumping parts of the shallow aquifer more distant from salt water. Boca Raton already has located prospective well sites west of the city, where water levels are maintained perennially high by the C&SFFCD and local water-control districts. Water supplies for the remainder of the coastal strip of Palm Beach County are relatively safe because water levels in the shallow aquifer there are maintained high by constant recharge from canals connected with the water-conservation areas. The aquifer contains salt water only immediately adjacent to the coast.

Sea-Water Intrusion -- West Coast

Available data concerning fresh water in Lee County suggest that near the coast the supply is not adequate to satisfy future demand. Scattered information from exploratory work in interior parts of the county suggests that water supplies may be available there, but the sites are distant from urban areas, and will be costly to develop.

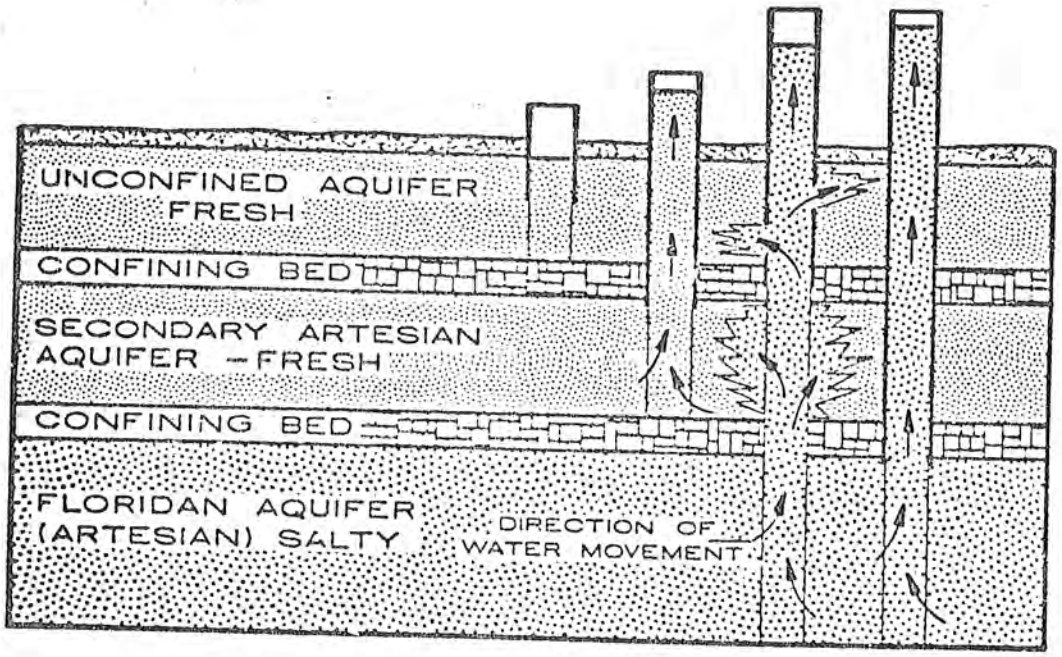
Sea-water intrusion is a major threat to water supplies in coastal communities in Lee County. Shallow aquifers are of low permeability and will not yield as much water as will likely be needed. Therefore, municipal water is obtained from several well fields that penetrate a shallow artesian aquifer at an average depth of 185 feet. The aquifer is separated from the deeper Floridan aquifer, which contains salt water, by clay layers. During peak purping in these well fields, the drawdowns of water levels form coalescing cones of depression over a large area, creating inland hydraulic gradients over the affected area. Water levels are drawn down as much as 100 feet below sea level. As pumping increases, the area of depression will deepen and expand, thereby accelerating the rate of sea-water intrusion and possible upward leakage of salty water. Exploratory work for additional water supplies for these communities was intensive in 1972 in the southeast part of Lee County.

Water for Fort Myers is pumped from wells that tap an isolated lens of shelly limestone of small extent 3 miles east of the city. The aquifer is about 30 feet deep. The wells yield about 5 mgd. Exploratory drilling for other water-yielding material near the cluster of wells proved fruitless. To provide for the rapidly increasing water demands, a 12-mile pipeline was constructed to divert water from the Caloosahatchee River to the municipal well field. The intake of the pipeline is a short distance upstream from boat lock Structure 79 on the river. Water is pumped from the river to spreading ditches in the well field area to recharge the well field by infiltration.

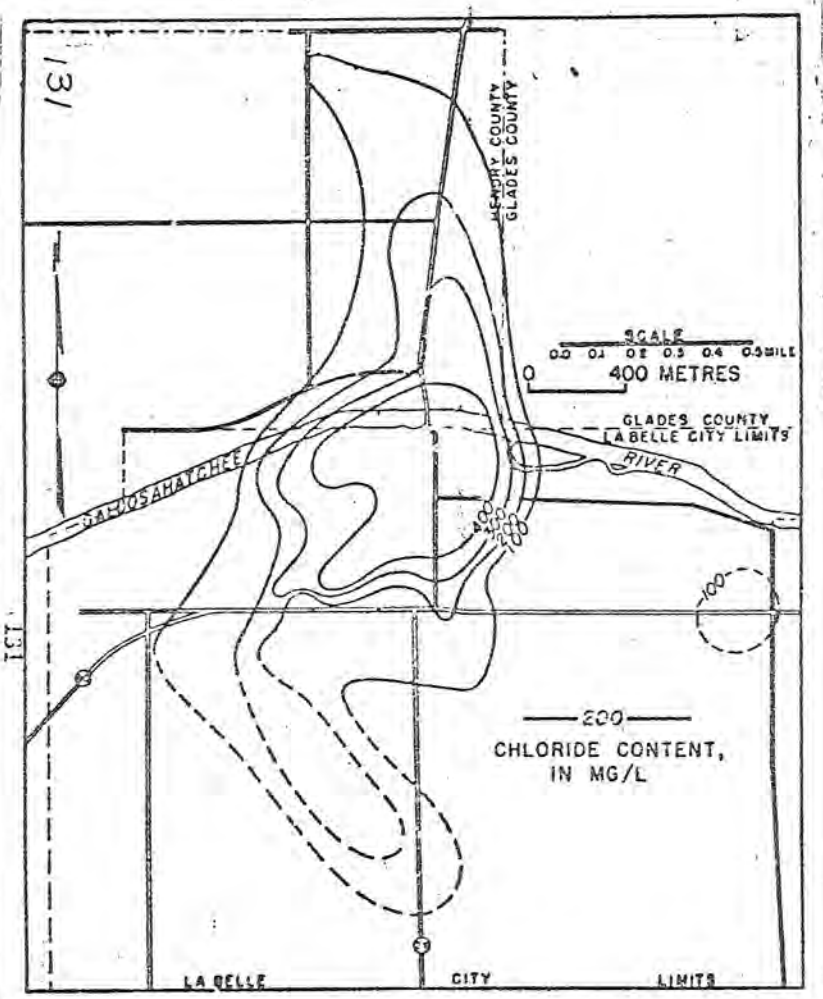
The prime water-supply problem of Fort Myers is the poor quality of the water diverted from the Caloosahatchee River to the well field during prolonged dry seasons. As a result of boat lockages at Structure 79, slugs of salty water migrate to the controlled reach of the river. In April 1968, water containing more than 250 mg/l of chloride extended 5 miles upstream from the structure. Nearly every dry season the river upstream from Structure 79 becomes contaminated with chloride. During long dry seasons, the quality of the raw water pumped from the well field is similar to the quality of the river water.

Possible measures to improve the raw-water quality of the Fort Myers well field follow: (1) restrict boat-lock operation at S-79 during the prolonged dry seasons; (2) furnish water from Lake Okeechobee to flush salt water from the controlled reach of the Caloosahatchee River; (3) establish additional ground-water or surface-water sources in the interior of Lee County to satisfy increasing demands; (4) use desalination units; and (5) plug artesian wells in the Floridan aquifer, which contaminate shallow aquifers by upward leakage. Measures (1) and (2) must receive concurrence from the Corps of Engineers and the C&SFFCD; however, at times sufficient water may not be available for flushing. Measures (3) and (5) could be implemented by exploratory drilling, hydraulic testing, and well plugging, together with other hydrologic programs.

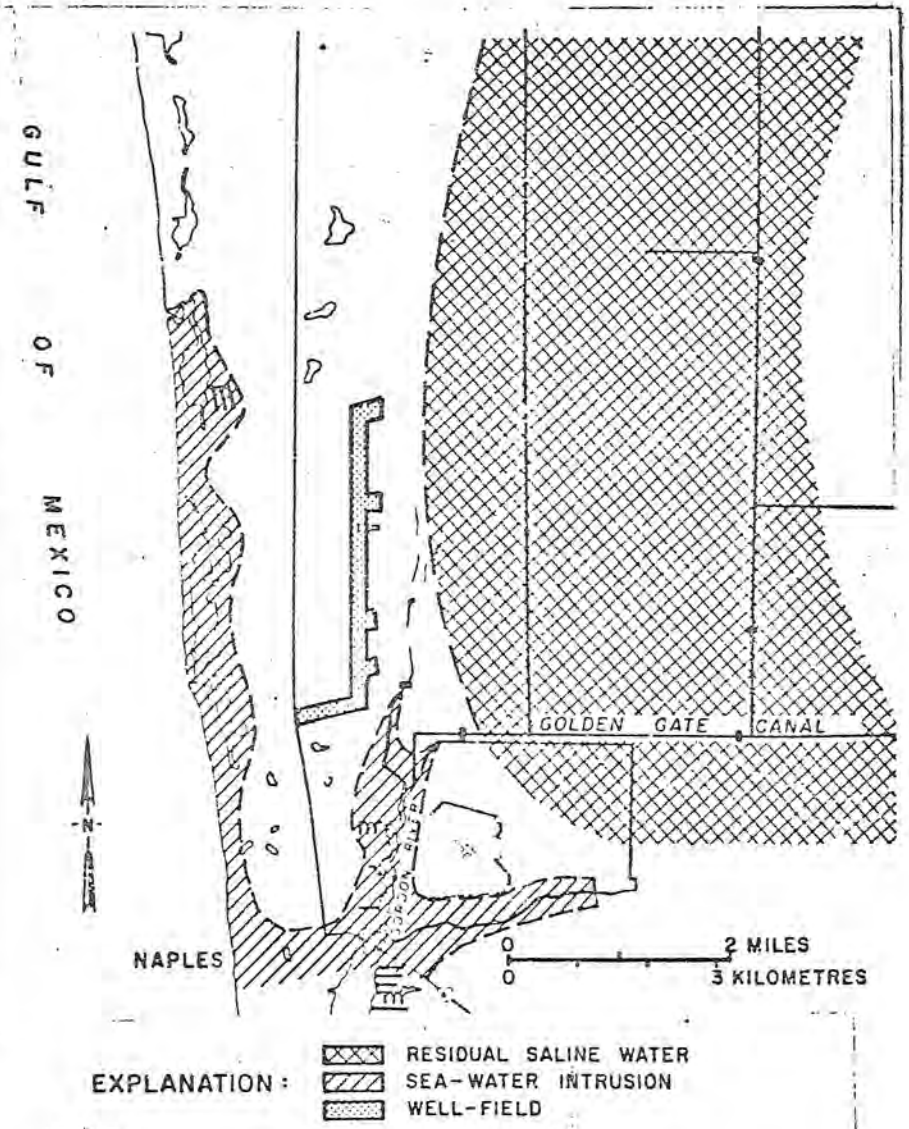
A source of contamination of shallow aquifers, particularly in Lee and Hendry Counties, is the upward leakage of salty water through open well bores or leaky casings from deep wells penetrating the Floridan aquifer. Several thousand deep artesian wells have been drilled in Lee and Hendry Counties. The casing in many is too short to seal off shallow fresh-water aquifers; the casing in others has corroded. As a result, mineralized artesian water under high pressure moves upward along well bores and migrates laterally into shallow aquifers that are under low hydraulic pressure. Shallow fresh-water aquifers in places where artesian wells are concentrated have become contaminated; two such places are the McGregor Isles area, south of Fort Myers, and the town of LaBelle, in Hendry County. Contamination has reached a degree where potable water is available only in scattered parts of those two areas. At McGregor Isles, the State has issued orders to plug artesian wells that are contributing to deterioration of shallow-water quality. LaBelle has established a new well field south of the contaminated zone.



Contamination of shallow aquifers in Lee and Hendry counties has been caused, in part, by upward leakage of salty water through open well bores or leaking casings of deep wells penetrating the Floridan aquifer.



Upward leakage of salty water from old artesian wells in La Belle in Hendry County, has contaminated the shallow aquifer.



Contamination in the Naples area of Collier County is caused by: (1) Intruded sea water near surface bodies of salt water; (2) Salty water residual from ancient sea inundations, or upward leakage from the Floridan aquifer.

Sea-water intrusion resulting from lowering of fresh-water levels is less extensive along the southwest coast than it is along the southeast coast because urbanization there is not yet widespread, and drainage of interior areas has only recently begun. Water supplies for Naples, on the lower Gulf coast, were threatened by sea-water intrusion during the early years of urban growth (early 1950's). The original well field was in the south part of Naples and it was exposed to surface salt water from three directions and from salty ground water to the south. As pumping increased, inland movement of salt water was noted. As a protective measure pumping from the field was gradually reduced, and new wells were drilled north of the original field.

During the 1960's, urbanization began to move eastward from Naples to the west edge of the Big Cypress. Drainage canals were dug, and the water level was lowered 2 or more feet, thereby decreasing the extent and duration of inundation in more than 35 square miles east of Naples. Overdrainage was prevented by a system of weirs in the canals. A series of test wells in the newly drained area showed that potable water in the shallow aquifer extended only to depths of 30 to 40 feet and was underlain by salty water to 130 feet or more. The salty water is either unflushed sea water that entered during the final high stand of the sea in late Pleistocene time or Floridan aquifer water that leaked upward under high pressure.

City and county officials had planned to use the Naples water system as a nucleus to supply municipal water in the future to all the urban coast. Water for the future system was to be obtained inland from Naples. Disclosure of the poor quality of water to the east, the construction of finger canals connected to the Gulf for real-estate enhancement, and the rapid increase in water demands in the late 1960's and early 70's dictated the need to explore areas in the interior of the Big Cypress for adequate water resources.

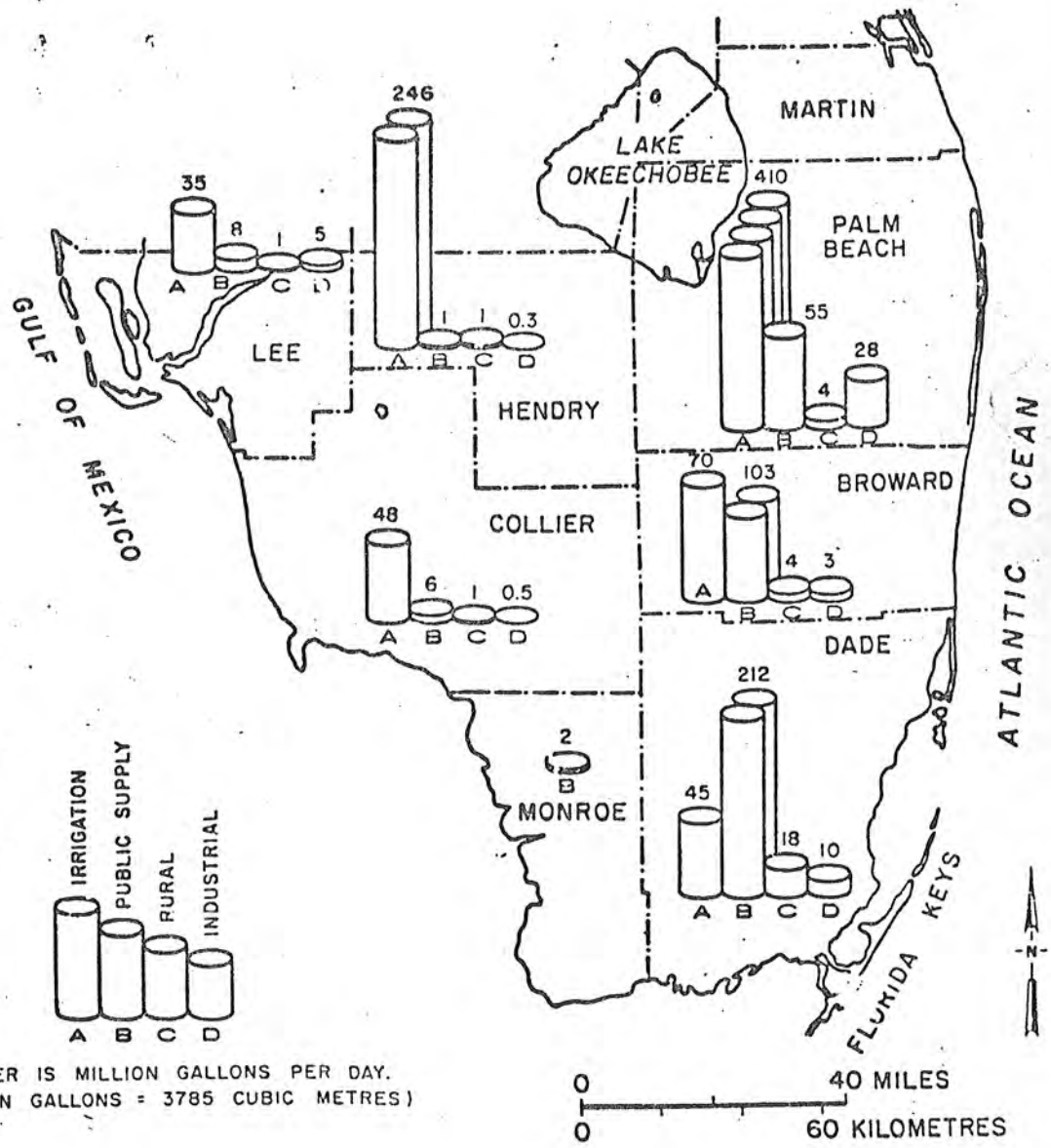
Exploratory holes drilled in a line eastward to the Broward County boundary in 1969-70 revealed that the shallow aquifer contained highly permeable limestone that extends from 12 to nearly 40 miles east of Naples. The aquifer is capable of high well yields and contains typical limestone water of high bicarbonate but low chloride content. This permeable section can probably satisfy part of the future urban water demands for the lower Gulf Coast, provided that water is managed properly and that pollution can be controlled. However, further exploratory drilling in 1974 indicated local chloride contamination from undetermined sources in the shallow aquifer about 15 miles east-southeast of Naples.

WATER USE--ITS EFFECTS ON THE ENVIRONMENT

Water-Use, By Type

More than 5.3 billion gallons of water was withdrawn from the ocean and land sources each day during 1970 in south Florida. About 75 percent was saline water from the ocean, bays, and estuaries for use as cooling water in thermoelectric-power generation. The remaining 25 percent, withdrawn from fresh surface-water and ground-water sources, was used by municipalities, agriculture, and industry. Ground-water use was about 720 mgd (million gallons per day). This did not include water withdrawn from thousands of residential wells used to water lawns and shrubs. Slightly more than 597 mgd came from canals and lakes and was used primarily for crop irrigation.

Excluding saline water used for cooling in power generation, irrigation accounts for nearly two times that of all other uses. Florida is a major producer of winter vegetables for the Nation. Winter is the dry season in south Florida; therefore, truck farming and citrus production require regular irrigation. In 1970 about 854 mgd, or almost 1 million acre-feet per year, was used for this purpose. This volume is equivalent to a cover of slightly more than 1.6 feet over every irrigated acre in south Florida. Almost two-thirds of the water used for irrigation is surface water, and it is usually pumped directly from canals near the fields. Irrigation in the Everglades agricultural area, just south of Lake Okeechobee, accounts for about half of all the irrigation water used in south Florida. More than 50 percent of the water withdrawn for irrigation is consumed, that is, evaporated or transpired.



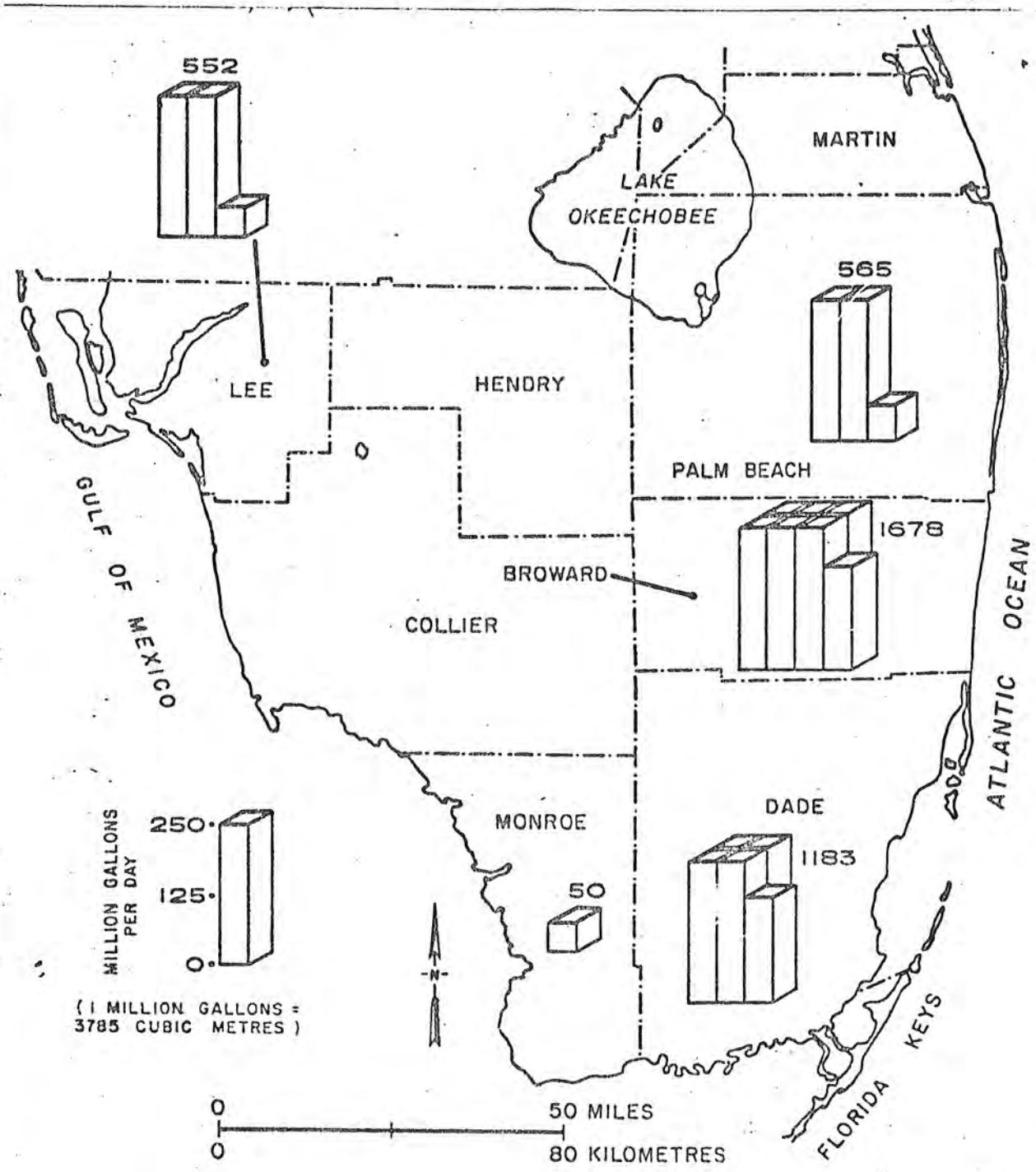
About 1.3 billion gallons of fresh water was used each day in south Florida during 1970.

Industry used about 100 mgd in 1970, of which 25 mgd was consumed. About half the water was obtained from public supply systems. By comparison with other users, south Florida industries use a small part of the total water withdrawn--about 7 percent.

Rural, domestic and livestock water-use was estimated to be slightly less than 30 mgd. About 24 mgd was consumed, which means that only 1 of every 5 gallons was available for subsequent use. All rural livestock water and about 75 percent of rural domestic water was consumed. Most of the rural water was withdrawn from private wells.

Water provided by public supply systems amounted to 388 mgd, or 162 gcd (gallons per capita per day). Per capita use, however, ranged from 91 gcd in Lee County to 215 gcd in Hendry County. Water used by thousands of south Florida residents from private wells is not included in these totals.

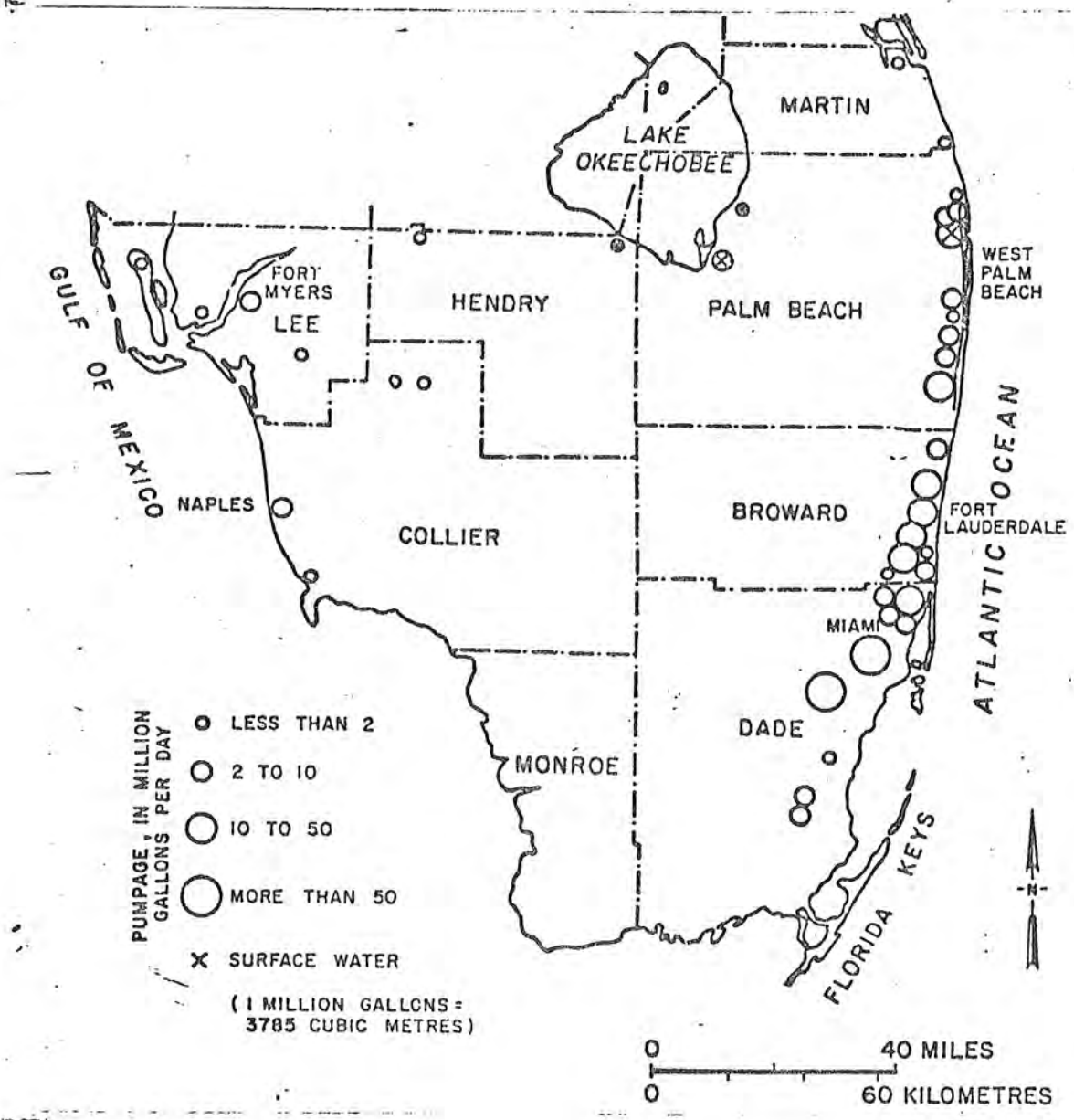
Large quantities of cooling water are required to condense steam in thermoelectric-power plants. In south Florida, power plants are built near the coast, where large quantities of saline water are available. Nearly all the cooling water, about 4 billion gallons per day, is saline. This water is, in essence, not consumed; the quantity that evaporates is less than 1 percent.



Nearly all of the 4 billion gallons used each day for cooling water in thermoelectric power generation during 1970 was sea water.

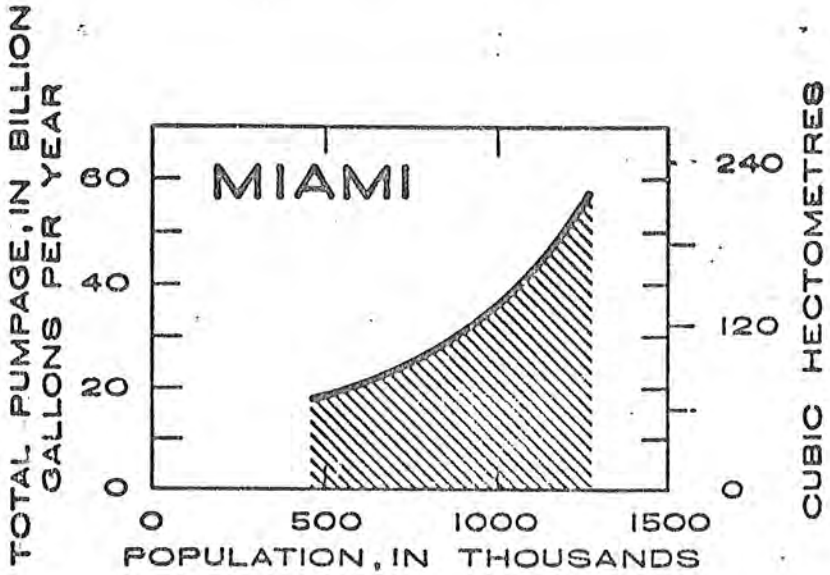
Trends in Municipal Water Use

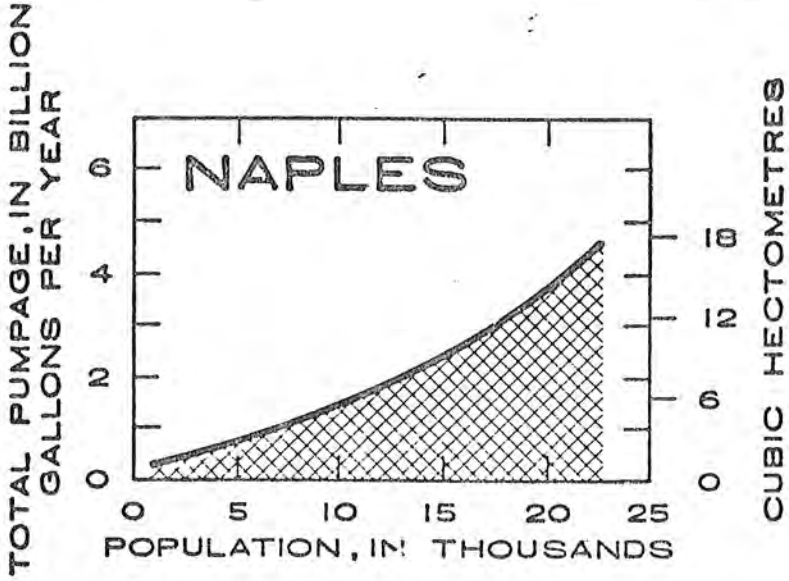
In 1970, approximately 388 mgd of water was pumped by public supply systems in south Florida. More than 90 percent of the total was withdrawn from ground-water sources. Nearly all the water provided by public systems in Dade and Broward Counties, about 315 mgd, was withdrawn from the Biscayne aquifer. This is about 80 percent of all public supplies in south Florida. West Palm Beach is the only major municipality supplied by surface water. Its source is Clear Lake, just inland from the coast. The map shows the source--ground water or surface water--and pumpage of major municipal systems in south Florida.



Most major municipal water-supply facilities are along the east coast. The average daily withdrawal during 1970 is shown for each.

Total water pumpage, if per capita use were to remain constant, would increase proportionally with population. For example, if per capita use were to remain constant at, say, 162 gallons per day and if population were to increase by 1,000, an additional 162,000 gallons per day would be needed. Per capita use in south Florida has not remained constant; it is increasing. Per capita use will probably stabilize, as water demands are more fully met and as rising costs eventually force less lavish use of water. The curves relate population to municipal pumpage. Because the per capita use is increasing, the curves bend upward. If per capita use were constant, the curves would be straight lines. If it were decreasing, the curves would bend downward.





Per capita water use is increasing

In 1968, the Corps of Engineers predicted that water in southeast Florida would be in short supply by 1976 and that competition would develop among water users unless measures were taken to increase the storage capacity of Lake Okeechobee, to backpump part of the water that is presently being discharged to the sea, and to increase the capacity to route stored water in the conservation areas to the lower east coast. Future water deficits will probably be forestalled, in part, however, by reduction in storm runoff to the ocean. (Meyer, 1971).

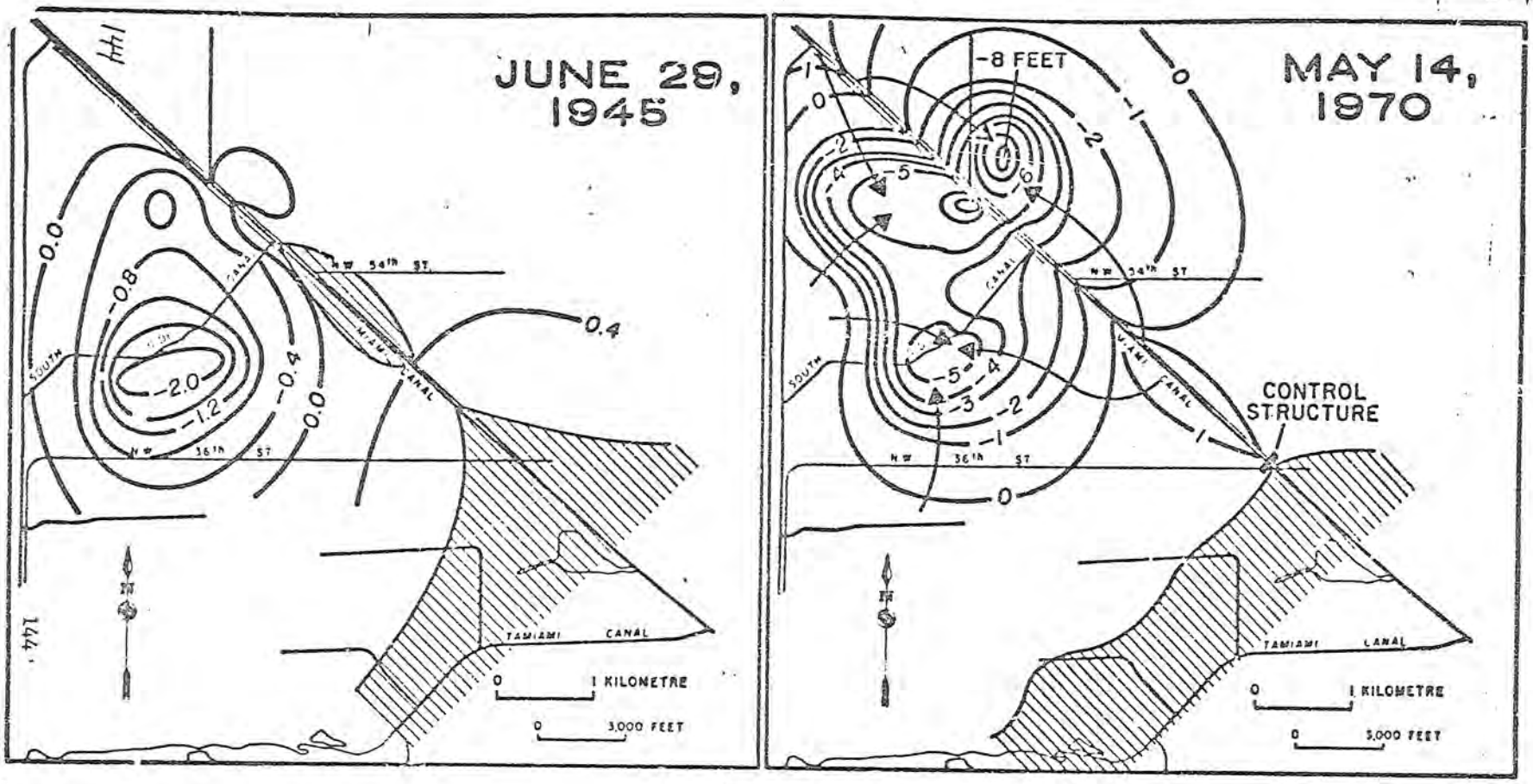
Along the Gulf Coast, enough water of good quality is available for short-term future demands. Future demands in the Naples area will probably be satisfied by a new source established in the interior of the Big Cypress. This source has been shown adequate to satisfy long-term future needs. (McCoy, 1972).

Effects of Municipal Pumping

Superimposed on the water-level changes brought about by flood control, water management, and urbanization and other land development, are those resulting from increased pumping from large municipal well fields and modifications required to protect those fields.

Major changes have been observed through the years in the Miami and the Alexander Orr well fields of Miami and the Prospect well field of Fort Lauderdale. Sequential maps for the Miami and the Alexander Orr well fields and the Prospect well field show changes as pumpage was increased.

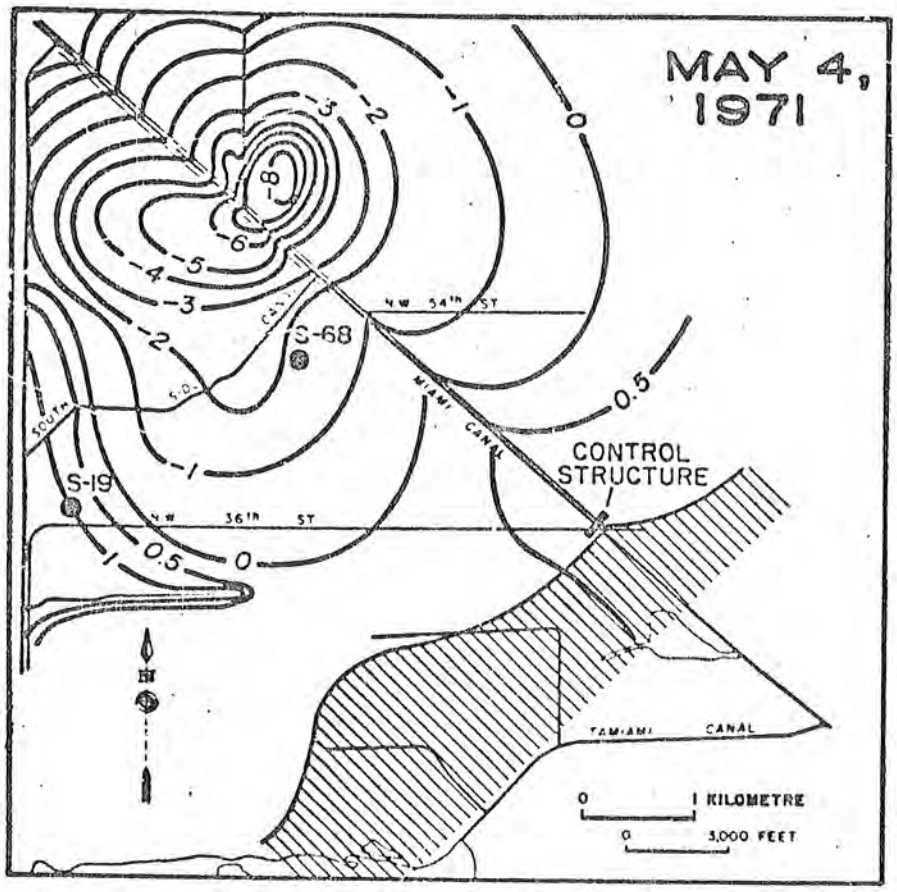
The first sequence represents water-level and chloride conditions in the Miami well-field area in June 1945, before the Miami Canal was controlled and when pumpage was 30 mgd; in May 1970, when pumpage was 120 mgd: and May 1971, at the end of a prolonged drought, when pumpage was reduced from 120 to 90 mgd. In 1945 salt water in the Biscayne aquifer had moved inland along the uncontrolled Miami Canal and laterally toward pumping wells to contaminate some wells.



Although water levels have declined in the Miami well field, the fresh water-salt water interface has been relatively stable in recent years.

The map for 1970 shows the effects of withdrawing 120 mgd for several weeks. The lowest water level was 8 feet below sea level, more than 5 feet lower than in 1945; but pumpage in 1970 was 4 times that of 1945. Although there was a fourfold increase in pumpage and the lower water levels in pumping centers, the inland extent of salt water at the bottom of the aquifer was not appreciably different from that of the 1950's and 1960's. The lack of movement is attributed to the effectiveness of the salinity-control structure and water management in maintaining adequately high fresh-water levels in the vicinity of the well field.

The last map of the sequence represents the low of May 1971, when the threat of advancing salt water in the aquifer from the south brought about a 25-percent reduction in pumpage. Curtailment of pumping in the south part of the well field permitted the water level to recover 3 feet, thereby reducing the rate of inland movement of salt water, which had already advanced more than 3,000 feet beyond its 1970 position. Reduction of pumpage and importation of water from Lake Okeechobee to the lower controlled reach of the Miami Canal stabilized the salt front until the heavy rains of June 1971. Hydrographs of well S-19, at the southwest edge, and well S-68, near the center of the well field, show the overall decline in water levels as a result of the increased pumpage through the years.



EXPLANATION:

-2

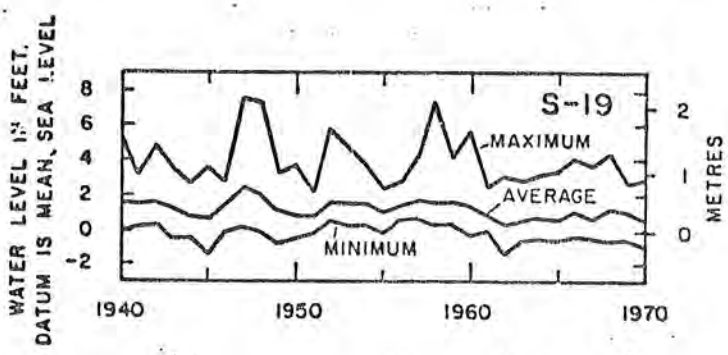
CONTOUR OF EQUAL WATER ELEVATION, IN FEET. DATUM IS MEAN SEA LEVEL (1 FOOT = 0.3 METRE)

S-19

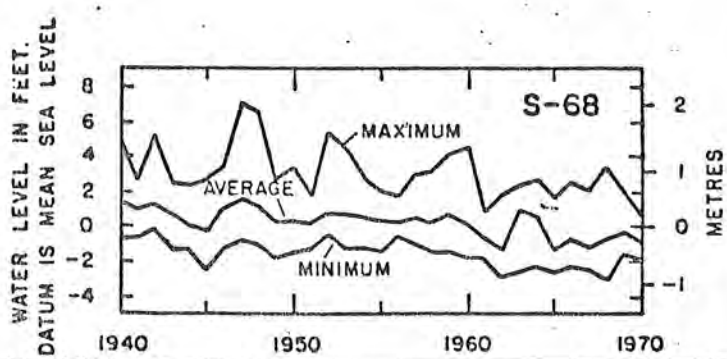
OBSERVATION WELL

AREA AFFECTED BY SEA WATER INTRUSION

DIRECTION OF WATER MOVEMENT



Water levels within and adjacent to the Miami well field have declined as pumpage was increased.



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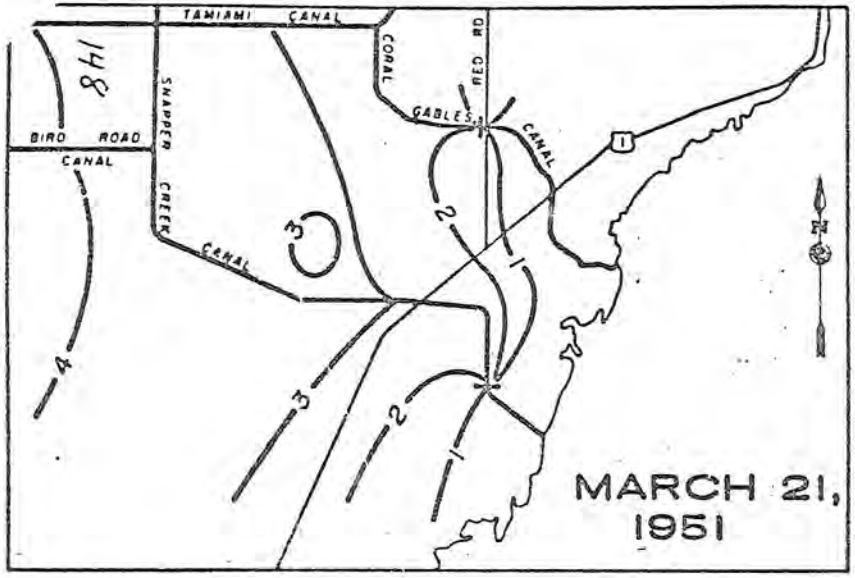
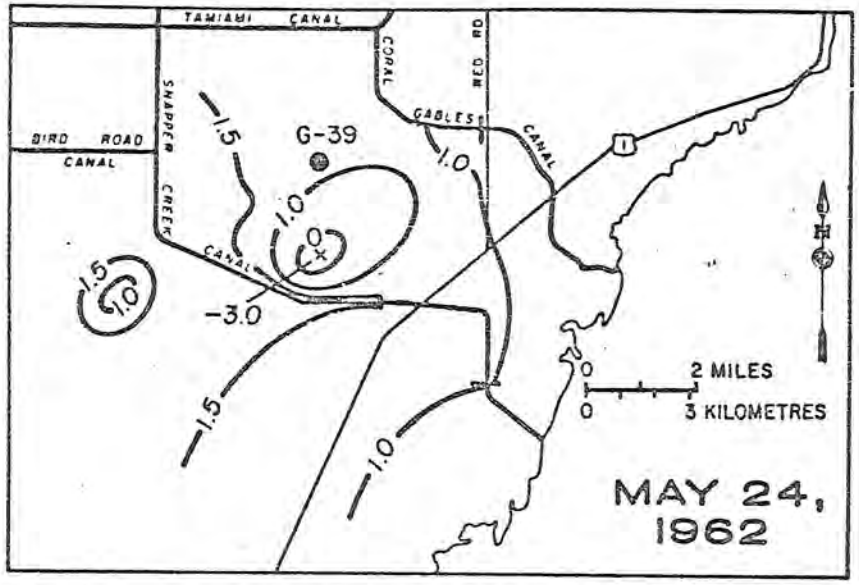
Large increases in pumpage in Miami's Alexander Orr well field similarly have changed water levels in the Snapper Creek-Coral Gables intercanal area. The sequence of contour maps shows the widening of the area influenced by pumping from 1951 to 1971. The first map shows the effect of steadily pumping 6.7 mgd from the Orr well field. The second map shows the enlarged effect of pumping 42 mgd at the end of the drought in 1962 after the Orr field was converted from standby to primary-supply status. The third map shows the effect of continuous 80 mgd pumpage in May 1971. The map also shows the inland extent of salt water at the bottom of the aquifer at that time. The deepest water level in the well field at that time was nearly 5 feet below sea level, as compared with 3 feet below in 1962. The hydrograph of well G 39 north of the well field shows the progressive declining trend in water level as pumpage was increased.

South Florida Water
Management District
Resource CENTER





EXPLANATION:

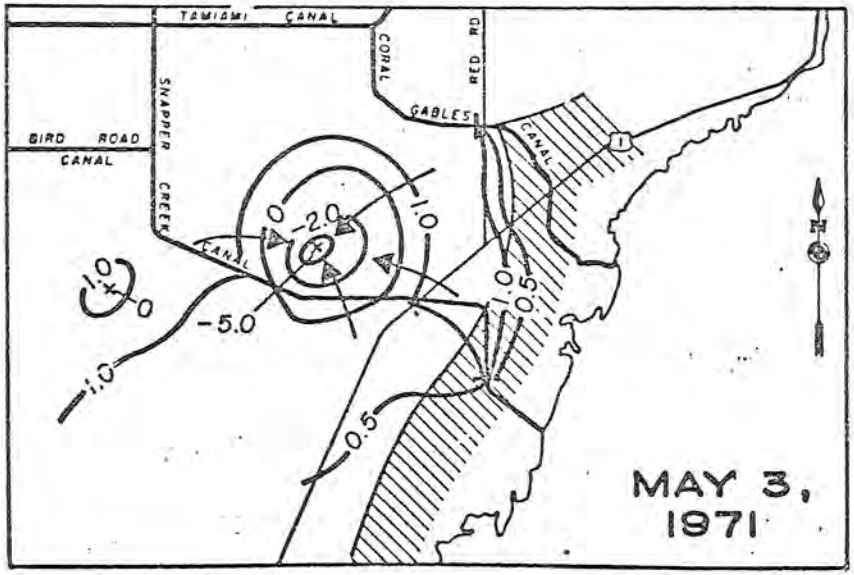
—3— CONTOUR OF EQUAL WATER ELEVATION, IN FEET. DATUM IS MEAN SEA LEVEL. (1 FOOT = 0.3 METRE)

G-39 OBSERVATION WELL

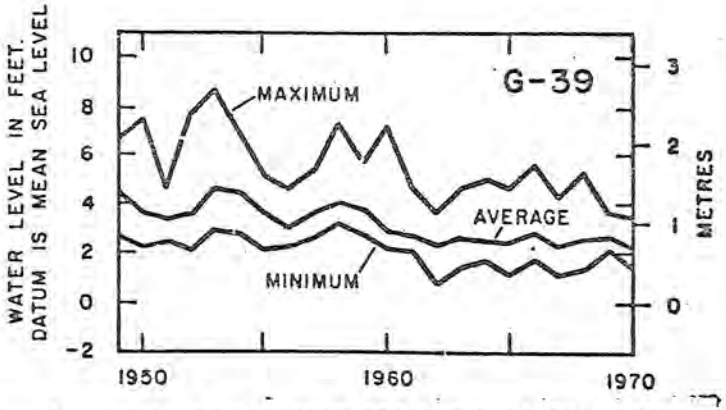
CANAL AND CONTROL STRUCTURE

AREA AFFECTED BY SEA-WATER INTRUSION

DIRECTION OF WATER MOVEMENT



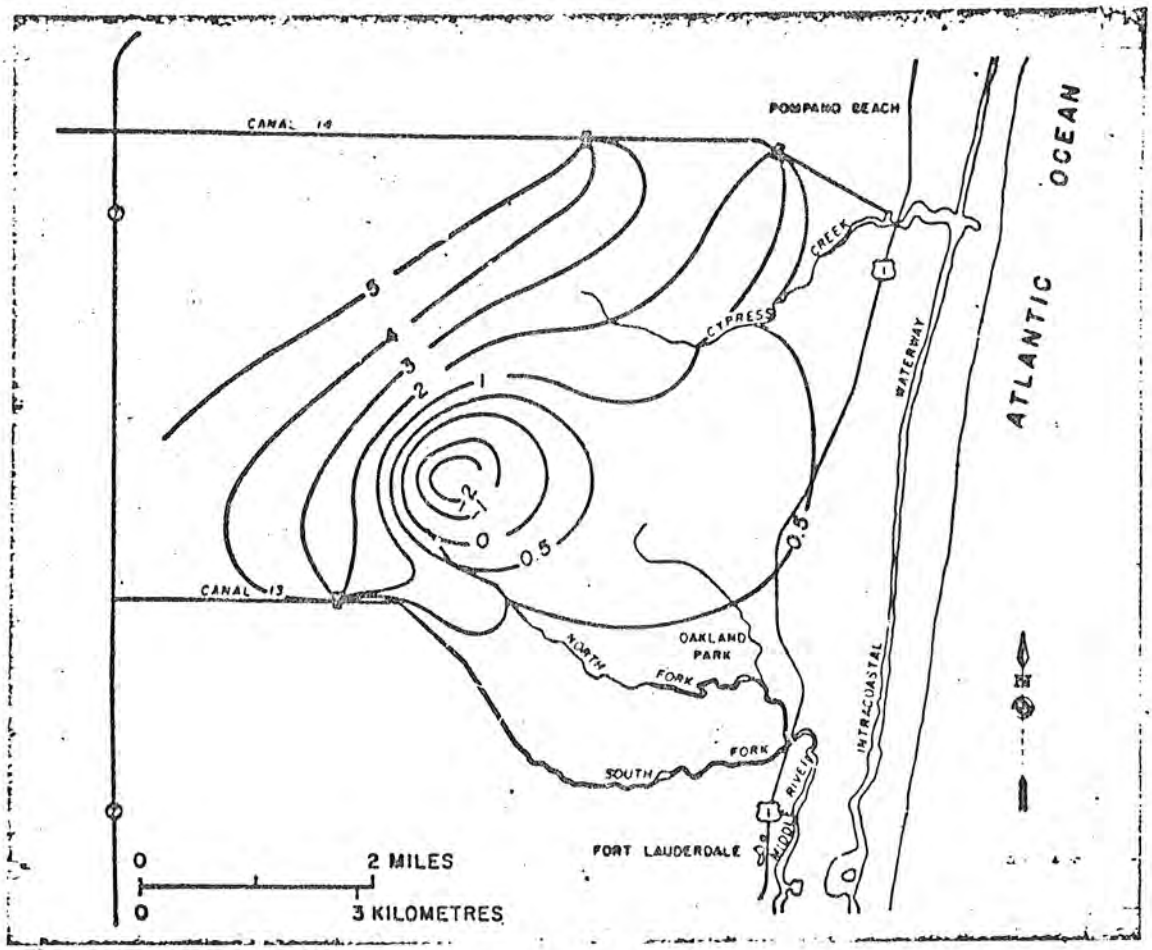
Increased withdrawals from the Orr well field have caused increased drawdowns in water level.



Water levels in a well near the Orr well field have declined over the years.

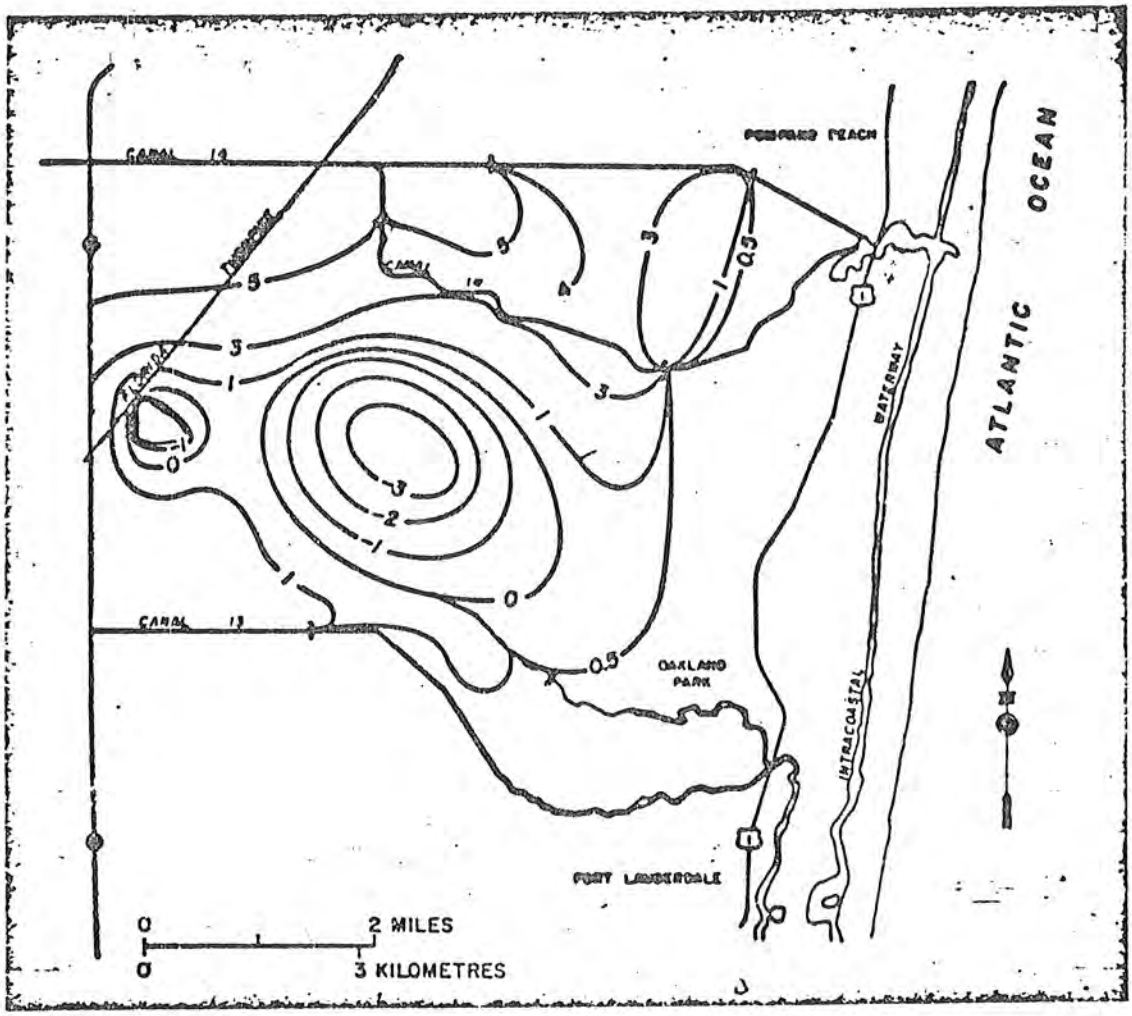
The contours in both the Miami and the Orr well fields indicate that a major part of the recharge water infiltrates from the Miami and Snapper Creek Canals. The arrows within each area of pumping influence show the approximate paths of ground-water flow. The role of the canals in each case is beneficial. Because the canals extend several miles inland, where water levels are relatively high, they gain water from the aquifer or the conservation areas and convey it toward the coastal control structures. In this way, sufficient water enters the canals to recharge urban well fields and to maintain levels upstream from control structures near the coast high enough to retard salt-water intrusion for long periods. Only during 1 or 2 months of prolonged drought, (such as during 1961-62 or 1970-71) are canal flows deficient and water levels low enough that salt water moves toward municipal well fields. As the rainy season begins, water levels rise, canal flow increases, and salt water no longer advances.

The sequential maps of Fort Lauderdale's Prospect well field between Canals 13 and 14 in Broward County indicate changes caused by increased pumpage. The map for August 1956 represents new-field conditions when pumpage was 7 mgd. The map for April 1968 shows expanded-field conditions and the effect of pumping from a mined out rock pit west of the well field. Pumpage was 30 mgd, and the deepest water level in the center of the field, was nearly 4 feet below sea level, as contrasted with 2 feet below in 1956.



AUGUST 1956

The area of water-level decline was expanded with increased withdrawals from Fort Lauderdale's well field.



APRIL 1968

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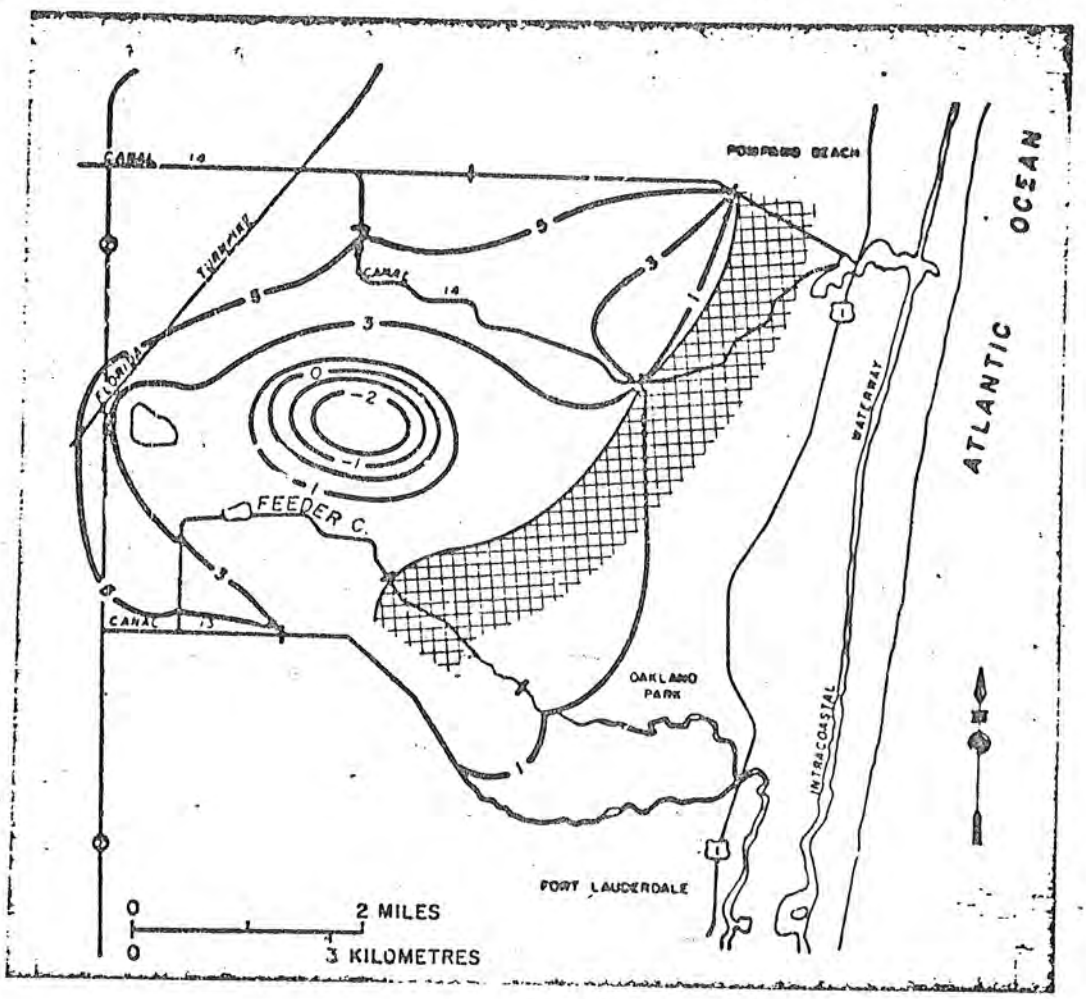
After 1968, a feeder canal was constructed, which connected with the controlled reach of Canal 13; it extended northward to the area of declining water levels. The purpose of the feeder canal was to recharge the aquifer. Its beneficial effects are strikingly illustrated in the map for 1972. The pumping rate in May 1972 was also 30 mgd. The higher water levels south and southeast of the field reduce the possibility of further salt-water intrusion from the vulnerable southeast area. Control structures in Canals 13 and 14 and in the feeder canal reduce losses of fresh water to the ocean and maintain high water levels over long periods to insure adequate infiltration to the well field. The map for May 1972 also shows the inland extent of salt water at the bottom of the aquifer.



MAY 1972

EXPLANATION:

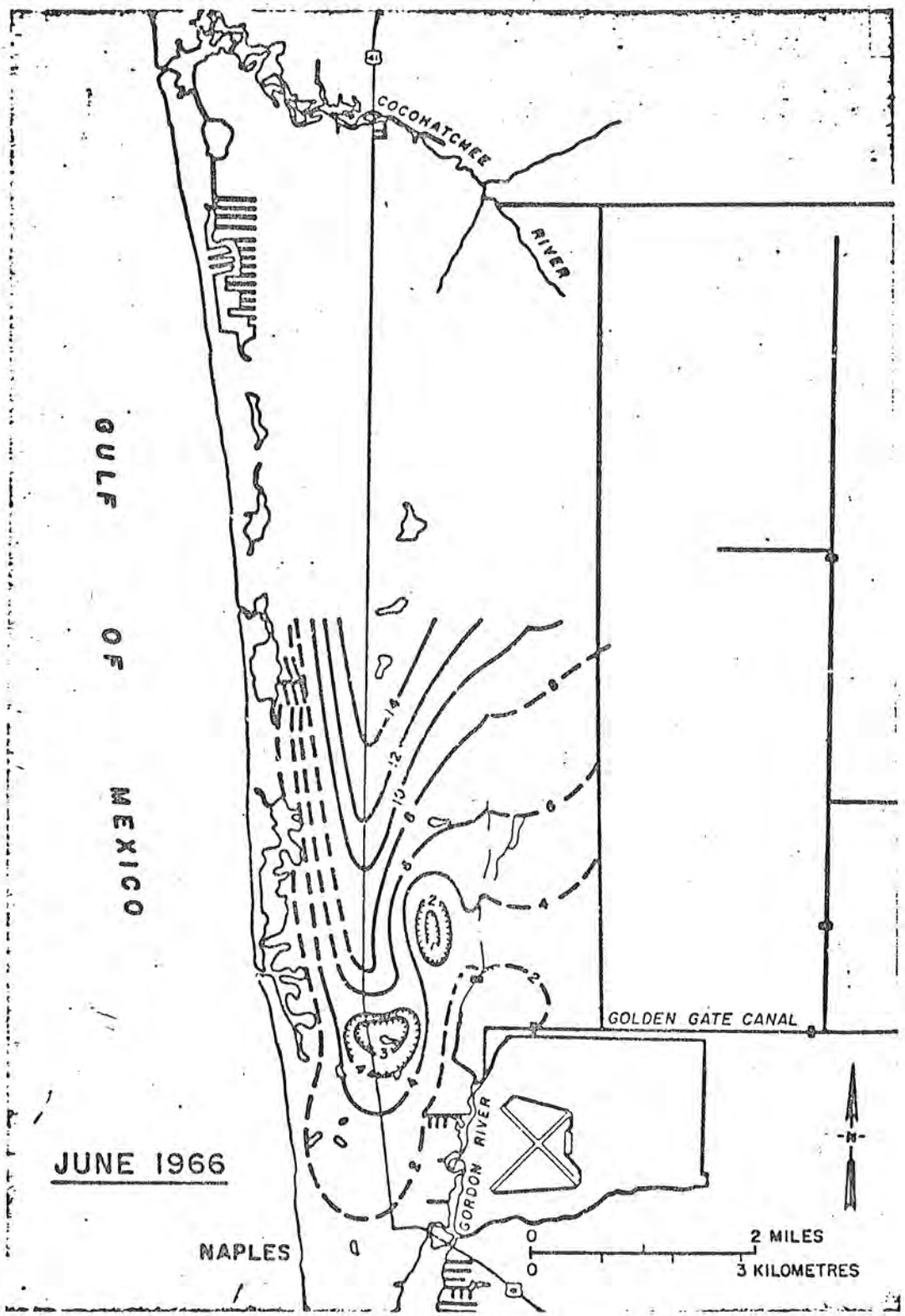
—3— CONTOUR OF EQUAL WATER ELEVATION, IN FEET

AREA AFFECTED BY SEA-WATER INTRUSION

CANAL AND CONTROL STRUCTURE

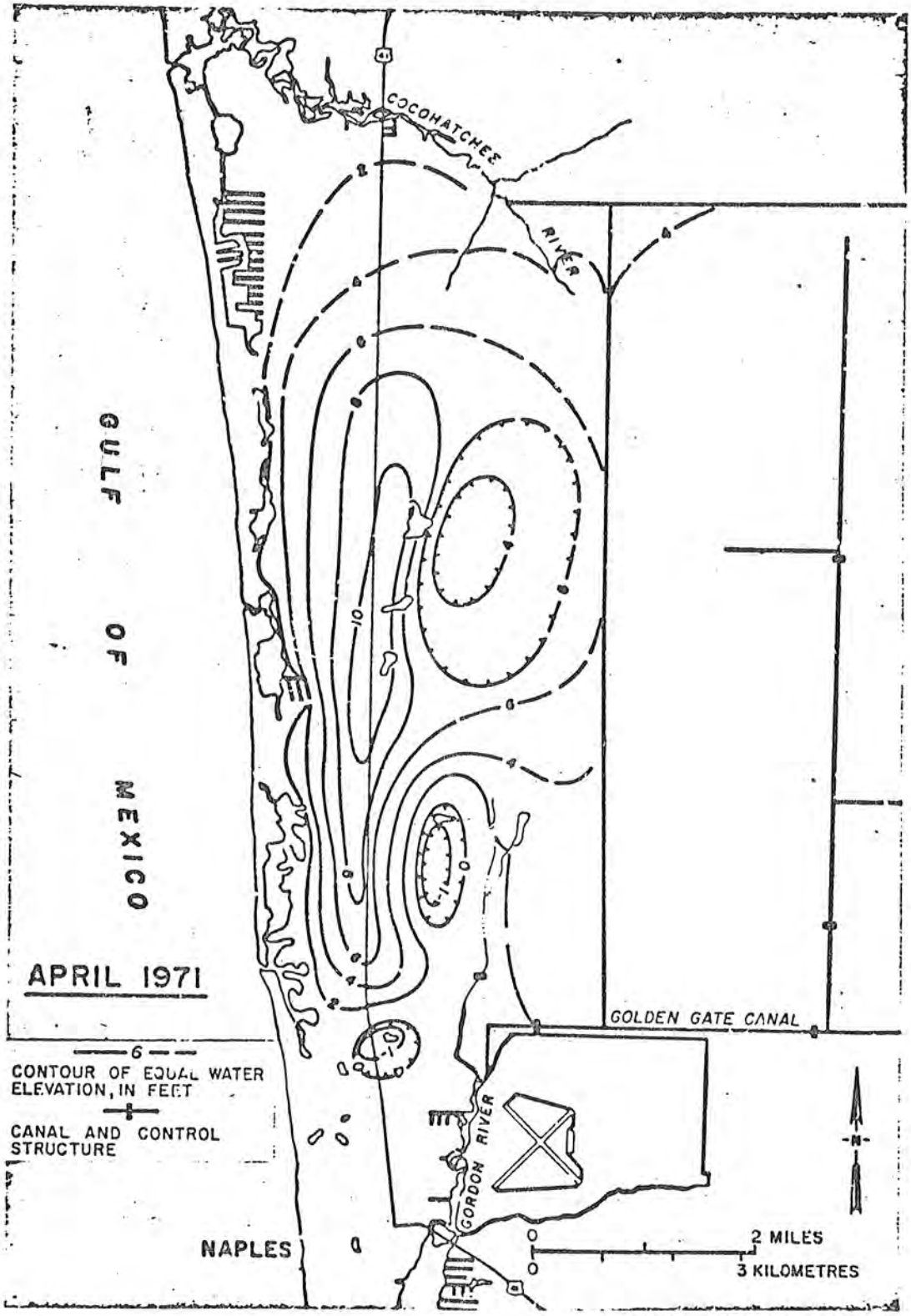
Water for rapidly growing Naples is obtained from wells just inland from the coast. The contour map for June 1966 shows water levels when pumpage was 3 mgd. The area affected by pumping was localized in the south. The lowest level was 1 foot above sea level. The contour pattern suggests that the aquifer at the well field was being recharged primarily by water moving under high gradient from the west and the north.

The well field was expanded northward after 1966, and the map for April 1971 shows the marked changes caused by that expansion. The 1971 contour pattern shows not only that most recharge comes from the area immediately west of the field, but also that more was moving westward from the edge of the Big Cypress than before. Pumping has affected the entire Naples coastal area. In April 1971 pumpage was 8.5 mgd.



More water was diverted westward from the Big Cypress after the Naples well field was extended northward after 1966.

156


COCOHATCHEE
RIVER
GULF OF MEXICO
APRIL 1971
GOLDEN GATE CANAL
CONTOUR OF EQUAL WATER ELEVATION, IN FEET
CANAL AND CONTROL STRUCTURE
GORDON RIVER
NAPLES
2 MILES
3 KILOMETRES
N

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RELATION OF WATER TO PLANT AND ANIMAL COMMUNITIES

Water is a major controlling factor in the ecology of south Florida. Plant and animal communities are intricately related to and dependent on the water environment. The distribution of plants is controlled, in part, by the duration and depth of inundation and by water salinity. Areas seldom flooded are usually overgrown with pine forest, hardwood hammocks, or grasslands. Areas flooded part of the year include wet prairies, marshes, and swamps. The species of plants growing in these lower areas depends on the salinity of the water. The animal communities are, in turn, closely related to the plant communities and to the water regime. Many animals are water-dependent--the aquatic invertebrates, fish, amphibians, many reptiles and mammals, and more than 80 species of birds.

The biota of south Florida is adapted to and dependent on seasonal rainfall. During the rainy season, much of the land is inundated, allowing aquatic life to be widely distributed. Fresh-water runoff mixes with sea water to provide the water of intermediate salinity required by some estuarine species. The dry season provides the necessary contrasting conditions of reduced inundation and high salinity in the estuaries.

Agriculture, urbanization, and water control have changed large parts of south Florida, and plant and animal communities have been disrupted or replaced. Because of rapid population growth and the increased demand for and value of land, drainage and filling, which provide land suitable for development, have been major causes of ecosystem alteration and disruption. Logging, increased access to wilderness areas, poaching, and resultant fires have also adversely affected the ecosystem. If trends of the last 20 years in drainage and filling continue, destruction of the remaining natural ecosystem can be expected.

Only a few regions in south Florida remain relatively unchanged; one is the southern Big Cypress. Although affected by activities of man, it remains a natural habitat for plant and animal communities.

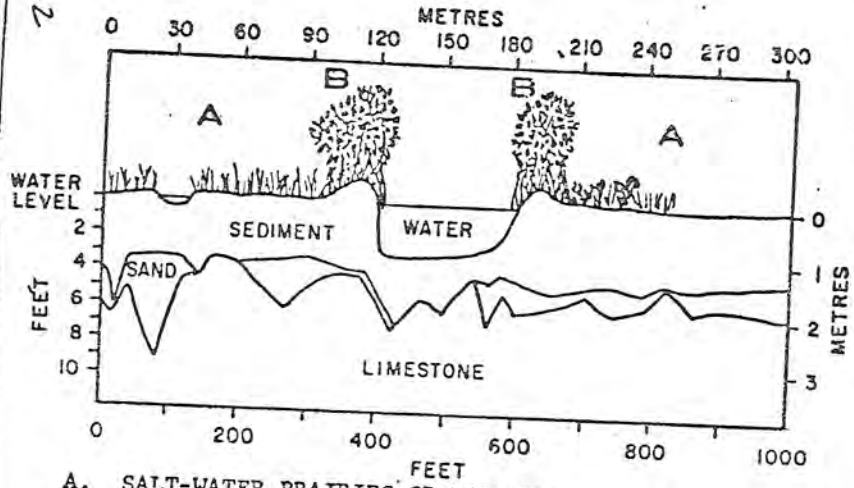
Big Cypress - A Case Study

The Big Cypress has a drainage area of 2,450 square miles. It is a flat swampy region that drains into a coastal-marsh and estuarine environment. The vegetation is divided into 10 associations on the map to show major ecological units and to relate these to water.

The vegetal associations are related to, among other factors, water depth, period of inundation, and water salinity. CYPRESS FOREST and MIXED SWAMP FOREST grow on land seasonally inundated by fresh water for several months. CYPRESS FOREST varies from relatively small sparsely distributed trees, called scrub cypress, to larger more densely distributed trees that commonly form domes or strands. Large trees are generally associated with fairly deep water and soil. HAMMOCK FORESTS grow on land seldom flooded. HAMMOCK FOREST develops in the absence of fire, whereas PINE FOREST requires periodic fire. The frequency and severity of fire are related to the duration of inundation and depth of water adjacent to the forests and on humidity and soil moisture in the forests. COASTAL FOREST is subject to inundation from both fresh and salt water. Areas often inundated usually support mangrove trees; those seldom inundated usually support hammock vegetation.

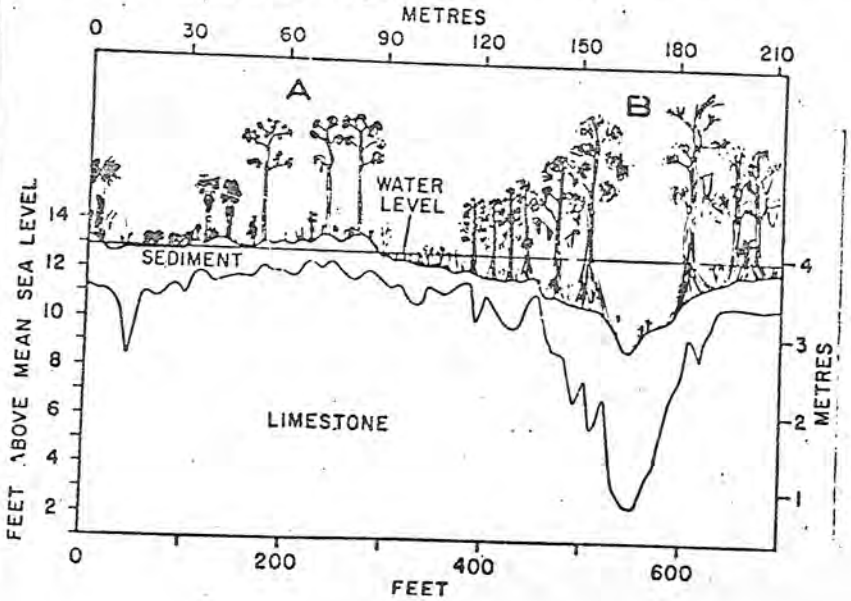
MARSHES, SLOUGHS, PONDS, and PRAIRIES are treeless or sparsely treed regions that are seasonally inundated by fresh water. MARSHES, SLOUGHS, and PONDS generally have deeper water and longer periods of inundation than PRAIRIES. SALT-WATER MARSHES and PRAIRIES and COASTAL MARSHES are subject to periodic inundation by brackish as well as fresh water.

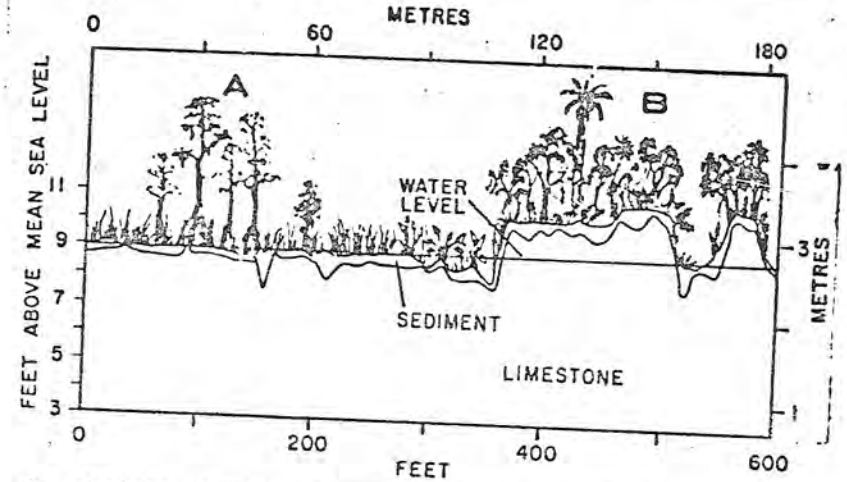
PINE FOREST: Open forest of pine (Pinus elliottii), cabbage palm (Sabal palmetto), saw palmetto (Serenoa repens), and scattered hardwood shrubs and trees. Grasses are usually the dominant ground cover. Common genera include beardgrass (Andropogon), three-awn grass (Aristida), and panic-grass (Panicum). Sedges, rushes, and composites may also be present in the ground cover. Land surface is several inches to several feet higher than surrounding cypress land. Pine forest is a sub-climax association maintained by fire, which restricts the spread and reduces the density of hardwood trees.



A. SALT-WATER PRAIRIES OR MARSHES: Include rushes sea purslane, string lily and small white mangrove.

B. COASTAL SWAMP FOREST: Red mangrove is dominant. Other plants include sawgrass, leather fern and string lily.





A. CYPRESS FOREST: Cypress trees are widely spaced. Intervening areas are mixed grasses, sedges, and rushes.

B. HAMMOCK FOREST: Includes wild tamarind, strangler fig, gumbo limbo, pidgeon plum, wild coffee, cabbage palm, and paradise tree.

A. PINE FOREST: Includes pine, cabbage palm and wax myrtle. A variety of ferns, grasses and sedges are present, including swamp fern, sawgrass, brown sedge, lovegrass, panic grass, and muhly.

B. CYPRESS FOREST: Cypress trees form a dome. Understory includes wax myrtle, pond apple, swamp fern, and air plants. The pond contains arrowroot, pickerelweed, arrowhead and aromatic figwort.

HAMMOCK FOREST: Dense forests of hardwood trees, palms, shrubs, ferns, and epiphytes that grow on land slightly higher than surrounding marshes, prairies, or cypress forest and that often stand out on the horizon as "tree islands." Hammock forest often represents a climax community developed in the absence of fire. Areas surrounded by deep water or areas of dense vegetation that retain high humidity and soil moisture are protected from fire. In the northern part of the Big Cypress, temperate-zone trees, such as red maple (Acer rubrum) and laurel oak (Quercus laurifolia), predominate in lower areas, and live oak (Q. virginiana) and cabbage palm predominate in higher areas. To the south, broad-leaved tropical trees and shrubs, such as strangler fig (Ficus aurea), wild tamarind (Lysiloma latisiliqua), pigeon plum (Coccoloba diversifolia), gumbo limbo (Bursera simaruba), poison wood (Metopium toxiferum), red bay (Persea borbonia), and cocoplum (Chrysobalanus icaco) become dominant, where they grow on numerous small tree islands. These islands are most abundant in the southeast part of the Big Cypress. Near the coast, red mangrove (Rhizophora mangle) and cabbage palm are generally abundant.

CYPRESS FOREST: Open forest of small cypress trees (Taxodium distichum) and a scattered sparse growth of herbaceous plants, such as sawgrass (Cladium jamaicensis) or beak rushes (Rhynchospora), growing on a thin layer of marl soil or sand over limestone. Cypress domes and strands of larger trees grow over much of the forest. Cypress trees forming dome shaped profiles are circular or egg-shaped features.

The trees are tallest in the center and become successively shorter toward the borders. Strands are elongate reaches of large trees that follow drainage depressions. Water and soil are deeper in the domes and strands than in the surrounding open forest. Shrubs and small swamp trees, such as wax myrtle (Myrica cerifera), cocoplum, and pond apple (Annona glabra), are common understory species within the domes and strands.

MIXED PINE AND CYPRESS FOREST: Open forest of pine, cypress, and cabbage palm with an understory of mixed herbaceous plants, shrubs, and scattered hardwood trees. Scattered prairies.

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MIXED SWAMP FOREST: Dense forests of trees, shrubs, vines, ferns, and epiphytes that usually occur as elongate strands that follow low drainage areas. Elevation of land within a forest is variable and ranges from deep-water areas that are inundated most of the year to higher areas that are seldom inundated. Most land is seasonally flooded for months. Forest is usually a mixture of many shrub and tree species. Cabbage palm, red maple, wax myrtle, cocoplum, sweet bay (Magnolia virginiana), and red bay are widely distributed. Cypress, willow (Salix caroliniana), pop ash (Fraxinus caroliniana), and pond apple tend to be more common in deeper water. Hammock vegetation, such as laurel oak, dahoon (Ilex cassine), wild coffee (Psychotria undata), myrsine (Myrsine guianensis), and occasionally live oak and pine grow on the higher land. Willows may predominate in small burned areas, or pop ash, pond apple, or cypress may predominate in deep water. Large cypress trees dominated much of the forest before logging, but virtually all large trees have been removed. Cabbage palm predominates at the seaward end of some strands. Stippled areas within this code color on the map represent patches of dense broad-leaved vegetation and cabbage palms.

COASTAL FOREST: Predominately red (Rhizophora mangle), black (Avicennia germinans), and white mangroves (Laguncularia racemosa) and button wood (Conocarpus erecta), but often with fresh-water swamp trees, particularly in landward regions along creeks. Scattered salt-water marshes and prairies are interspersed in the forest. Hammock vegetation grows on elevated areas, such as shell mounds or creek banks. Stippled areas within this code color on the map correspond to dense forest.

PRAIRIES: Associations of mixed grasses, sedges, and other herbaceous plants with few trees. Prairies may be seasonally inundated for months (wet prairies) or seldom inundated (dry prairies), depending on elevation. Many prairies are intermediate. Common species in wet prairies include maidencane (Panicum hemitomon), blackhead rush (Schoenus nigricans), star dichromena (Dichromena colorata), muhly (Muhlenbergia capillaris), water dropwort (Oxypolis filiformis), ribbon lily (Crinum americanum), hempvine (Mikania batatifolia), the low shrub stillingia (Stillingia sp.), and scattered marsh vegetation, particularly sawgrass. Common species in dry prairies include saw palmetto and some of the grasses and sedges found in the pine forest. Wet prairies cover large areas south of U.S. 41, where they merge, in places, with marshes. Dry prairies are more common in the northwest part. Some prairies, in the west part of the Big Cypress, have been farmed.

INLAND MARSHES, SLOUGHS AND PONDS: Areas dominated by such forms as cattail (Typha sp.), dense sawgrass, arrowhead (Sagittaria lancifolia), pickerelweed (Pontederia lanceolata), fire flag (Thalia geniculata), water rush (Rhynchospora inundata), spike rush (Eleocharis cellulosa), and bladderwort (Utricularia sp.). Vegetation may be dense or sparse. Water is usually several inches deeper than in surrounding prairies.

COASTAL MARSHES: Area near the inland edge of the coastal forest, usually containing fresh water except after storm tides or during droughts. Common species include spike-rush, cattail, cordgrass (Spartina spartinae), sawgrass, sea purslane (Sesuvium sp.), small scattered red mangrove, cabbage palm, and salt-rush (Juncus roemerianus). Cordgrass is abundant and commonly dominant in the southwest part of the Big Cypress.

SALT WATER PRAIRIES OR MARSHES: Mostly treeless except for scattered mangroves. Common species include: Saltgrass (*Distichilis spicata*), cordgrass, salt-rush, saltwort (*Batis maritima*), and woody glasswort (*Salicornia virginica*).

VEGETAL MAP OF THE SOUTHERN

BIG CYPRESS

U.S. GEOL. SURVEY

HYDROLOGIC INVESTIGATIONS

ATLAS HA-492

1973

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Although the natural vegetation in the southern Big Cypress has changed less than in most other places in south Florida, disruption has resulted from logging and severe fires. Logging began in the early 1900's, primarily near coastal settlements, but became extensive in the interior after 1920, when rail transportation became available. Logging reached its peak in the mid-1900's, when virtually all large cypress trees were cut and removed. Tramways, relict from logging operations, are still detectible on the ground and on aerial photographs. Tramways are elongate mounds on which railroad track was laid to haul the trees. Although the track was later removed, the mounds remain and are densely covered with hammock vegetation. Tramways extend through most of the MIXED SWAMP FOREST.

Fire in the south Florida environment, has increased in severity and frequency through some of man's activities. Hunting and logging bring men with matches and machines. Other activities of men, have tended to eliminate catastrophic fires through efficient fire-fighting. Drainage and the consequent shortening of inundation periods inevitably increase both the time available for and susceptibility to burning.

The maps of Fakahatchee Strand, prepared from aerial photography taken in 1940 and 1971, indicate effects of logging and fire on the vegetation of the Big Cypress. In 1940, before the strand was logged, the outstanding feature was a sharply defined narrow north-south band of large trees that extended some 20 miles along the central axis of the strand. Most of the large trees were removed by logging in the late 1940's and in the 1950's, so that the distinct band is absent in the 1971 map. The most obvious features of the strand in 1971 are the MIXED SWAMP FOREST, which was present in 1940 but less obvious, fire scars, and tramways, which total more than 130 miles in length.

The areas burned in the strand between 1940 and 1971 are now dominated almost exclusively by willow, whereas other areas not burned contain several species of swamp trees.

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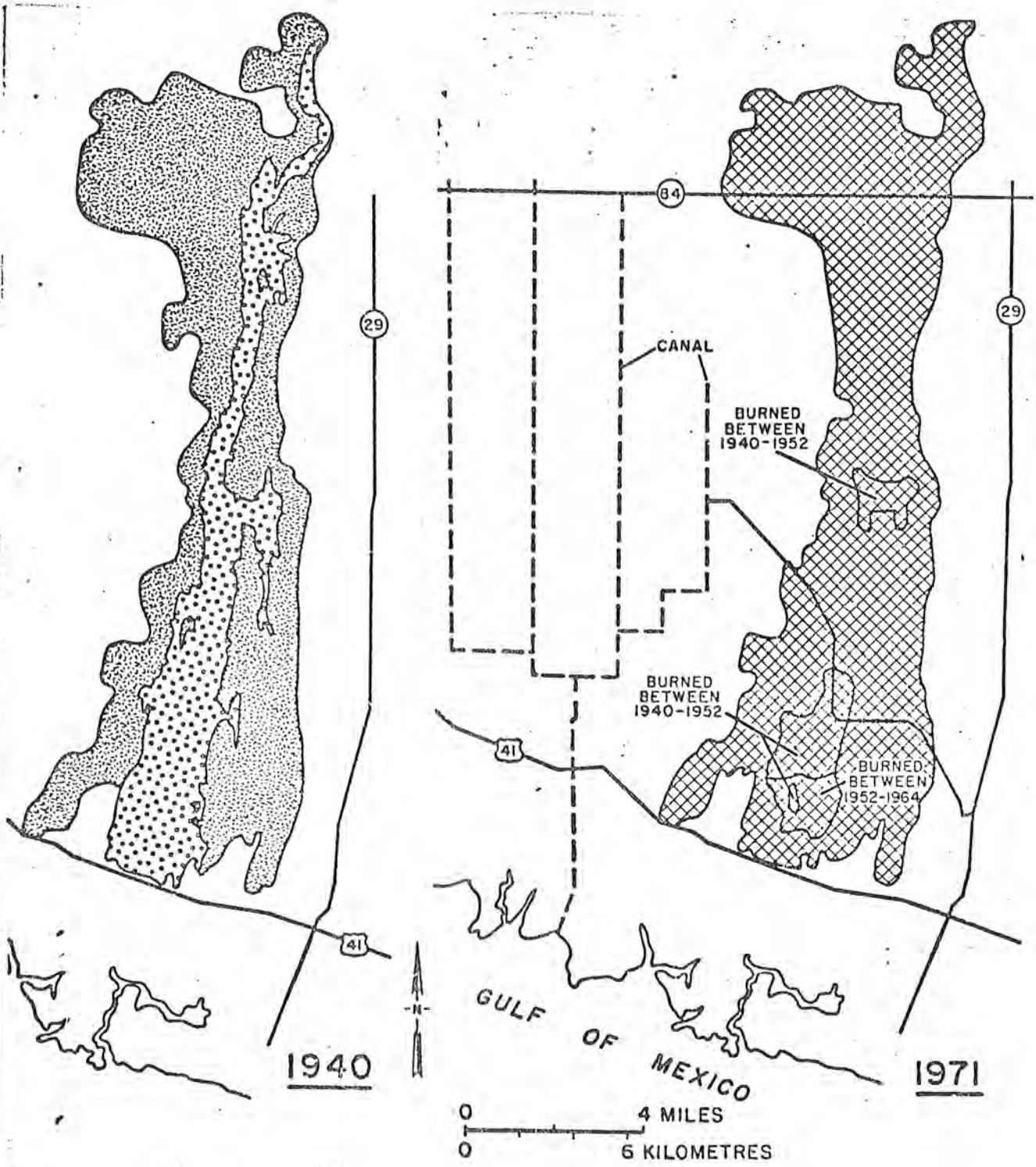

Patterns show changes in the Fakahatchee Strand of the Big Cypress between 1940 and 1971. The pattern of circles shows area of large cypress trees (1940), most of which were later removed by logging. The Strand was further altered by fires, railroad trains for logging and by access roads. Willows became the dominant trees in burned areas. Drainage by recently dug canals west of the Strand may cause further alteration.

Animals in the Big Cypress depend on aquatic plants for food. In the fresh-water environment, the swamp trees, the herbaçeous marsh plants, and the periphyton constitute the main base of the food chain. Organic material is produced by the plants over large areas during high-water periods; this stored energy then ascends the food chain to aquatic invertebrates and small fish and, ultimately, to larger fish, reptiles, birds, and mammals. In the estuarine environment, the mangrove trees are the main producers of organic debris. Debris from the trees falls into the water, where it is partly consumed by microorganisms and converted into minute detritus. The detritus and its attached microorganisms are the major source of food for estuarine animals.

In the fresh-water environment of the Big Cypress, the seasonal fluctuation of water levels is important to the food cycle. During high water, the increased production of organic matter results in large populations of small aquatic animals. As water levels decline, the small animals concentrate in the remaining ponds, creeks, and sloughs, where they become food readily available to larger animals. An example of the seasonal concentration of aquatic animals in the Big Cypress is shown in the biomass diagram. In general, the biomass per unit of water was low in the cypress pond during the high-water periods of 1970-71 and peaked as water levels dropped. Fresh-water prawns increased in biomass as water levels first began to decline. Later, populations of the prawns dropped sharply in both years coincidental with increases in the biomass of flagfish and sunfish, probably indicating predation on the prawns by the fish. The numbers of fish, in turn, decreased markedly soon afterward as a result, at least in part, of predation by wading birds, which fed in the pond at these times. The lowered water levels allowed wading birds to feed in the pond.

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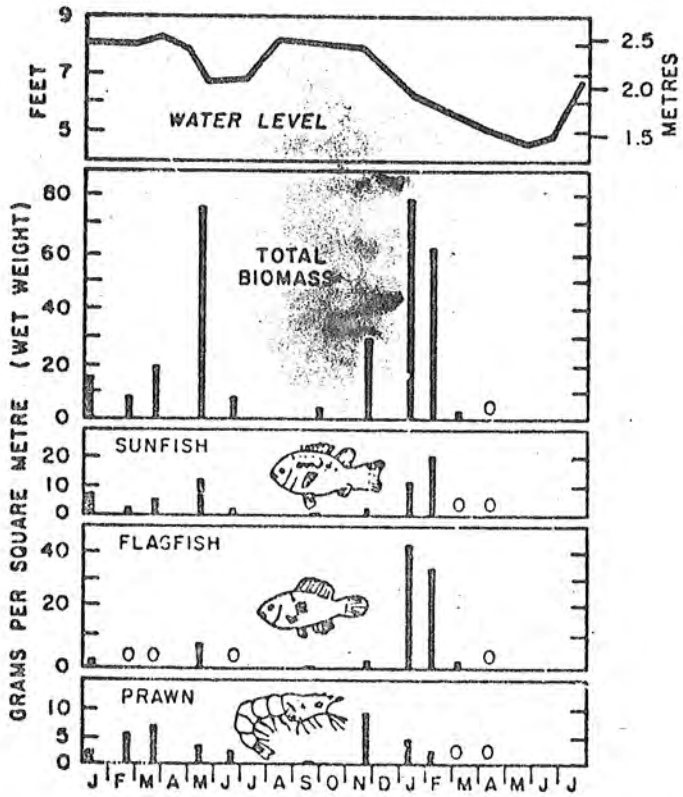

The biomass of small fishes and macroinvertebrates trapped in a pond in the Big Cypress during January 1970 - July 1971 is related to surface-water levels. Zeros indicate that no animals were trapped.

The wood ibis, a wading bird, feeds on small fish by groping with its bill. The efficiency of feeding depends directly on the number of food items per volume of water. In south Florida the wood ibis can obtain enough food for breeding only in winter, when the density of small fish becomes high as a result of declining water levels. Two thirds of the wood ibis of the United States breed in the Big Cypress and are dependent on the seasonally fluctuating water levels there.

Most other large animals of the Big Cypress derive some food from the aquatic food chain. The water-dependent reptiles include several water snakes and the alligator. The alligator population, although once widely distributed and common in the Big Cypress, is now greatly diminished as a result of poaching. Alligators maintain open ponds, which serve as survival holes for other aquatic species during droughts; in the absence of alligators, such ponds commonly fill with aquatic plants and organic debris. Many water-dependent birds, including rare and endangered species, such as the roseate spoon bill, the Florida everglades kite, and the southern bald eagle, inhabit the Big Cypress. Other birds and some mammals, such as the Florida panther and the black bear, are not as water-dependent as others, but they exist in the Big Cypress primarily because it is a wilderness. The wilderness, although now reduced in size, remains because the aquatic nature of the environment has made development difficult.

The estuaries of the Big Cypress are among the most biologically productive areas in Florida. Sixteen commercial species of marine animals depend on the brackish water of these estuaries at some stage in their life cycle. These estuaries also support a large bird population and many important sport fish, including tarpon, snook, and redfish.

Life in the estuaries depends on seasonal runoff from the interior, which mixes with sea water to provide the brackish water. Many marine species, including crabs, shrimp, and fish, require brackish water as juveniles, then move out of the estuaries as adults. Other species live in the estuaries throughout their lives or move freely from the sea to the estuaries. The commercially important pink shrimp requires brackish water during part of its life cycle. They spawn offshore, and the newly spawned larvae migrate to estuaries, where food is abundant and where they are protected from marine animals. The larval shrimp then develop into juveniles before migrating seaward to offshore breeding grounds. The Big Cypress estuaries thus contribute substantially to the multi-million dollar shrimp fisheries of south Florida.

The plant and animal communities of the northwest part of Everglades National Park depend on the fresh-water runoff from the Big Cypress. Altering the pattern of sheet flow of fresh water from the Big Cypress would affect these communities.

Urban expansion preceeded by drainage threatens the remaining undrained regions of the Big Cypress. Expansion of drainage and water control would not only affect the ecology of the basin itself, but would also affect the productive estuaries of Everglades National Park, the commercial and sport fisheries, and the urban areas along the west coast.

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ENVIRONMENTAL QUALITY

Sources of Contamination by Man

Contamination may result when environmentally harmful materials accumulate. Fertilizers, for example, contain nutrients that are needed by crops and that accumulate on cropland. Some of the nutrients are subsequently washed from cropland by precipitation and overland runoff. When they reach surface-water bodies, they may cause prolific growth of algae and other undesirable plants by enriching the water bodies. The materials that cause such undesirable effects are considered to be contaminants, regardless of their initial or intended beneficial effects. Other materials, such as pesticides, serve a useful purpose in controlling pests, both plant and animal. Some, however, accumulate in the food chain and can damage animals that are not pests and, hence, do not need to be controlled. Detergents, indispensable in the home, become contaminants in streams. In any case, whether benefits outweigh consequences is moot.

Nature, herself, of course, can be a contaminator. Examples of natural contaminating forces include: hurricanes, floods, droughts, fires, earthquakes, volcanic eruptions, tsunamis, and minor wayward litterings.

South Florida Water
Management District
REFERENCE CENTER

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The three major sources of introduced contaminants to the environment are industries, municipalities, and agriculture. Wastes produced and expelled by these sources have different characteristics, but all have a common feature -- they can contaminate, degrade, or at least change the hydrologic environment.

Industrial wastes consist of a variety of chemicals, gases, and heat. Numerous light industries dispose of small quantities but wide varieties of wastes. Chemical wastes, often untreated or cursorily treated, sometimes are discharged into open water bodies. Most waste water from industry can be treated to minimize the effects on the quality of the water where waste is disposed. Food processing wastes, for example, can often be discharged into effective municipal waste-treatment systems, and production processes can also be designed to minimize wastes.

Thermal contamination, generally caused by discharge of cooling water, particularly from thermoelectric-power production, is a problem in south Florida. Thermal contamination becomes a problem when discharge of heated water raises the ambient temperature of a receiving water body above the tolerance of major plant or animal species native to the water body. The temperature tolerance of many plants and animals, however, is generally not specifically known.

Wastes from municipalities include not only domestic wastes but also wastes from some industries, fertilizers and pesticides used on home lawns and gardens, oil and other matter from city streets, and, in places and at times, sediment removed by erosion from urban areas. Domestic sewage can be treated to minimize contamination of inland and offshore waters.

The major types of contaminants from agriculture include wastes from feed lots, fertilizers, pesticides, and sediments from erosion. Modern methods for raising large numbers of livestock on small plots of land concentrate more animal wastes per unit area than previously used methods. Disposal of this waste is an increasingly difficult problem. Fertilizers contain nutrients that are washed into streams or leached into ground-water supplies by rainfall and irrigation.

Most pesticides are applied by spraying. Aside from their benefit, pesticides contaminate air, the land on which they fall, and the water that eventually receives particulate fallout and runoff from the sprayed area. Within these environments, they threaten plants and animals that were not intended targets. This type of contamination has caused wide concern among environmentalists and the public in general.

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Solid and Liquid-Waste Disposal

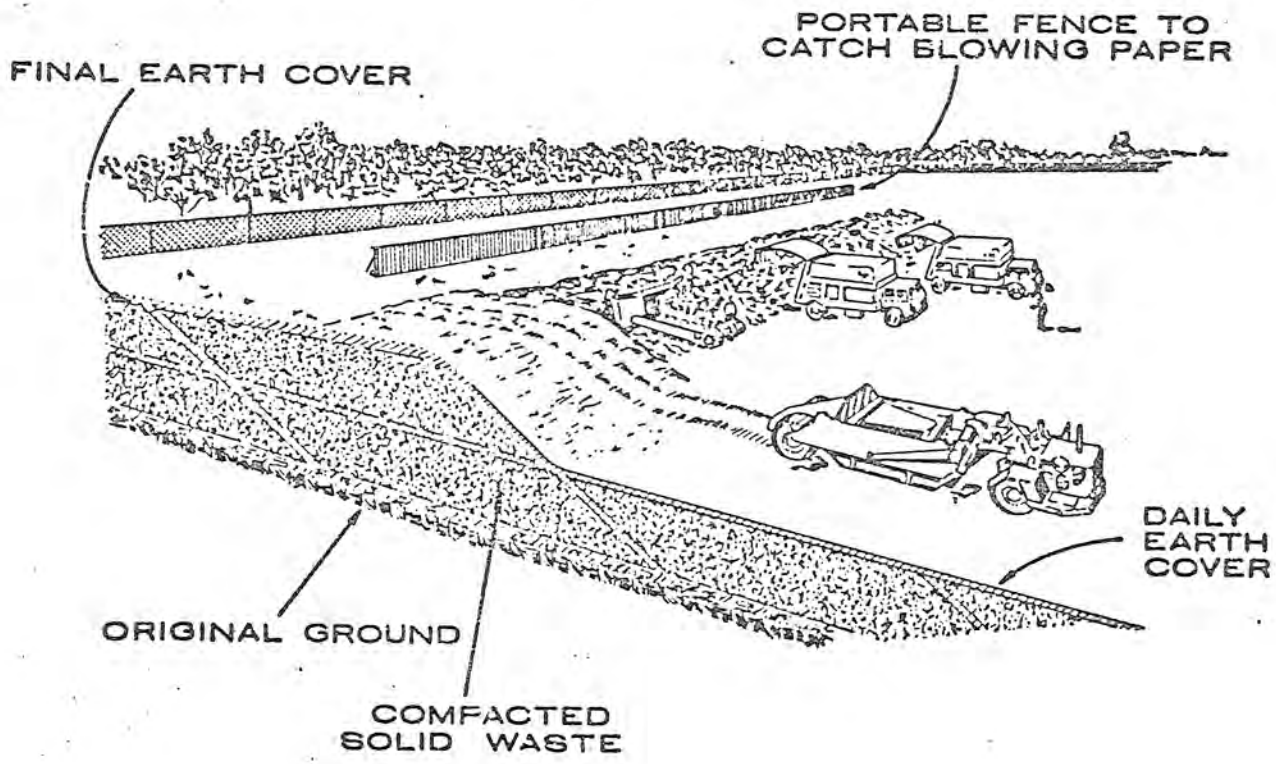
Solid wastes are probably the most obvious of all wastes. Litter can be seen in open dumps, on streets, highways, beaches, vacant lots -- and floating on oceans, streams, and public fountains. Disposal of solid wastes can create problems that are not so obvious. One of the most serious is the contamination of surface water and ground water by rain that flows over or infiltrates through solid-waste materials that have been improperly disposed.

About 2 million tons of solid waste are produced in south Florida each year, approximately 5 pounds per person per day. This does not include industrial and agricultural refuse. The wastes range in variety from paper and bottles to old automobiles and furniture. The main problems of disposing solid wastes are finding environmentally acceptable places and methods to dump or burn it. Hydrologic and geologic characteristics of the area, such as high permeability of aquifers and a high water table, make even the use of sanitary landfills less than ideal.

Several large cities in south Florida incinerate part of their solid waste. This generally produces large volumes of smoke and adds tons of particulate matter to the air. Noxious gases are often expelled from burning plastics and related materials. Methods of reducing noxious gas, smoke, and particulate matter in stack effluent are being developed, as are methods for the beneficial use of materials reclaimed from incinerator refuse.

Dumping is the other means of solid-waste disposal in current use. The problems associated with open dumps are obvious -- esthetic eyesores, odors, rats, and flies. Sanitary landfills solve the obvious problems because they have a thin cover of soil over each day's accumulation of waste. In south Florida, sanitary landfills above ground could create new land, which could eventually be used for parks, golf courses, and other esthetic or recreational pursuits.

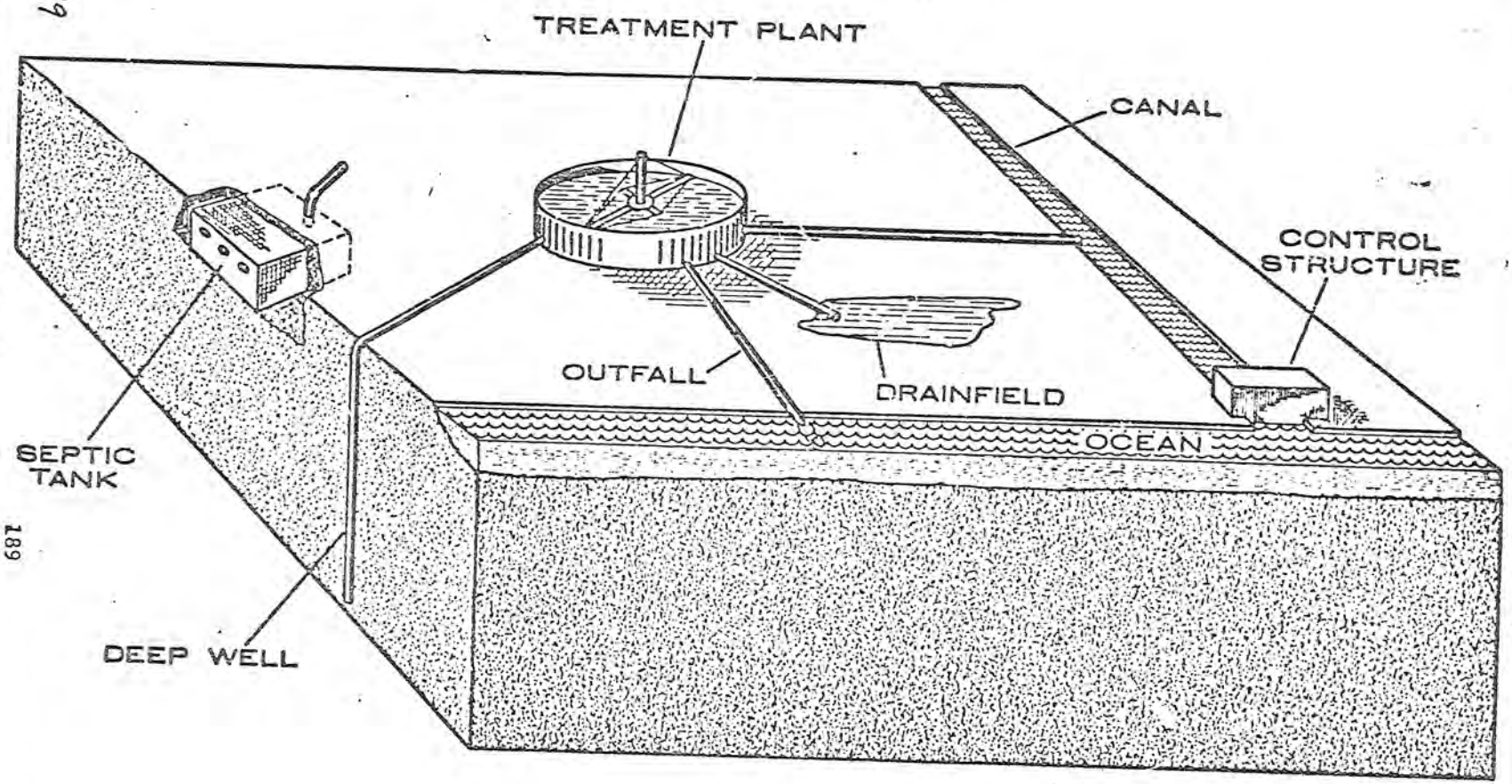
The high permeability of the shallow limestone aquifers and the shallow depth to the water table in south Florida intensifies problems caused by leaching. Rain infiltrating alternating layers of soil and waste in sanitary landfills can carry contaminants to the water table. Sanitary landfills are much more efficient than open dumps, however, because the alternate layers of soil filter some leachates.



Sanitary landfills are used in some areas of south Florida in lieu of open dumps or incinerators. Landfills might be a method of creating useable land.

Liquid wastes are generally discharged into streams and canals, the ocean, disposal wells, drainfields, or septic tanks. More than 200 mgd of liquid waste was collected by sewer systems in south Florida during 1970. Of this amount, 125 mgd was discharged directly to the ocean, 70 mgd into inland canals, and 5 mgd into deep disposal wells and drainfields. Total sewage production was about 400 mgd. The additional 200 mgd of waste was disposed through private septic tanks. The above figures are only estimates, as much liquid waste is not metered. Estimates of quantities disposed through septic tanks are based on approximate per capita production from sewered areas.

The large volume of sewage that south Florida discharges into water bodies and into aquifers is more than can be safely handled by these water bodies, chiefly because the sewage is insufficiently treated. The primary reason sewage is often insufficiently treated is that the treatment plants are overloaded.



Disposal of waste water includes discharge to ocean outfalls, inland canals, septic tanks, drainfields and deepwells.

Historically, waste water has been discharged into waterways. Nature was relied upon to assimilate the waste and to dilute it or spread it to innocuous proportions.

A volume of contaminant discharged into a body of water is diluted by the receiving water. If the water body is flowing, the diluted waste is carried downstream. Movement in a ground-water system is similar, especially where the aquifer leaks or is pumped.

The extent to which waste water is treated and the location of inland discharge sites into canals have an important effect on the water-supply systems of south Florida. Because canals and aquifers are hydraulically connected and because salinity controls are closed to prevent fresh-water loss during prolonged drought, untreated or partly treated sewage dumped into canals is capable of contaminating adjacent aquifers. Contamination of aquifers, of course, is particularly dangerous near municipal well fields.

In agricultural areas where pesticides and fertilizers are applied by spraying, a considerable part of these materials remains in the air. Wind currents can then convey them far afield.

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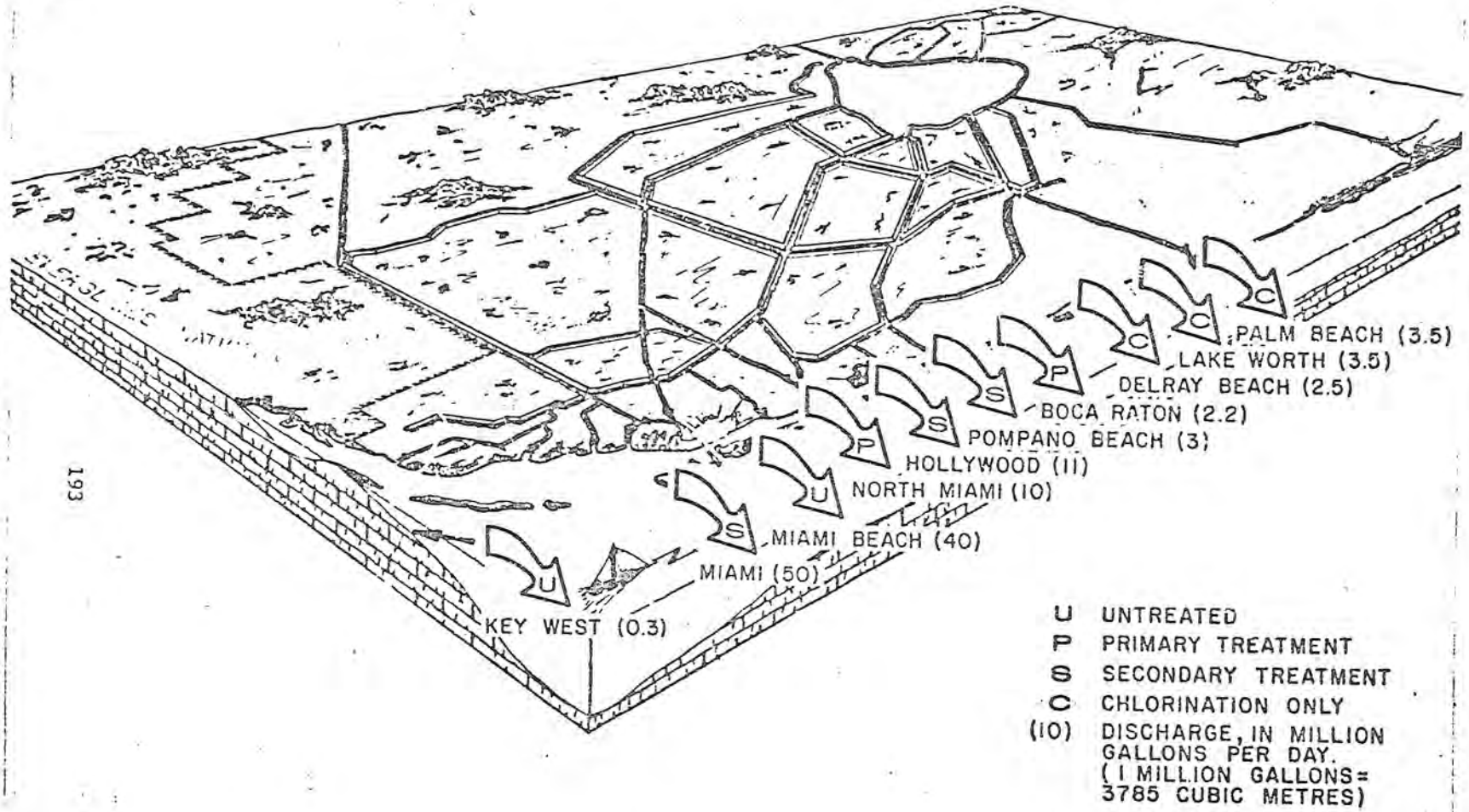
Disposal Into the Ocean

Ocean outfalls are used in south Florida to dispose of municipal and industrial waste. The outfalls consist of pipelines. through which treated or untreated sewage is pumped into the ocean.

Ten cities in southeast Florida dispose all or part of their sewage through ocean outfalls. They are Palm Beach, Lake Worth, Delray Beach, Boca Raton, Pompano Beach, Hollywood, North Miami, Miami Beach, Miami, and Key West. These cities discharged a total of 125 million gallons per day of sewage in 1970. Three provided secondary treatment, two provided primary treatment, three provided chlorination only (for odor control), and two discharged untreated sewage. North of Palm Beach County, ocean outfalls are not permitted unless the sewage has had secondary treatment.

The Gulf Stream is close to the Florida southeast coast, and has been considered in the past to be effective in removing or diluting discharged effluents. The capability of the Gulf Stream to handle increasing quantities of waste has recently been questioned, however, which has led to revised criteria. In 1970 the Florida legislature stipulated secondary treatment by 1973 for all waste discharged to the ocean.



In 1970 ten cities disposed all or part of their waste water through ocean outfalls. The total volume pumped to the ocean was about 125 million gallons per day.

Two of the uncertainties concerning ocean outfalls are the short length of the outfalls and the changing Gulf Stream currents. The outfalls are all less than 2 miles long, and some are less than a mile. The west edge of the Gulf Stream is generally about 2 miles offshore in the southernmost part and farther offshore to the north. Its exact position, however, is indeterminate, because it meanders and changes position. As it meanders, it frequently generates large eddy currents between its west edge and the shore.

Discharge from outfalls, therefore, reaches the Gulf Stream only at times, and, even when it does, it is not necessarily moved into ocean depths and diluted. At times it is carried by eddy currents to shallow inshore waters or strewn along the beaches. The ability of the ocean to continue to accomodate contaminants is by no means assured. Experience with Lake Erie, Lake Superior, and the Mediterranean indicate eventual damage to even large water bodies through intransient disposal of contaminants. Dumping contaminated wastes into the ocean is akin to dumping them into streams and lakes, except that streams and lakes can be cleansed in human lifetimes.

Water Quality

The quality of water relates to its chemical, physical, and biological characteristics. Quality is usually measured in terms of the intended water use. Water is of poor quality or contaminated if some characteristic exceeds reasonable limits for a particular use.

Contamination of water affects man directly as a health hazard or esthetic degradation and indirectly by damaging the aquatic environment.

Water-borne diseases, such as typhoid, dysentery, salmonellosis, infectious hepatitis, and eye, ear, and nose infections, constitute a threat in south Florida from drinking water not adequately treated or from contact sports in unsafe areas. More than 100 cases of typhoid fever occurred at a migrant labor camp in south Dade County in early 1973. The epidemic was apparently caused by contamination of drinking water by sewage. Local county health departments warn, with few exceptions, that most inland waterways, canals, ponds, and lakes are unsafe and should not be used for contact water sports; only ocean and gulf beaches are recommended. Virtually all inland waters are subject to periodic contamination.

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Shellfish concentrate some pathogenic organisms to levels many times those found in the surrounding water. The Florida Division of Health prohibits commercial shellfishing for direct marketing along the entire east coast of south Florida and along parts of the Gulf coast.

The variety of chemicals in water is another cause for concern by public health authorities. Little is known of the health effects, if any, of low levels of toxic chemicals in drinking water. The increasing numbers and amounts of exotic chemicals released to the environment by industry and agriculture also are cause for concern.

The esthetic quality of water is also subject to impairment. Many canals in south Florida are visually offensive because of aquatic plants and floating debris and garbage. Dead and dying aquatic plants putrify canals. Bays and coastal areas are also subject to similar degradation.

Water is enriched by runoff or an influx of excessive amounts of nutrients. Excessive amounts of nutrients usually accelerate eutrophication of a body of water. Overenrichment results in prolific growth of algae and other plants and in deterioration of water quality. In south Florida, many canals are overenriched, as indicated by excessive blooms of algae and luxuriant growths of water hyacinths and other aquatic plants.

In order to show how the quality of surface water is affected by various land uses, south Florida was divided into nine areas based on patterns of land use. The land uses of the nine areas shown are as follows:

Area 1. Dense cattle and dairy farming.

2. Cattle farming in the lower part, citrus in the upper part.

3. Generally swampy area of cattle farming.

4. Water storage and recreation.

5. Truck farming.

6. Sugar-cane farming in the north and truck farming in the south.

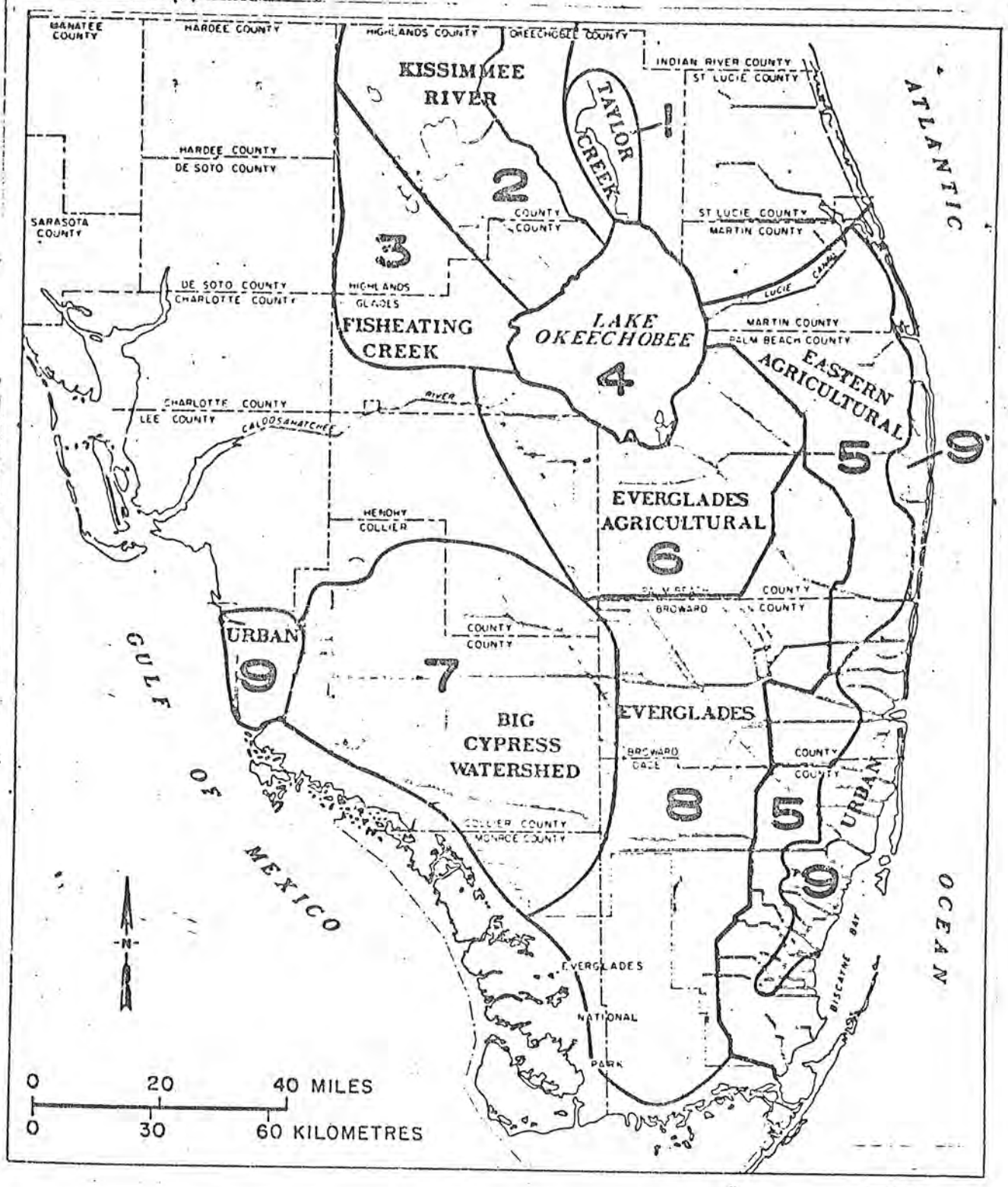
7. Undeveloped marshland and water storage.

8. Natural swamp forest.

9. Urban and industrial.

Land-use areas in south Florida can be grouped into four general subdrainage areas, according to hydrology and water regulation:

(1) Lake Okeechobee subarea comprising units 1, 2, 3, 4, and 6; (2) Everglades subarea comprising the water-conservation areas and most of Everglades National Park, unit 8; (3) East and west coast subarea comprising units 5 and 9; and the Big Cypress, unit 7.



Generalized land-use areas as they relate to surface-water quality.

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Average dissolved solids, orthophosphate, and nitrate are shown for different climatologic conditions. The years 1962-65 represent a dry period, 1966-69 a wet period, and 1970-71, a moderately dry period. The earliest date of sampling was about 1950.

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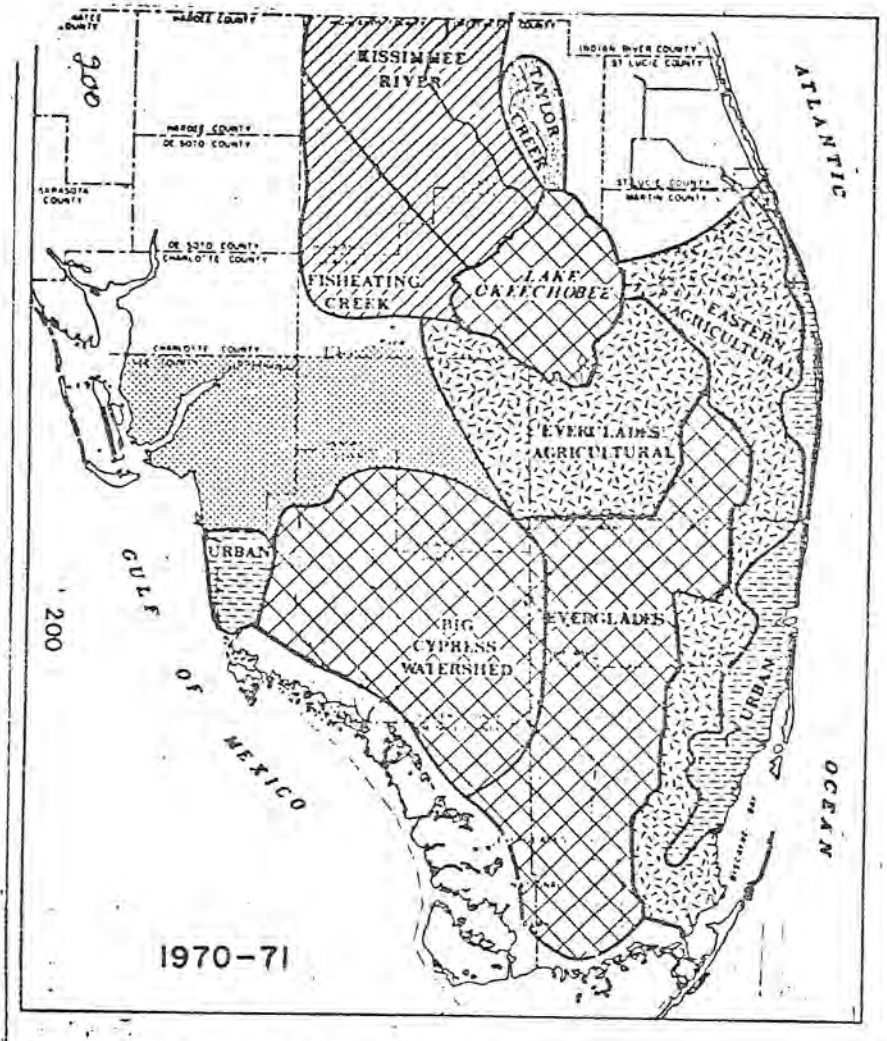
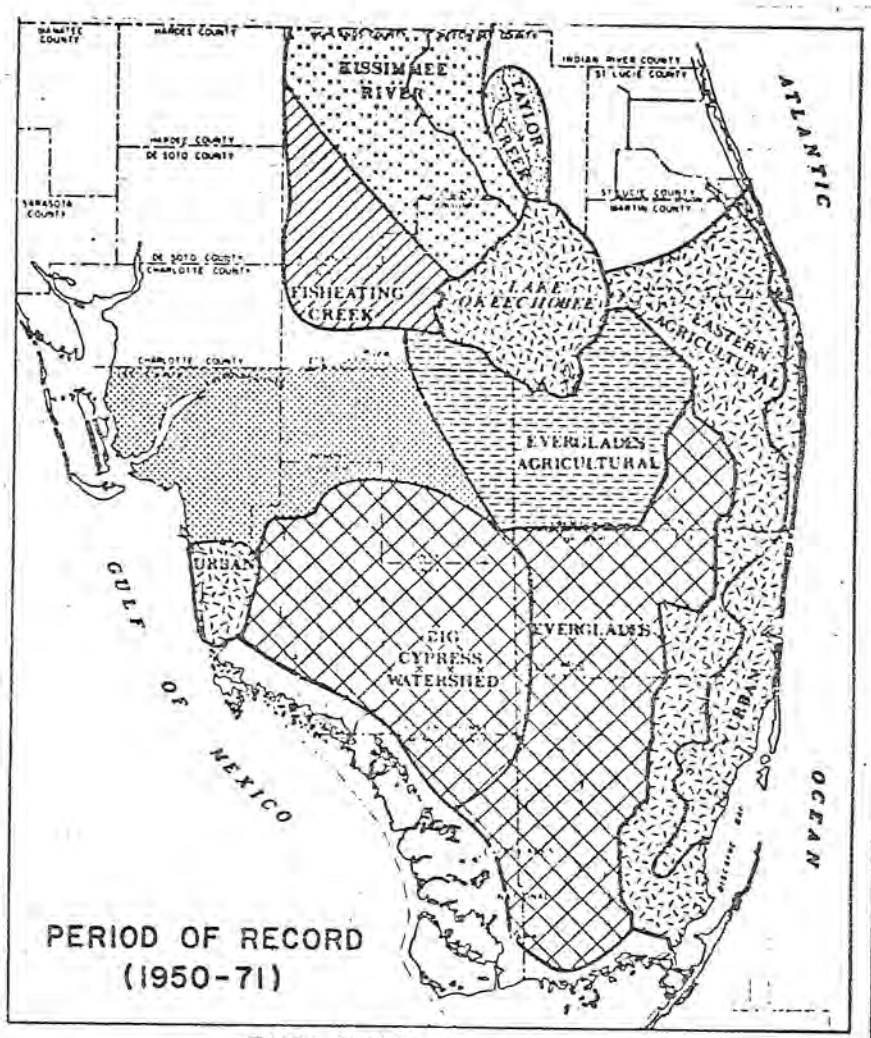




0 20 40 MILES

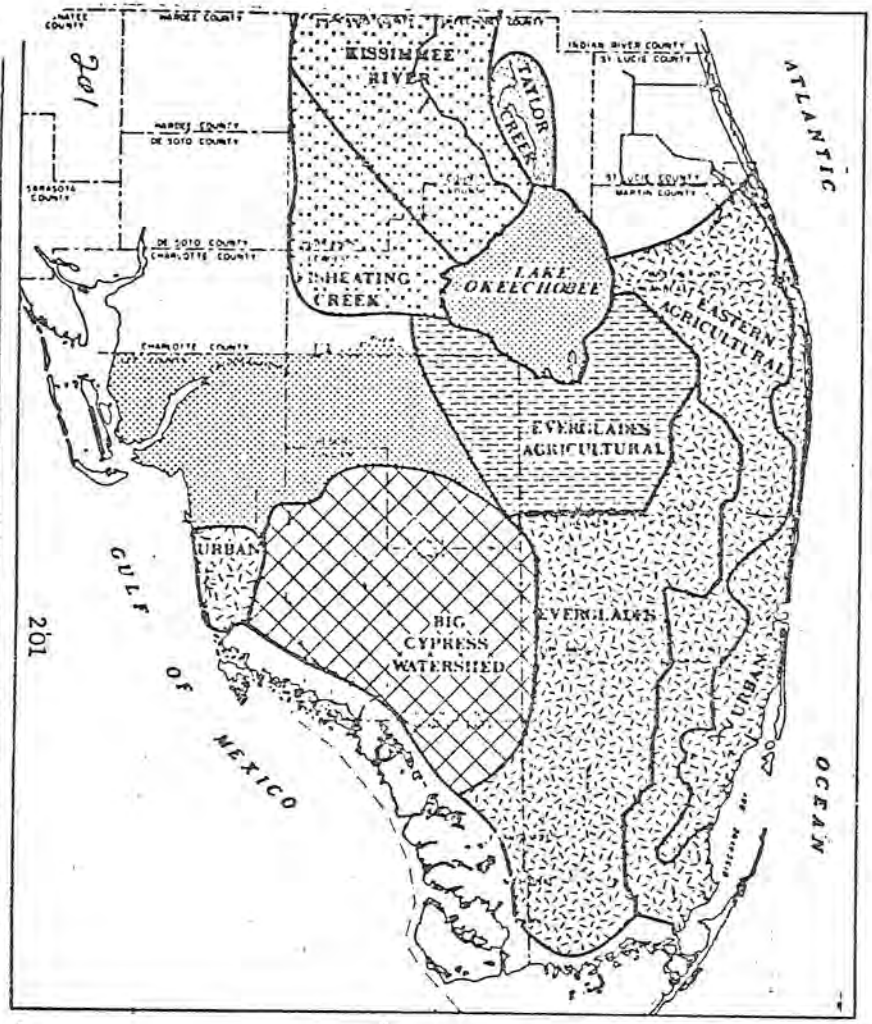
0 30 60 KILOMETRES

Dissolved solids in surface water, in milligrams per liter.

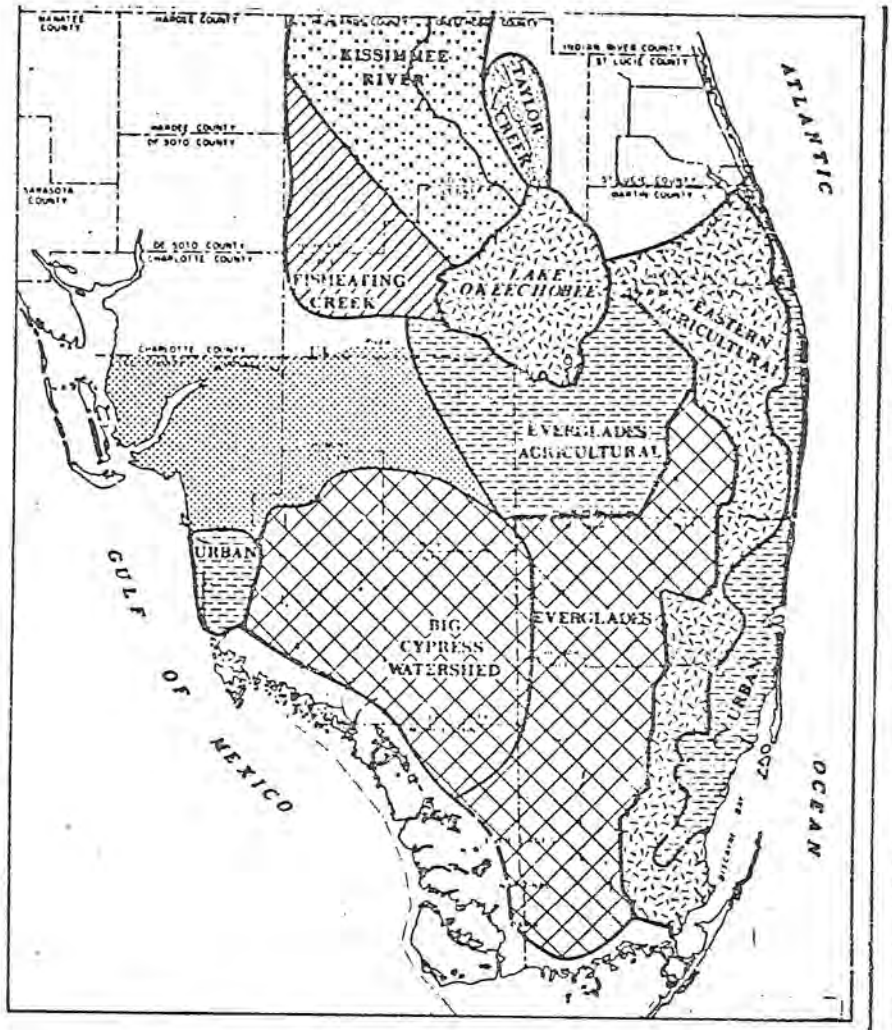
EXPLANATION:

DISSOLVED SOLIDS IN SURFACE WATER, MILLIGRAMS PER LITRE

- 0-100
- 100-200
- 200-300
- 300-400
- 400-500
- MORE THAN 500
- INSUFFICIENT DATA



DRY PERIOD (1962-65)



WET PERIOD (1966-69)

DISSOLVED SOLIDS (cont'd)

South Florida Water Management District Resource Center

How Water Quality is Affected

Water quality is affected by natural or man-made factors or combinations of both. Major natural factors are geology, topography, climate, and the natural biologic processes of plants, animals, and bacteria.

Geology and topography govern the depth and rate of water circulation over and through soil and rock and the extent to which minerals are dissolved by it. The circulation of water through the limestone of south Florida dissolves calcium carbonate, which hardens the water and increases its dissolved-solids content.

Climate, to a large extent, determines water quality. The distribution of rainfall in time is a key to changes in water quality. During dry seasons, water levels in canals are maintained by ground water, and the mineral content of the canal water approaches that of the more mineralized ground water. During wet seasons, the mineral content of canal water is reduced by dilution with heavy runoff of low mineral content.

In addition, plants, animals, and bacteria all contribute to water quality. Plants produce oxygen through photosynthesis. An ample supply of oxygen is essential for bacteria to degrade organic material, either natural or man-made. Fish and other animals consume these organic materials, often helping to suppress algal blooms.

The major man-made factors that affect water quality include land development and use, and water-management practices.

Agriculture results in wastes, which eventually enter the water system by runoff or by infiltration into the ground. Irrigation commonly adds to the mineral content of water. Irrigation water of poor quality may be sprayed or otherwise applied to the land. Many of the minerals left on the land surface by evaporation are eventually washed into canals by runoff. In general, most agricultural wastes degrade water quality.

Urbanization affects water quality, usually in adverse ways. Sewage dumped into canals and runoff that flushes relatively impervious areas, such as parking lots and streets, of foreign materials, including oils and greases, degrade water quality. Industrial effluents, some of which contain potentially toxic contaminants, are discharged into canals or onto the land surface.

Virtually all water-management practices, including drainage, regulation of water levels and flow, and backpumping of surplus water, have some effect on water quality. Man's activities, of course, do not always degrade water quality; for example, the use of salinity-control structures retards sea-water intrusion in coastal areas. On the other hand, some of his apparently innocuous or beneficial activities may degrade water quality in a real sense. For example, control of fresh-water flow to estuaries may change the salinity of estuaries and, thereby, change biotic productivity. Routing of water from one area to another may upgrade the quality of the receiving water, but generally it downgrades the quality. Water quality is generally not the prime consideration in water routing.

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Past Water-Quality Conditions

Before man began to drain and develop land in south Florida, water quality depended almost entirely on natural factors, such as geologic and climatologic conditions, sea-water intrusion, and life processes of plants, animals, and bacteria. Water quality was then probably much the same in most of south Florida as it is now in the Big Cypress. Concentrations of various chemical constituents in water have changed little since 1962 in the Big Cypress area and probably changed little before that time. In effect, the Big Cypress can be used as an index of past water quality in most of south Florida and to show changes in other areas.

Dissolved-solids content is an indicator of the general water quality of a given fresh-water environment. Dissolved solids in the surface water of Big Cypress average about 250 mg/l and are mainly a function of the chemical characteristics of the underlying geologic formations and the small amount of fresher water (only from direct precipitation on the Big Cypress) available for dilution. The underlying limestone dissolves readily, thus rendering the water naturally high in dissolved solids and hardness. Water hardness, generally a function of calcium and magnesium content, averages 175 mg/l in the Big Cypress. Water whose hardness exceeds 180 mg/l is considered to be very hard.

Dissolved solids and hardness of water in the Big Cypress area are not indicative of natural water quality in the Kissimmee River and the Taylor Creek and Fisheating Creek basins. Those areas are underlain by quartz sand that does not dissolve readily. These areas are no longer in a natural state, but the data collected to date indicate that the average dissolved-solids content and hardness were appreciably below 100 mg/l in past years.

Concentrations of toxic metals, such as chromium, arsenic, lead, and mercury in the waters of south Florida have recently raised concern. Little of these toxic metals have been detected in the Big Cypress, however, and the trace amounts that were detected were well below recommended limits of the U.S. Public Health Service (1962) for drinking water. The only metals found in natural waters in south Florida are iron and manganese. Both are in concentrations below recommended limits.

Several nutrient elements are essential for life. Among the most important and most publicized nutrients are phosphorus and nitrogen. When these elements are abundant in water, they may cause excessive growth of aquatic plants, which can degrade the recreational and esthetic values of an area. Concentrations of phosphorus, as P, and nitrate, as N, are low in the Big Cypress, averaging 0.03 and 0.10 mg/l. The major source of phosphorus and nitrogen in the Big Cypress is probably decayed organic matter. Nutrients that are produced there are quickly utilized by the dense vegetation.

The natural processes of plants and animals help to determine the amount of dissolved oxygen, important in maintaining water of good quality. Dissolved oxygen is necessary for biota to flourish and for bacteria to break down organic materials. During daylight, plants produce oxygen through photosynthesis. To maintain life, the oxygen produced during the day must last through the night, when oxygen production ceases. In the Big Cypress dissolved oxygen concentrations are sometimes naturally lower than in other areas of south Florida because of the dense forest cover, which reduces penetration of sunlight, essential for photosynthesis. On occasions fish kills associated with low concentrations of dissolved oxygen have been reported in the Big Cypress.

The effects of organic pesticides in water have stirred much interest in south Florida. Pesticides were introduced ~~in~~ about 1940. They have been detected in the Big Cypress, mostly in sediment and biota, but in much smaller amounts than in most other areas in south Florida.

Although the water quality in the Big Cypress is considered to be little changed from the natural state, several factors certainly caused water-quality changes, even in the natural state. Variation in amounts of rainfall undoubtedly affected water quality in that during drought there was less water for dilution of mineral content, organic materials, and nutrients. Occasional intrusions of sea-water, especially during hurricanes, probably left surface waters higher in dissolved-solids content. Fires caused by lightning also had widespread effects at times.

Present Water Quality

Water quality in some areas of south Florida has significantly deteriorated, with respect to natural conditions, since man began to exploit the land intensively.

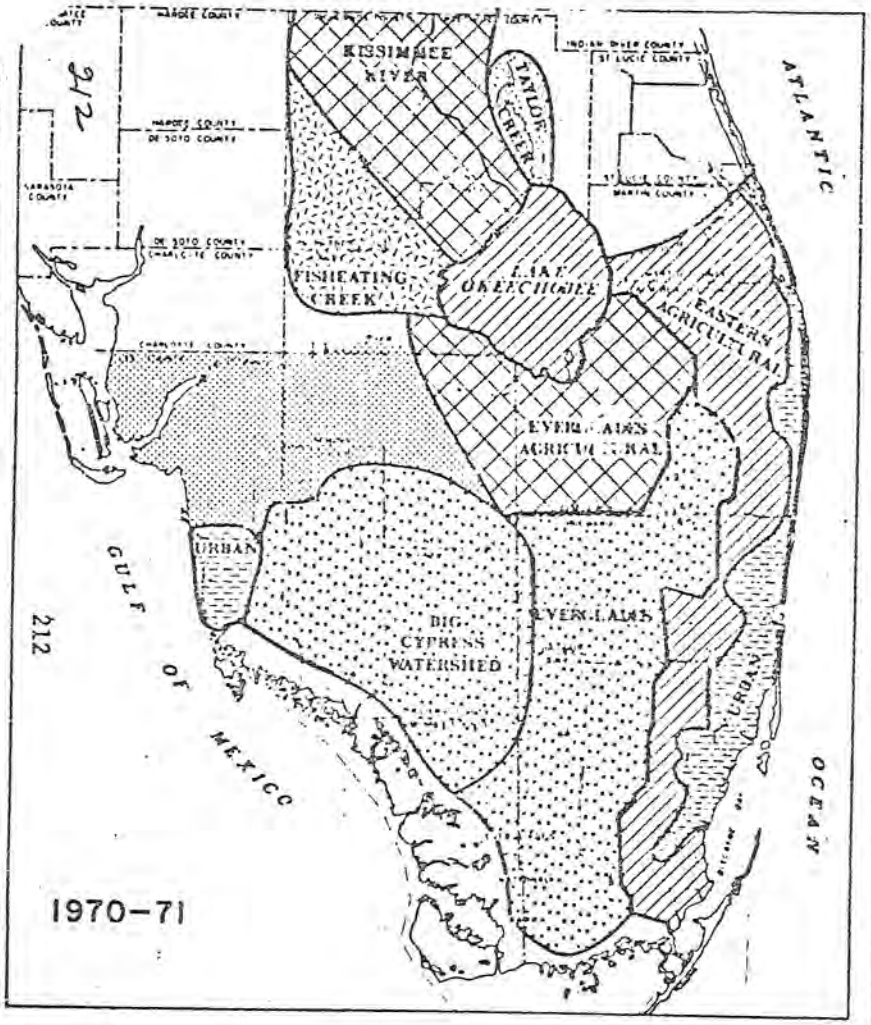
Water quality in the Lake Okeechobee subarea has been extensively degraded because of large-scale agricultural activities in the Kissimmee River and Taylor Creek basins and the Everglades agricultural area. Agricultural wastes, including large amounts of dissolved solids leached from soil exposed by cultivation and nutrients from animal wastes and fertilizers, are washed into canals during heavy runoff. During high-water periods, water is often backpumped from the Everglades agricultural area into Lake Okeechobee to reduce flooding. Average dissolved-solids content is higher in Taylor Creek and the Everglades agricultural areas than elsewhere in south Florida, excluding the salt-water areas. The average dissolved-solids content of Taylor Creek is 780 mg/l, more than three times the average in the Big Cypress. The relatively high dissolved solids content in the Taylor Creek and Everglades agricultural areas is partly the result of irrigating with highly mineralized water.

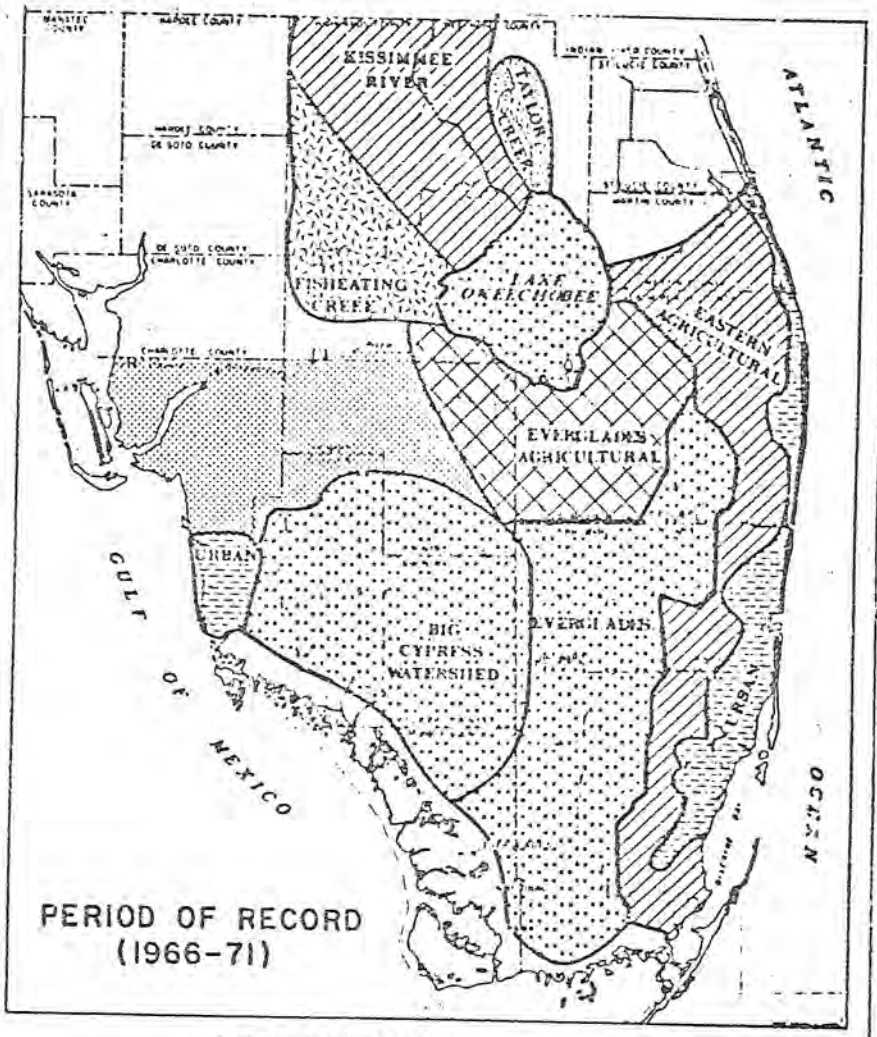
The rate of eutrophication of Lake Okeechobee is of major concern because it is the primary surface reservoir in southeast Florida. Overenrichment could seriously impair its water quality and could, thereby, affect downstream water users. Water quality and biologic data before 1970 indicate that the lake was in an early eutrophic condition at that time. A recent study by Joyner (1971), however, showed that the growth of algae increased greatly between January and July 1970. The dominant species also changed from a green alga, indicative of early eutrophic conditions, to a blue-green alga, indicative of late eutrophic conditions. The dominant algal species changed after a period of abnormally heavy rainfall and inflow from tributaries to the lake. Inflow was also increased at this time by the channelization of the Kissimmee River, the major tributary to the lake. As a result of channelization, water no longer moved slowly through the marshes into the lake, and nutrients in the water could no longer be utilized by the marshes. The growth of blue-green algae later subsided, but has generally remained well above the levels recorded earlier by Joyner.

That toxic metals are not prevalent in the Lake Okeechobee subarea is not surprising: toxic metals are more associated with industry than agriculture. Some trace amounts of lead, chromium, and other metals have been detected, but not in excess of recommended maximum limits.

Water quality in the Everglades subarea, which includes the water-conservation areas and most of Everglades National Park has not been extensively affected by land-use changes. However, water quality has changed where water from other subareas has been routed to the Everglades to alleviate critical water shortages. For example, dissolved solids and chloride have increased from water originating in or passing through the Everglades agricultural area. Water backpumped to the water-conservation areas from urban or agricultural canals has also changed water quality in the Everglades subarea.

Although concentrations of nitrate and phosphorus generally are not high in water in the Everglades, they become excessive at times, usually during droughts, when most of the marsh lands dry up, and all aquatic fauna are forced to the deeper water of ponds to survive. The wastes from these animals are concentrated in small areas and the nitrate and phosphorus contents of water are thereby increased to a great extent. Nitrate content is also increased by water distributed from the Everglades agricultural area.



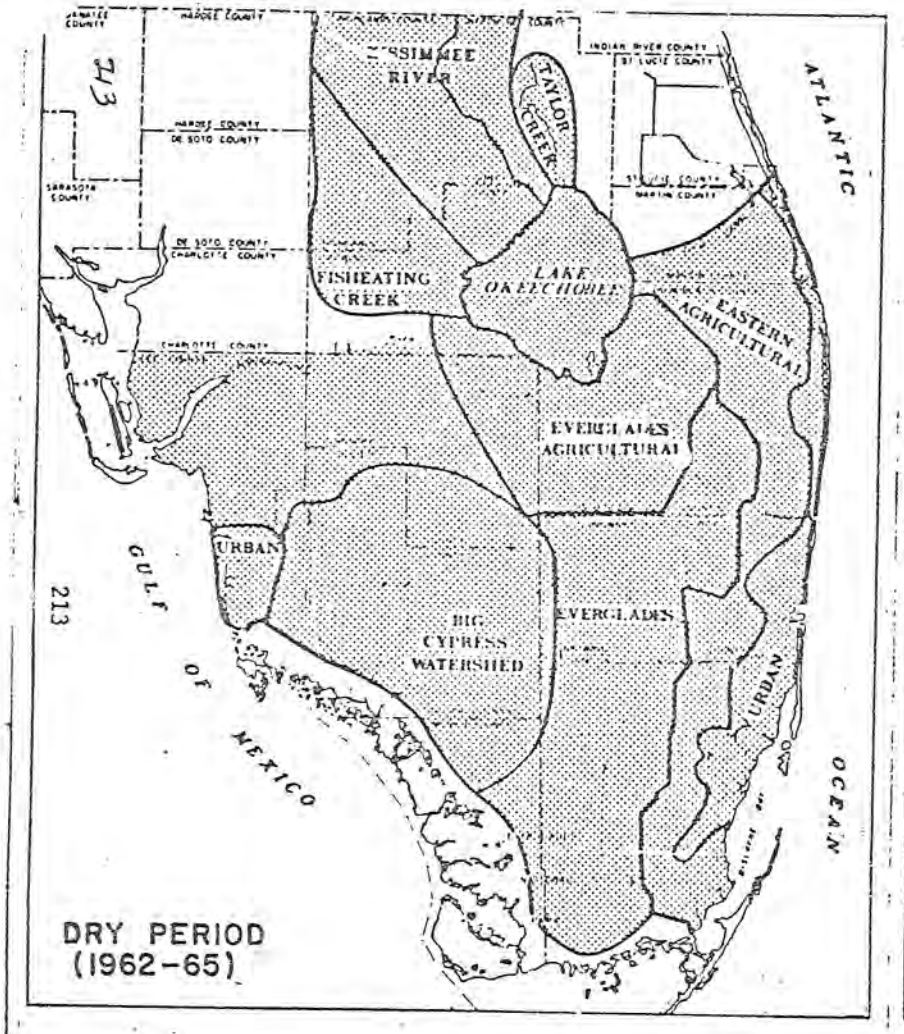


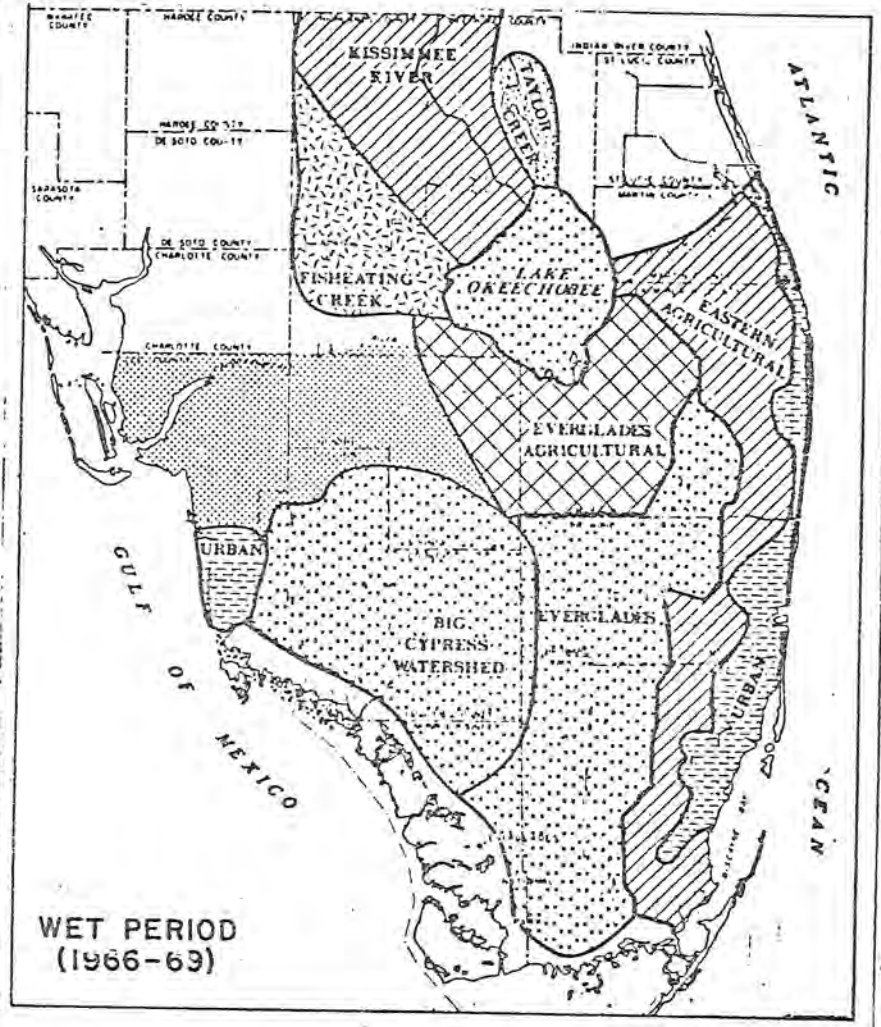
0 20 40 MILES
0 30 60 KILOMETRES

Orthophosphate (PO_4 as P) in surface water, in milligrams per liter.

EXPLANATION:
ORTHOPHOSPHATE (PO_4 AS P) IN SURFACE WATER, MILLIGRAMS PER LITRE

- 0.000-0.030
- 0.030-0.060
- 0.060-0.100
- 0.10-0.30
- 0.30-0.60
- MORE THAN 0.60
- INSUFFICIENT DATA



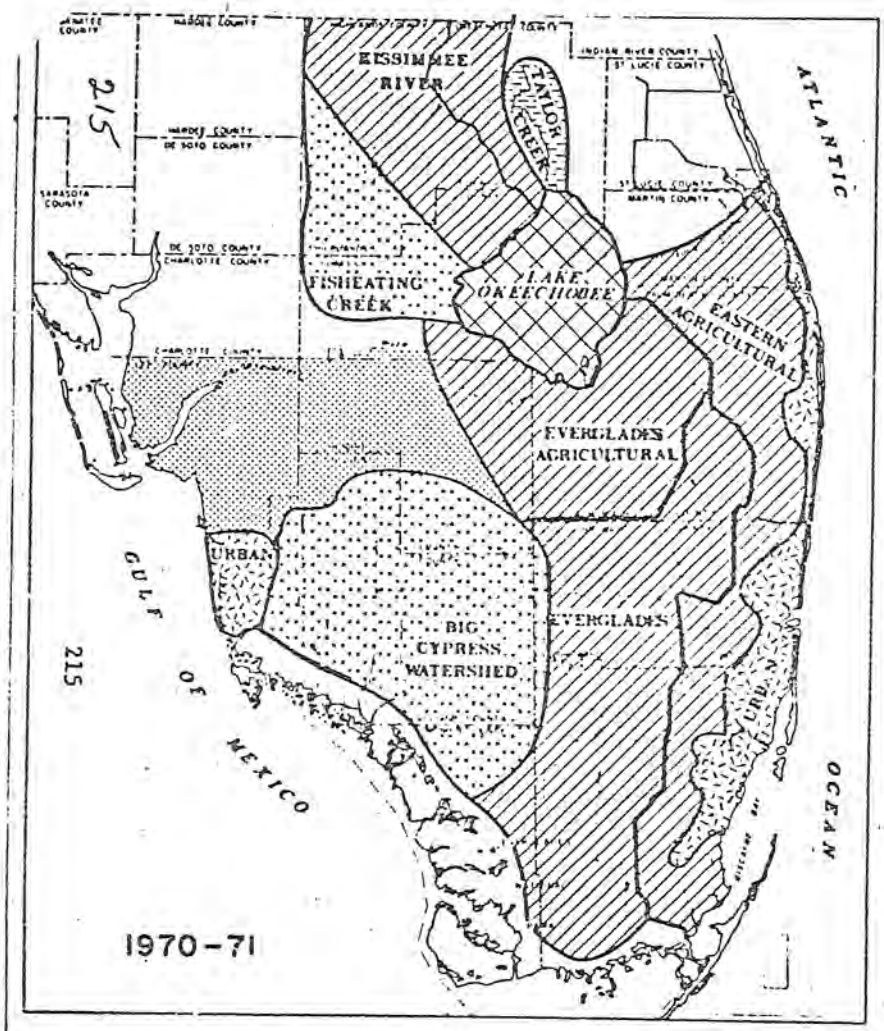


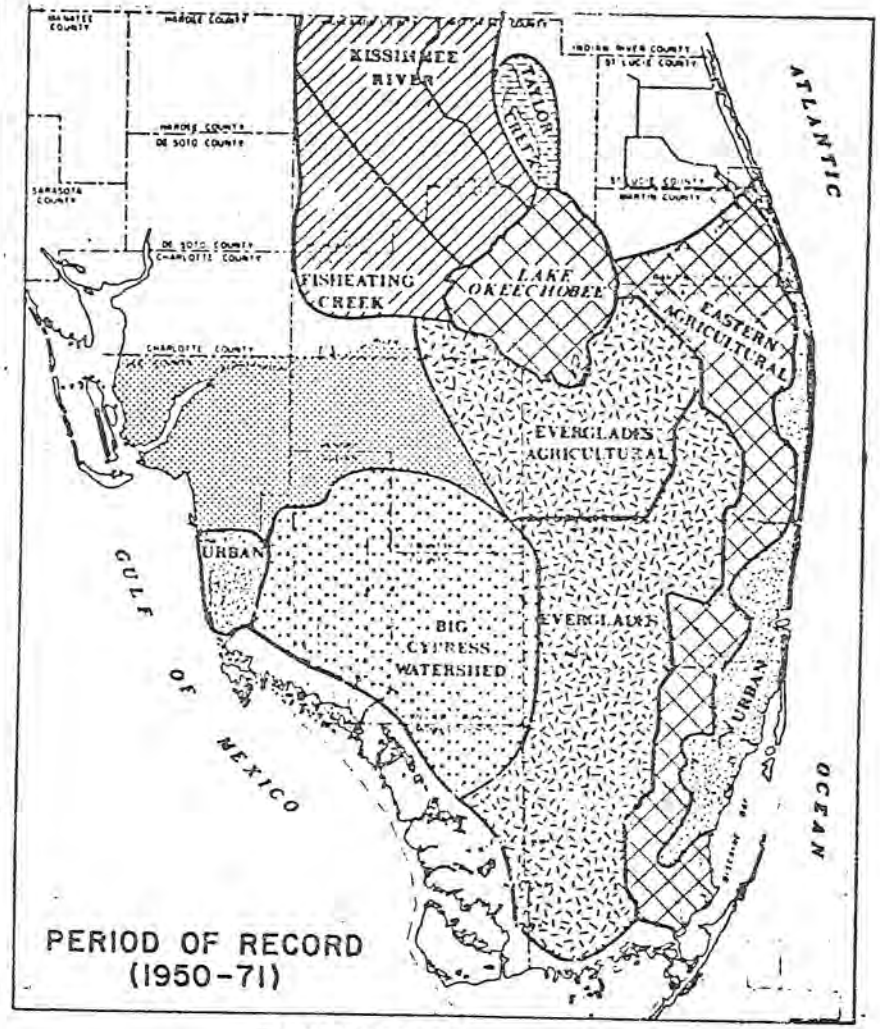
ORTHOPHOSPHATE (PO_4 as P)

(cont'd)

Dissolved oxygen content of water commonly becomes critical during droughts, when many aquatic organisms are crowded in small areas. Dissolved oxygen may be very high during daylight from photosynthetic oxygen production, but may be critically low at nightime, when photosynthesis ceases but demand for oxygen does not. Many fish kills have been caused by this natural phenomenon.

The east coast subarea, where degradation of water quality has been most noticeable in recent years, is composed of the urban-industrial and the eastern agricultural areas. The most apparent degradation has been in urban canals. During periods of low or no flow, many urban canals are covered with algae and scum and are choked with heavy aquatic growth, particularly water hyacinth. In addition, odors from the dead and dying plants are unpleasant. These conditions have been brought about through the discharge of partly treated sewage into canals. The sewage is high in nutrients. Average concentrations of nitrate and phosphorus in the water of urban canals were 6 to 15 times greater than that of the Big Cypress. Water in one canal in the urban area contained 125 times the average phosphorus content of Big Cypress water.



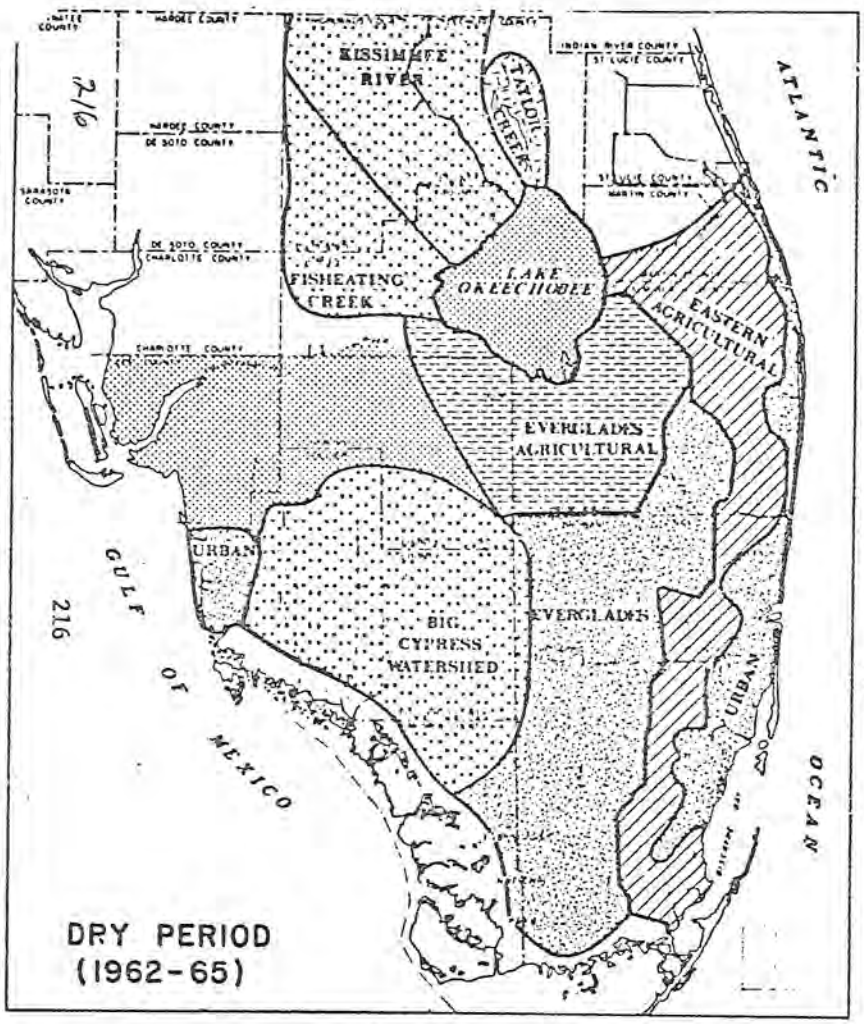


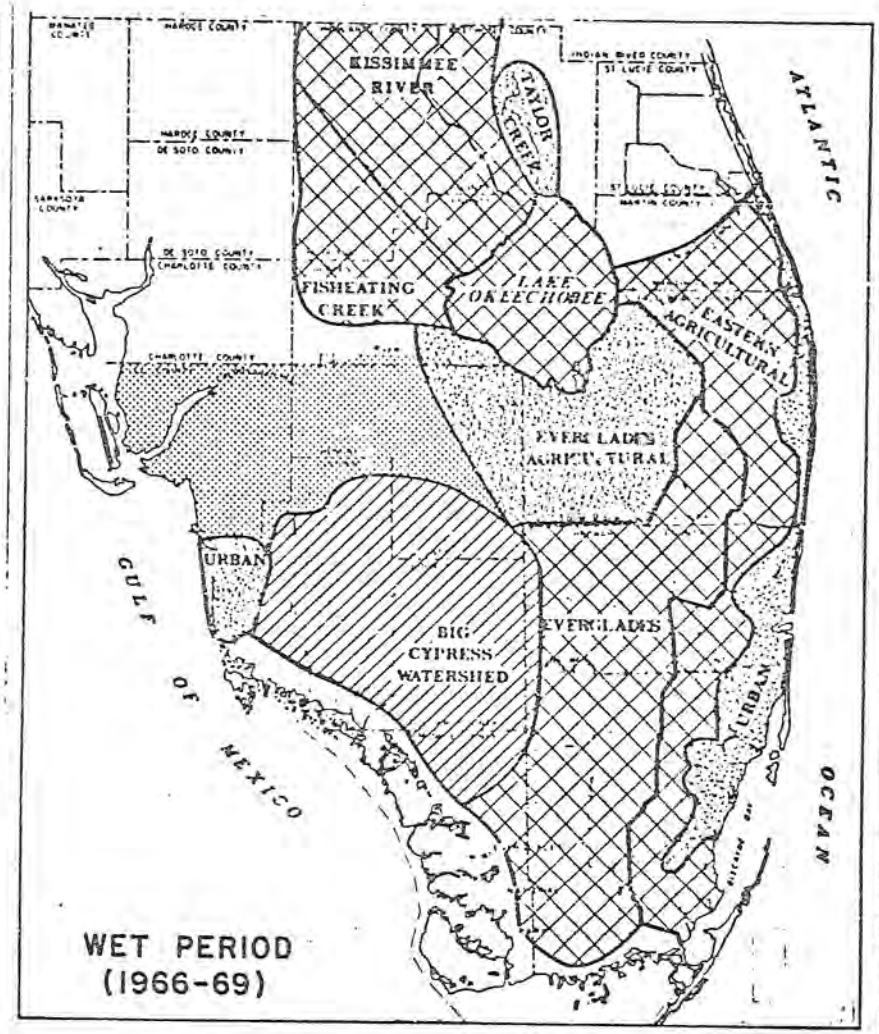
0 20 40 MILES
0 30 60 KILOMETRES

Nitrate (NO_3 as N) in surface water, in milligrams per liter.

EXPLANATION:
NITRATE (NO_3 AS N) IN SURFACE WATER, MILLIGRAMS PER LITRE

- 0.00-0.10
- 0.10-0.15
- 0.15-0.20
- 0.20-0.30
- 0.30-0.40
- MORE THAN 0.40
- INSUFFICIENT DATA





NITRATE (NO_3 as N)
(cont'd)

Rapidly expanding urbanization has increased the average dissolved-solids content of canal waters to about 400 mg/l, or about 50 percent higher than that of the waters of the Big Cypress. The increase in dissolved solids is mainly the result of storm runoff, which washes materials from parking lots, streets, and construction sites into canals. Included in the materials may be various kinds of debris, oils and greases, pesticides, and toxic metals.

Data collected in urban-industrial areas indicate that concentrations of toxic metals are clearly more prevalent there than in other areas. The toxic metals, lead and arsenic, have been found in water and sediment in concentrations above recommended limits. These and other toxic metals are extensively used in manufacturing, and some are included in waste products discharged into waterways, where they may enter the ground-water system and the public water supply.

An ample supply of dissolved oxygen in water is most important for water of good quality, especially in urban areas, where the decomposition of sewage depends on it. In many badly polluted canals, dissolved oxygen is very high during the day because of the tremendous growth of plants that are nourished by nutrients in the sewage. During the night, however, dissolved oxygen may approach zero, as all the oxygen is depleted to oxidize sewage. This is the reason that many urban canals often lack popular sport fish, such as bass, and are inhabited, instead, by other fish, such as gar and mullet, which are able to tolerate low dissolved oxygen in water.

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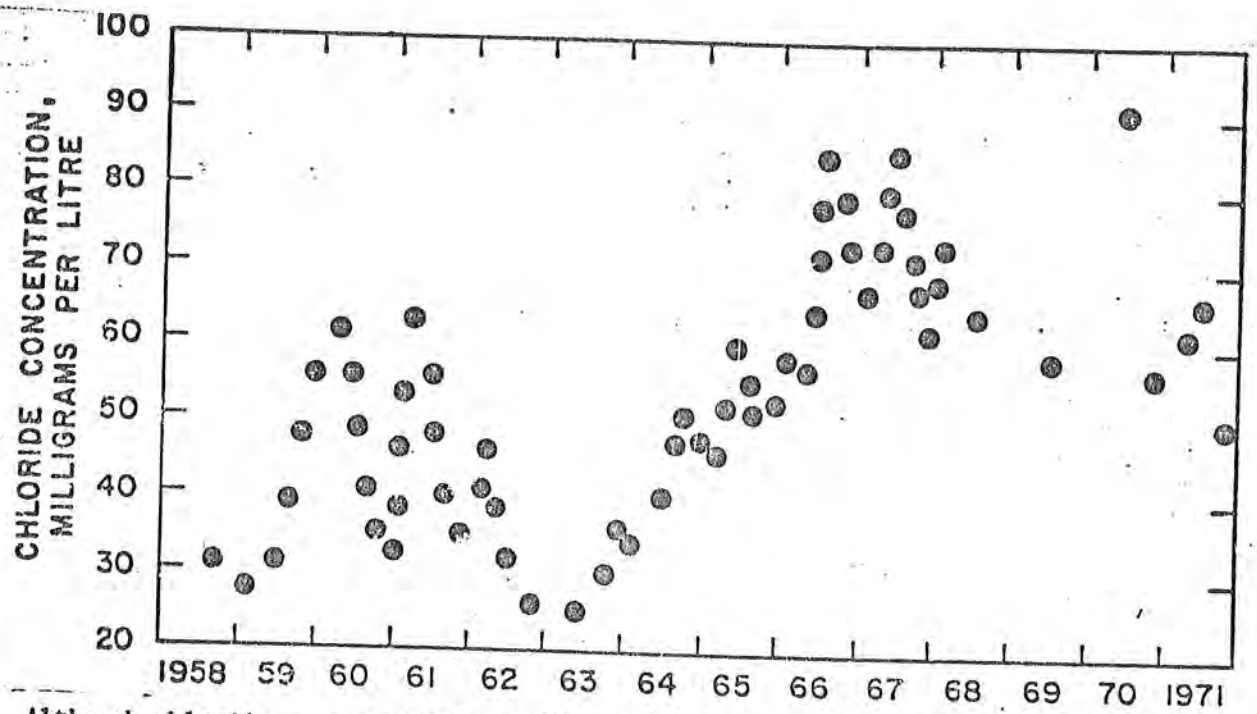
Projected Water Quality

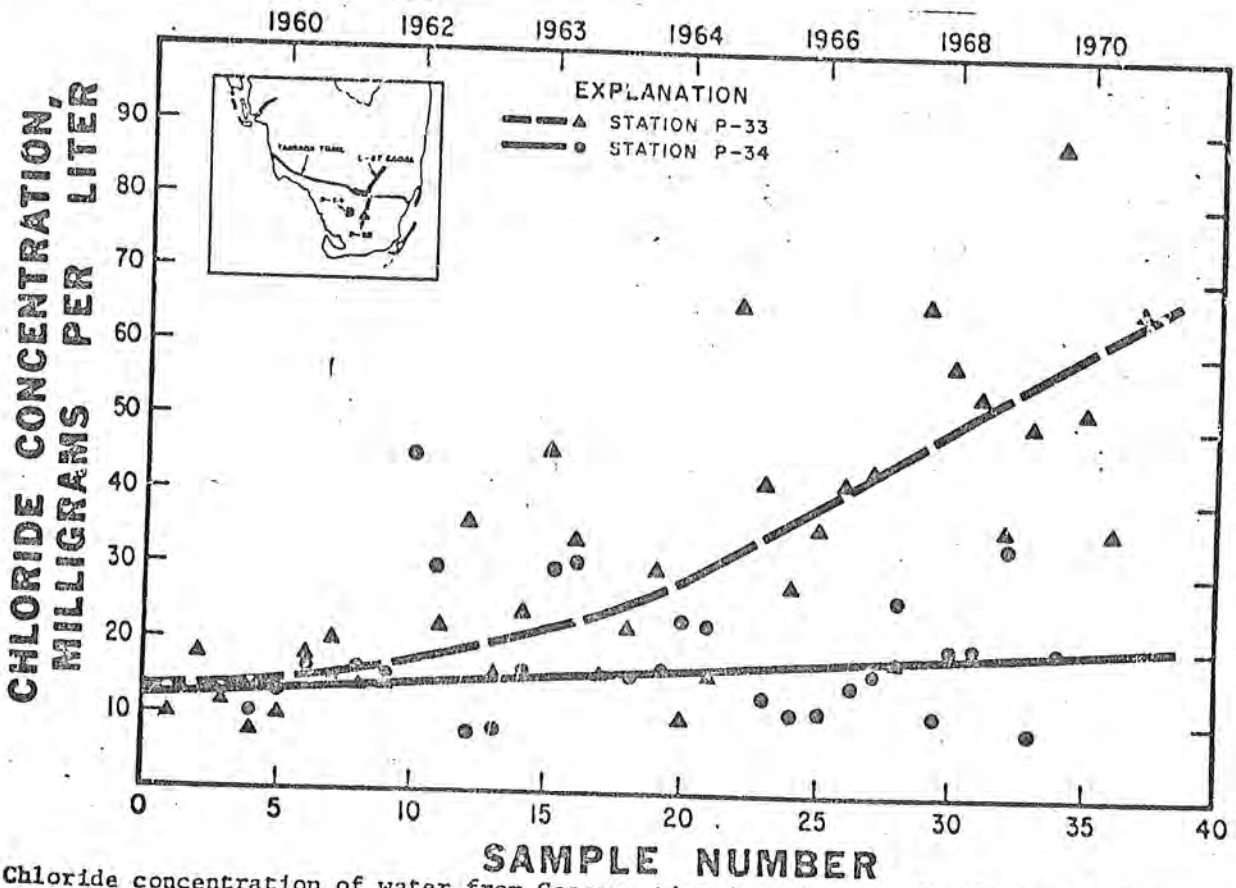
The quality of water in south Florida has changed over the years. In many areas water has become unfit for human consumption, unless it is extensively and expensively treated.

Water quality in South Florida depends largely on land use and human activity -- agriculture, urbanization, and water management -- primary factors in assessing future water quality.

Water control in the Everglades agricultural area will probably most affect the quality of water in other areas in the future. Water in this area is of poor quality and is not expected to improve in the future, as agricultural acreage in this area is not expected to decrease. Water is pumped annually from the Everglades agricultural area to Lake Okeechobee and the conservation areas, some eventually reaching the urban coast. The demands for water have been increasing, especially during droughts, and are expected to increase even more as urbanization increases. The time-trend analysis of chloride concentration from 1958 to 1971 at the Miami Canal east of Levee 30, shows how water from the Everglades agricultural area has raised the chloride content of water in other areas. The increase has accelerated since 1962, when the pump stations at the south side of the Everglades agricultural area began operation.



Although chloride concentration in Miami Canal east of Levee 30 has fluctuated, it has been generally higher since 1962.



Chloride concentration of water from Conservation Area 3 at a site in Everglades National Park (P-33) has increased; however the concentration in water at another site (P-34), originating in the Big Cypress has shown little change.

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Water movement from the Everglades agricultural area has also increased the average chloride concentration at station P-33 in Everglades National Park from 10 to 70 mg/l since 1959. Chloride concentration at station P-34, about 20 miles west of P-33, has not increased similarly as most of the water flowing by P-34 is from the Big Cypress.

Lake Okeechobee is in an early state of eutrophication. Nitrate and phosphorus entering the lake encourage plant growth. Most of these nutrients are derived from animal wastes from cattle feedlots in the three tributary areas to the lake and from backpumping of agricultural water. Water-management officials realize that nutrients in these streams, especially in Taylor Creek, have become excessive in recent years, and holding ponds have been constructed to intercept drainage from feedlots. Vegetation in these ponds possibly will consume most of the nutrients before they reach the waterways.

The east coast subarea has increased greatly in population in the last 10 years. Water quality there has also generally deteriorated. For example, the average dissolved-solids content of surface waters in the urban area has steadily increased from 350 to 410 mg/l. The trend is likely to continue as urban development increase. Dissolved solids also increased in the eastern agricultural area. That increase is partly the result of the westward urban expansion, not by increased agricultural activities. Much of the land in the eastern agricultural area south of Palm Beach County will probably become urban in the future.

Conclusive trends in concentrations of nitrate and phosphorus in surface waters in the last decade in the urban area are not indicated, but concentrations of nutrients could decrease as water problems caused by them become more painfully evident and if remedial actions are taken. Advanced treatment for removal of nitrogen and phosphorus could reduce the nutrient content of water in urban canals.

Concentrations of toxic metals and pesticides have shown no conclusive trends within specific areas. Short-term records indicate, however, that toxic metals are more prevalent in urban industrial areas, and that pesticides are found in higher concentrations at or near agricultural areas.

Pesticides

The use of pesticides in south Florida has undoubtedly reduced the number of rodents, weeds, and insects. The widespread and abundant use of chlorinated hydrocarbon insecticides, however, raises questions as to whether they are entering the waterways in significant quantities, and what effects they might have on humans and wildlife.

Pesticides reach waterways mainly by dustfall and rainfall. Most are applied by sprays, which disperse into the atmosphere to form nuclei of raindrops or to collect on dust particles. Wind currents can then convey them far afield. Pesticides also enter water bodies by spillage and overland runoff.

Data collected from many areas in south Florida indicate that pesticides concentrations in water are generally low. Pesticide concentrations in canal sediments are considerably higher because most pesticides of the DDT family are relatively insoluble in water. For example, some soil samples underlying marshes in the Everglades had concentrations of the DDT family (DDT, DDD, and DDE) as much as 1,000 times greater than the surface water. The data also showed that concentrations of DDT tend to increase and to accumulate in the higher orders of the Everglades food chains and in omnivorous marsh-dwelling crustaceans. Marsh fish, intermediate in Everglades food chains, concentrated these compounds as much as 10,000 times greater than residues in the water. The highest concentrations of the DDT family were found in the higher carnivores, such as the alligator, eagle, and Everglades kite.

A study of pesticides at 10 sites in the conservation areas showed that concentrations of DDT were extremely low in water samples from sites near agricultural lands and in marsh lands remote from agricultural lands. Sediment and fish samples in the conservation areas clearly indicated that DDT concentrations were much more prevalent near agricultural areas. DDT concentrations in sediments at sites influenced by agriculture averaged 53 μg/kg (micrograms per kilogram), whereas those more remote averaged 31 μg/kg. The difference was most pronounced in fish samples. The average DDT concentration in fish near agricultural areas was 340 μg/kg, whereas in areas more remote it was 70 μg/kg. The data not only show that concentrations of DDT are higher in areas influenced by agricultural activities but also, as in the previously mentioned study in the Everglades, that DDT is more concentrated in organisms in the higher orders of the food chain.

Concentrations of the DDT family in water, soil, and small fishes in the Everglades (Kolipinski and Higer, 1969).

Component	Sum of DDT+DDD+DDE in Parts per Billion
Surfacewater + groundwater	
Fresh and estuarine	0.02
Rainfall	0.08
Marsh soil	40.
Algal mat	200.
Small fishes	500.

Biomagnification of DDT Family

For comparison, average concentrations of DDT in sediment and fish samples collected at Miami International Airport, an urban-industrial complex, were 34 and 160 μg/kg, intermediate between average concentrations in agricultural areas and areas not significantly affected by agriculture.

The toxic effects of pesticides on humans and wildlife are not clearly known. It is known, however, that most pesticides are not easily broken down into nontoxic compounds and that they accumulate in the fatty tissues of both humans and wildlife. For example, a human being (top of the food chain) may easily accumulate and retain pesticides in fatty tissues by eating fish or meat from animals whose systems have accumulated pesticides.

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Much of the known information on the effects of pesticides comes from the study of birds. Many aquatic birds, including egrets, herons, and gulls, have died of insecticide poisoning. Some species of falcons, hawks, and eagles have laid eggs with abnormally thin shells. Experimental evidence shows that DDE, a metabolite of DDT, reduces the birds' ability to produce calcium for egg shells, thereby causing premature breakage and consequent loss of chicks.

Many birds and other animals native to the Everglades are presently on the rare and endangered species list. The buildup of pesticides in the Everglades may increase the length of this list and also cause some to become extinct.

In recent years, another chlorinated hydrocarbon compound, PCB's (polychlorinated biphenyls), has been detected in increasing concentrations in water, sediments, and fish in south Florida. These compounds, basically, have the same toxic effects on wildlife as pesticides, but, in addition, evidence indicates that PCB's have two distinct effects on human beings, adverse skin effects and toxic effects on the liver.

PCB's are used primarily in industrial operations and not as pesticides. They are commonly used in insulation of electric wiring and as ballast for fluorescent lighting fixtures and as additives in adhesives, formulation for epoxy paints, and carbonless reproducing paper.

Although PCB's have been found in trace amounts in the Everglades and the Big Cypress, they are most prevalent in the industrial areas. A fish sample collected adjacent to the Miami International Airport contained as much as 1,000 μg/kg of PCB's. PCB's can enter the ground-water system in urban areas and eventually find their way into the drinking-water supply.

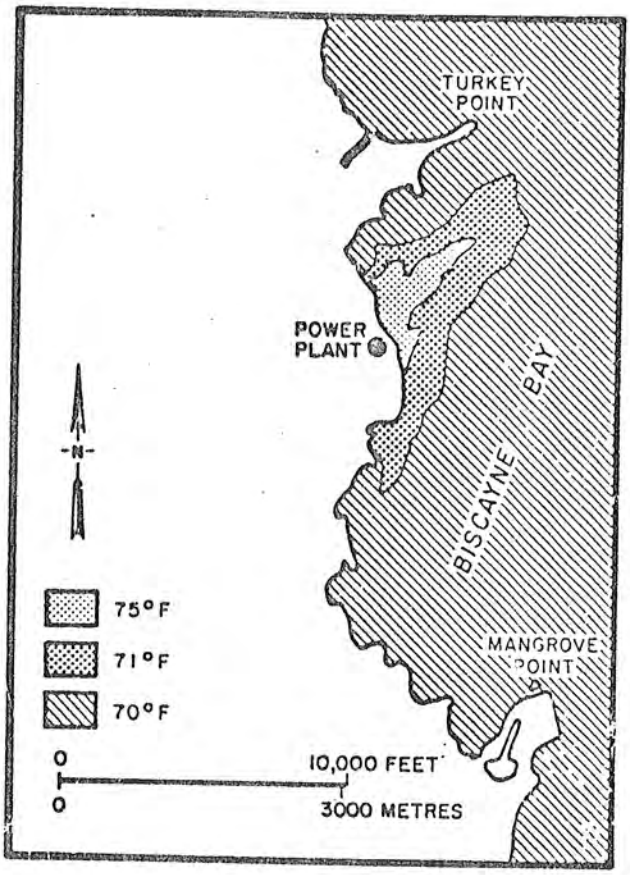
Chlorinated hydrocarbons were never part of natural water. Despite all efforts to protect the water supply, as to quantity, quality, and availability, the precautions may be worthless if the destructive effects of biologically concentrated chlorinated hydrocarbons prove to be overriding. Their presence in the environment of south Florida is a potential threat not only to wildlife but to human beings as well.

Thermal Loading

Heat is introduced to water primarily from electric-power production. Electric-power production in the United States doubles every 10 years. This fact, along with the trend toward larger nuclear power plants, which create 50 percent more heat per unit of power than fossil-fuel plants, will result in a rapidly increasing introduction of heat to the Nation's waters.

In south Florida, the major area of release of heat has been the south Biscayne Bay area. Two fossil-fuel power plants are operating at Turkey Point in south Biscayne Bay, and two nuclear plants began operations in 1974. The fossil-fuel units require 1,270 cubic feet per second of water for cooling. The predicted maximum rise in water temperature across the condensers is 9°C (16°F.). Because Biscayne Bay and adjacent waters are shallow and circulation is poor, heat from the power plant is not readily dispersed to the ocean. High temperatures, to 33°C (91°F.), are natural in the bay during July and August. The additional heat from the power plant may increase temperatures during the summer to levels that could affect the ecosystem of the bay.

Many species of plants and animals in semitropical waters, such as Biscayne Bay, are living within a few degrees of their thermal mortality range. The release of waste heat during the critical summer period could increase water temperatures beyond the upper limit of their tolerance range.



A heat plume is formed when heated water is discharged into a cool water body.

Investigations by the University of Miami and the Environmental Protection Agency show that the release of heat from the fossil fuel plants has locally affected the biota of south Biscayne Bay. Plankton, benthic algae, sea grasses, benthic invertebrates, and fish were affected by elevated temperatures near the discharge area. The most obvious effects were a decrease in the number of algal species and the death of sea grasses over several hundred acres of bay bottom. In general, animals were adversely affected by temperatures above 33°C (91°F).

To reduce the amount of heat released to the bay, an extensive closed circulating system of cooling canals was constructed that has a water-surface area of 4,000 acres. The cooling-canal reservoir was in use in 1974.

ALTERNATIVES FOR DEVELOPMENT

Regional Planning Versus Uncontrolled Growth

Society has many diverse resource needs, including water, power, food, and land. Increasing the availability of one resource, usually results in growth, and, thereby, the other resources are taxed. With growth, society requires not only more resources but also more parks, schools, sewers, law enforcement, and transportation. The ability to supply these needs is affected adversely by growth, particularly if the growth is unplanned. Random land development without regard for the long-term usually results in ecologic disturbances. For example, excessive drainage and development of land may eliminate vital biologic and hydrologic areas.

To avoid or minimize economic, social, and ecologic disruption, growth can be controlled by limiting population density. Population density can be controlled by limiting the necessary resources. For example, Odum (1971) suggested using the production of electric power as a limiting resource. Because it takes power to supply the other resources and the necessary public services in society, restrictions on power will restrict the use of other resources. Population density might also be kept low by restricting drainage. This doubtless would be a more practicable means of controlling population density because legislation for effective drainage control already is in existence. Further, Florida's history shows conclusively that wet lands are not amenable to development until they are drained. No one wants to live in a swamp. Yet, after that swamp has been drained it becomes a housing development overnight.

Land zoning could be made a useful tool in controlling growth. Zoning consists of assigning land to a specific use and population density. If zoning is regional, based on long-term public costs of resources and services and not subject to variances for special interests, it can be effective in controlling random growth. Unfortunately, however, regional growth has been haphazard. Land zoning has been ineffective in solving the problem of unplanned growth and preserving a quality environment because it has been based on local political boundaries, rather than ecologic boundaries, and on short-term economic benefits, rather than long-term ones. Growth has been encouraged by a supply of resources, including water, power, and land, that have been made increasingly available through public-financed management practices and through private speculation and development.

In September 1971 the Governor's Conference on Water Management recognized the need for and proposed a plan that places a limit on growth and development to halt or decrease social, economic, and ecologic disruptions in South Florida. Implementation would require restrictions on the use of some resources and efficient management of all resources. In recognition of the desire to maintain a quality environment the conferees concluded, "The State and appropriate regional agencies must develop a comprehensive land and water use plan with enforcement machinery to limit population." They further stated, "The population level must be one that can be supported by the available natural resources, especially water, in order to sustain a quality environment."

Urban and suburban renewal offers alternatives for present patterns of growth and development. Renewal would utilize construction industries, but would de-emphasize modification of the natural ecosystem. Based on ecologic planning, it would provide better living conditions in much of the urban-suburban community. Renewal could include modification of all aspects of the urban-suburban system, including transportation, sewage treatment and disposal, recreation, dwellings, and business centers. Impoverished areas could be first to be renovated, in accordance with an environmental design that emphasizes green belts, minimal motor traffic, sanitary conditions, and esthetically pleasing surroundings. Renewal would fulfill two important functions in a regional plan. It would provide jobs and really use and enhance the environment in an impoverished area--the city.

Reduction of Water Losses to the Ocean

As much of the south Florida environment is aquatic, permanent changes in water levels, water quality, or periods of inundation change the ecosystems. The water drained to accommodate urban and agricultural growth is water that might have been available to satisfy the demands of the growth. Measures have already been taken by water-management agencies to curtail water loss to the ocean, and these measures have in the past successfully protected the water resources of the system. Despite these measures, the Corps of Engineers (1968) predicted a water shortage in southeast Florida by 1976, unless the storage capacity of the system was increased and loss to the ocean was decreased. The curtailment of water use during the waning weeks of the 1970-71 dry season made the people of southeast Florida aware of the need to develop long-range plans for satisfying future water demands.

Fresh-water losses to the ocean can be further reduced in some places by adjustments in timing of control-structure operations; by adding secondary control structures in some canal systems upstream from primary coastal structures; by raising usual water-control elevation in selected canals; and by implementing plans for backpumping part of the excess storm water into conservation areas (Leach, 1972). Several other alternatives are: installation of impermeable canal liners upstream from control structures, providing for underground storage of excess storm water, construction of control structures on presently uncontrolled reaches of canals, and relocation of control-structure sites nearer to the coast.

Adjustments in timing of control-structure operations can be implemented only after careful study of past operations. Basically, however, this alternative suggests earlier closure of control structures after rainfall and less frequent releases.

Secondary control structures would provide several beneficial results in certain canals having only coastal salinity controls. Present steep canalward ground-water gradients in inland areas increase water pick-. by canals, causing water to move eastward to coastal salinity-control structures, where it must be released. Secondary structures in canals would rai.. .ater levels in inland reaches and would, thus, reduce hydraulic gradients to canals. The reduction would delay runoff from upstream reaches and would permit retention of greater quantities of water in upbasin storage, over and above the quantities already being stored in canals and aquifers upstream from coastal control structures. Secondary controls would also permit local recharge to large well fields, provided the structures are properly placed.

At some control structures, gates may be set lower than necessary. Raising of control levels as high as feasible for local conditions may make more storage capacity available.

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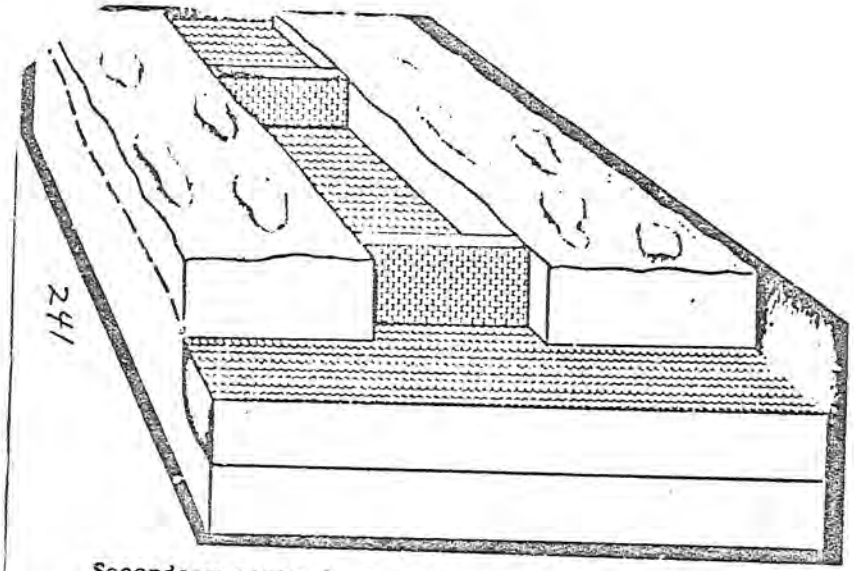
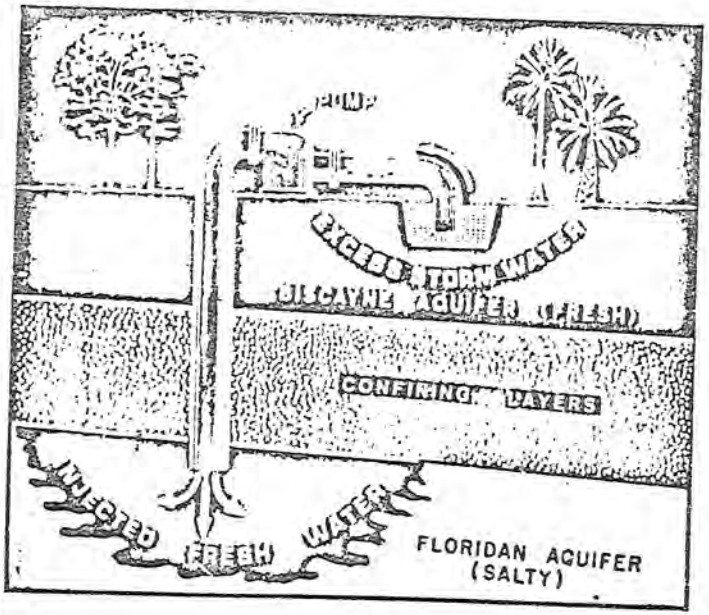
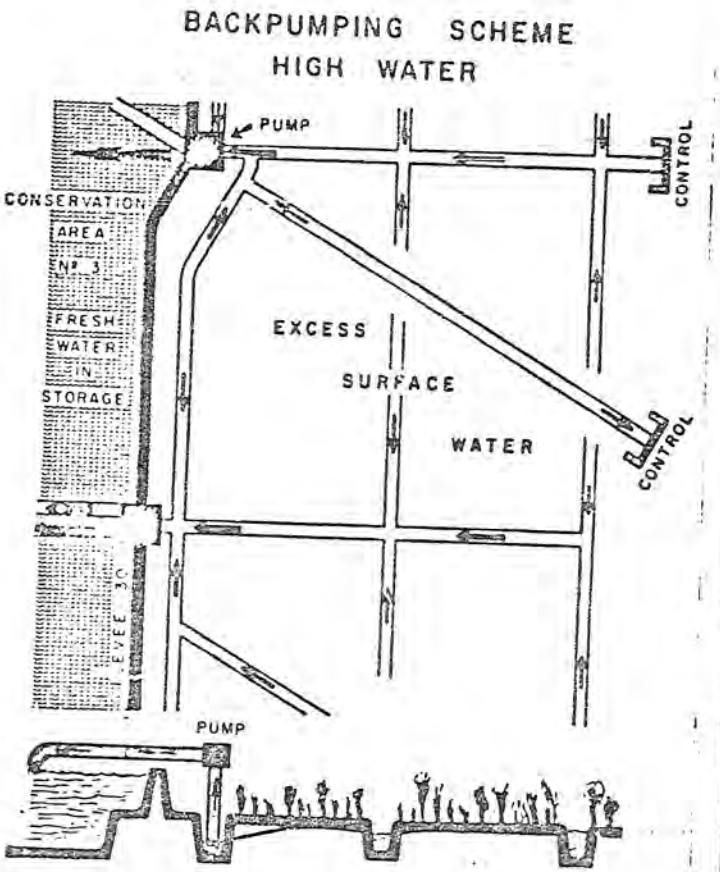


Secondary control structures in canals would step up water levels, regulate flow to downstream reaches, and increase upstream canal and aquifer storage.



Excess storm water might be stored underground by pumping it from inland canals into the Floridan aquifer.



Backpumping excess storm water from inland canals into conservation areas would conserve fresh water.

Several plans for removing excess water from many canals have been advanced. These involve backpumping water into conservation areas rather than opening coastal control structures. The alternative of backpumping has met with approval, and the principle of backpumping is effectively used during excessive runoff along the south side of Lake Okeechobee. The quality of the backpumped water, however, would be an overriding factor.

Considerable amounts of fresh water are lost by automatic operation of some coastal control structures. The structures are opened by the presence of excess water resulting from ground-water pickup by interior reaches of canals. Secondary control structures have been built in several canals to retard downstream flow of excess water, but in areas of highly permeable limestone much water seeps around secondary control structures. Impermeable linings or grout curtains flanking secondary control structures could reduce seepage. Studies by the C&SFFCD suggest that most of the seepage occurs within a few hundred feet upstream from the secondary structure on Black Creek Canal (Canal 1) in Dade County, an area of highly permeable limestone. By making part of the upstream reach impermeable, seepage could be reduced, and wastage through automatic operation of coastal structures could be decreased (Leach, 1972).

An alternative to backpumping excess water into conservation areas would be to pump it into the artesian Floridan aquifer. Part of the water stored underground, through deep wells, could be recovered in subsequent dry periods. The hydraulics of injection and recovery of excess storm water are the same as those for disposal and recovery of treated sewage injected into deep artesian aquifers. Water in the upper part of the Floridan aquifer is brackish. Fresh water injected into this part of the aquifer will tend to float on the denser brackish water. Because the aquifer is artesian, the fresh water could be recovered by natural flow. Study will be required, however, to determine the feasibility of injecting and recovering fresh water from the Floridan aquifer.

Water management has effectively reduced fresh-water losses to the ocean. Further management may further conserve much-needed fresh water.

Wastewater Management

In recent years, considerable study and increased public attention has been focused on the problems associated with wastewater disposal. Improper management of liquid waste, of course, can be hazardous to public health and to the environment. Most waste water, however represents a recoverable resource.

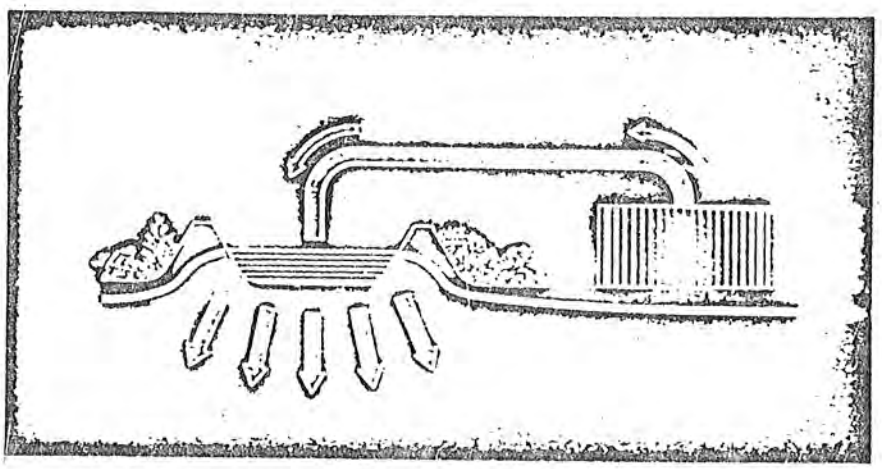
An average of about 200 million gallons of wastewater was collected in sewer systems each day in 1970 by the seven counties in south Florida. Ideally, this would represent an additional large resource that could be treated and reused beneficially. Much of the liquid waste is, of course, treated. But, how well is it treated? How is it reused? An honest answer, to the first question would be "not too well," and to the second, "not too wisely." Neither answer can possibly please nor compliment a society as technologically advanced as ours.

Master plans for several counties have recommended centralized sewage-collection systems, secondary treatment, cessation of disposal of liquid waste in inland canals, and disposal of all sewage into the ocean. These recommendations provide for more complete treatment but do not provide for the conservation of the potentially recyclable liquid resources. Alternatives may provide means for reducing contamination of south Florida's water resources while conserving water needed for controlling sea-water intrusion, maintaining high water levels, and for recharging shallow aquifers.

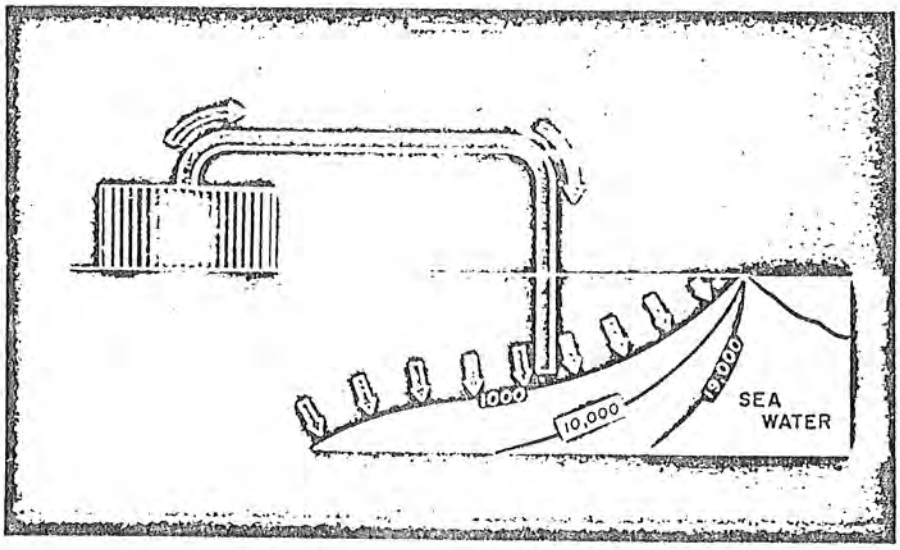
Septic tanks, the object of considerable controversy, provide an inexpensive means of disposing domestic sewage. Preliminary results of two separate studies in Dade and Broward Counties indicate that use of septic tanks in low-density areas is fundamentally safe, when the units are properly maintained. Septic tanks have one other quantitative advantage -- they return water to the aquifer. High density areas require sewers; at present not all are sewered, and constructing the required sewers will take significant effort. Waste from high-density areas needs to be adequately treated, the degree governed by the location and method of disposal.

Several pilot projects are being developed for investigating the feasibility of injecting secondary treated wastewater into wells penetrating the deep part of the Floridan aquifer. This would probably be a safe means of disposal, but the effluent is removed from the fresh-water part of the hydrologic system. The potentialities of recovery of the injected wastewater are unknown because the limestone is highly cavernous. Discharge of effluent into the cavernous zone may eventually result in indirect disposal to the ocean, as the zone is probably connected to the ocean several miles offshore. Large quantities of treated sewage disposed to this zone, however, may displace much of the salt water presently stored there and could be recovered, and used, after further treatment, in water-short periods.

Wastewater given secondary treatment, then special treatment for removal of phosphorus and nitrogen, could be disposed of in special ponds. Such disposal will be tested in Broward County. The ponds are formed by encircling an area with a levee. Treatment-plant effluent will be pumped into the enclosures and allowed to seep through the soil cover into the aquifer and through a levee. This disposal system could be modified by providing a septic-tank type of drainfield within the enclosure, thus permitting direct recharge of the shallow aquifer. Both of these systems provide for additional natural cleansing by infiltration through soil and limestone, by absorption by plants, and by utilization by fish and other animals. By locating disposal ponds remote from any withdrawal point, the threat of contamination would be minimized.



Highly treated waste water might be pumped into levee-enclosed ponds.



Highly treated waste water might be injected into a series of shallow wells near the coast to retard sea-water intrusion.

Wastewater provided with secondary treatment and adequate chlorination for destruction of harmful bacteria might be disposed of, to advantage, by land spreading. Effluent from the treatment process is spread on a tract of land where vegetation can remove organic constituents.

Water similarly treated might be effectively used for irrigation, as it is on several golf courses in Broward County. Treated water might also be used to irrigate crops, the organic constituents acting as fertilizers.

It is also possible that treated wastewater, a contaminant, can be used to combat sea-water intrusion, another contaminant, in the coastal regions. Liquid wastes that have received tertiary treatment, including removal of nitrogen and phosphorus, could conceivably be injected into shallow aquifers through a network of wells near the coast. The water would act as a deterent to intrusion by saline water in the same manner as other fresh water. As in all the previously discussed alternatives, this use of treated effluent would furnish water to recharge the shallow aquifer of south Florida's coastal areas.

Two other alternatives might be considered for disposal of wastewater that has received a minimum of tertiary treatment, denitrification, and phosphorous removal. First, the effluent could be injected into the shallow aquifers, inland from the coastal urban areas. The injected water would raise water levels in the aquifers and also the shoreward water-level gradients, which would ultimately aid in abating sea-water intrusion and in recharging the aquifers from which municipal water supplies are withdrawn.

The second alternative would allow this treated water to be discharged into inland canals instead of into wells. The additional water would help control sea-water intrusion by maintaining sufficiently high water levels in the canal and would be available for use during prolonged drought. Injection of tertiary treated waste water into the shallow aquifer or discharge into the canal might result in risk of contamination by viruses and carcinogens.

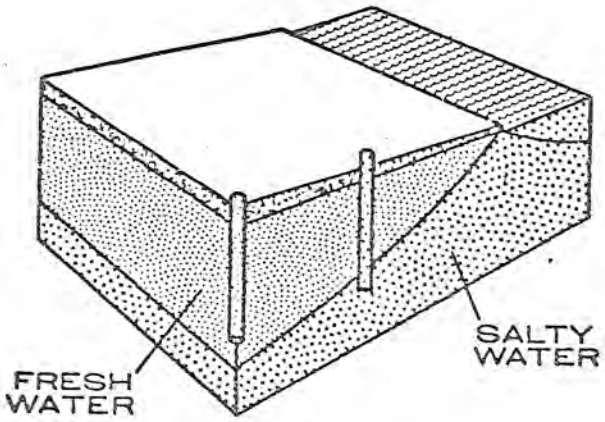
The actual reuse of wastewater, especially to recharge aquifers may still be distant, However, decisions are going to be made in the future concerning treatment methods and the location of points of discharge. These decisions are necessary preliminaries to wastewater reuse.

Methods of developing additional fresh water

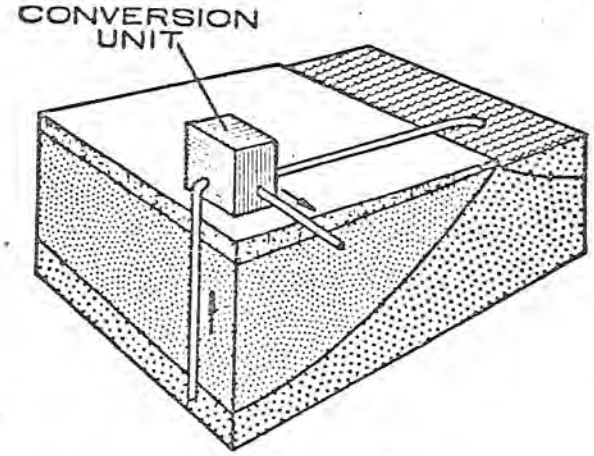
The prolonged dry season of 1970-71 in south Florida emphasized the urgent need to develop means for providing additional fresh water for general use and for preventing sea-water intrusion. Although the water shortage during the drought never became critical, residents were asked to minimize water use.

Alternative solutions to problems posed by waste-water management may provide means for supplemental fresh-water supplies. Also reduction of flow to the ocean is obviously a method of conserving fresh water. These alternatives are by no means the only ones available for consideration.

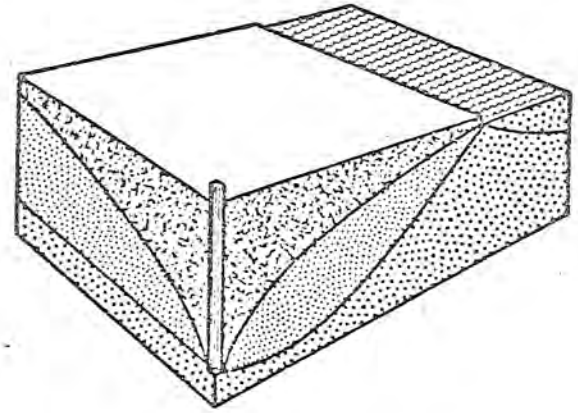
Most municipal well fields in south Florida are relatively near the coast and, consequently, are susceptible to contamination by sea water. Emergency or supplementary well fields could be established farther inland, where the threat of contamination during periods of low water levels would be lessened. Should the demand for water exceed the supply available from near-shore well fields, both systems could be used.



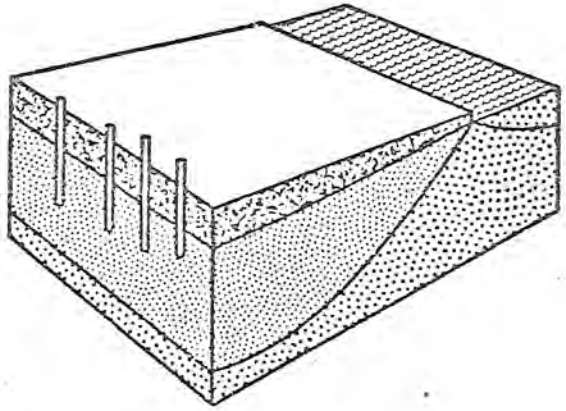
When wells near the coast become contaminated with salty water, drilling new wells farther inland would furnish temporary supplies.



Desalination of ground water or surface water might be considered.



Heavy withdrawals from wells near the coast can induce inland movement of salty water.



Small withdrawals from several shallow wells near the coast would reduce threat of contamination of the wells.

Another, less expensive means of developing additional fresh ground water would be a network of local "mini well fields." These well fields would be low-capacity facilities that would provide water to the part of the urbanized area surrounding the field. These small systems of shallow wells would minimize drawdowns and would lower water levels more uniformly than large well fields, where peak withdrawal is likely to be massive. The addition of "mini well fields" would provide for flexibility of water supply during an emergency, such as a hurricane, when main well fields may become inoperative.

A virtually untouched supply of saline ground water and surface water is available in south Florida. Therefore, another alternative for providing fresh water is desalination. Key West has one of the largest single-unit desalination plants in the country, with a capacity of 2.6 million gallons per day. The cost of desalted water from this system is less than 1 dollar per 1,000 gallons. Note that per-unit cost for conventional water is rising, while per unit cost for desalination is falling. Thus, both economic and resource conservation are favorable.

A proposal to increase the height of the levees surrounding Lake Okeechobee is being considered. Raising the levees 2 feet would provide an additional 1 million acre-feet of storage capacity in the lake. During droughts, the additional water in storage would be released to downstream areas. Although the efficiency of water delivery to urban coastal areas in times of drought is only 20 to 25 percent, the additional water available for delivery could reduce the possibility of a gross water shortage.

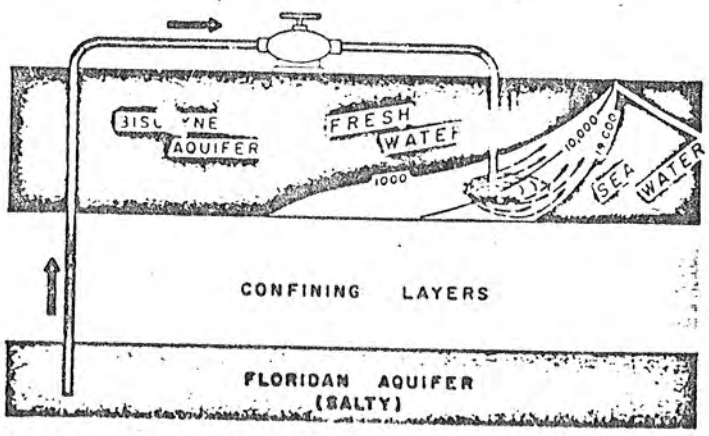
Recent studies of the feasibility and the effectiveness of weather modifications provide hopeful indications for increase of precipitation through cloud seeding. Such modifications would be particularly important during droughts. A Federal-State study was made in south Florida during the drought of 1971 to investigate the potentialities of cloud-seeding during droughts. The conclusions were that the seeding did, in fact, increase rainfall--conservatively, an increase between 5 and 10 percent in the area tested.

Use of artesian water to control sea-water intrusion

The problem of sea-water intrusion in southeast Florida has been discussed in considerable detail in many reports. Several measures have also been discussed for its control. Each of the measures has been based on maintenance of sufficient fresh-water head in canals and in the Biscayne aquifer near the coast to prevent intrusion. An alternative measure presented here is based on the principal of diluting the zone of diffusion to retard sea-water intrusion, as suggested by Sherwood and Klein (1963).

The zone of diffusion is the area within which fresh water and salt water meet, forming a zone of diluted salty water. Kohout (1960) described the form and movements of the zone of diffusion between fresh and salt water in the coastal area of Miami. The position of the zone of diffusion is not static, rather it moves seaward during the wet season and landward during the dry season. The movement corresponds to outflow from the aquifer. Ideally, the zone should be stabilized near the coastline, thus minimizing the threat of intrusion.

In areas of recurring salt-water intrusion that are underlain by the highly porous Biscayne aquifer, it may be feasible to stabilize the zone by injecting artesian water from the Floridan aquifer into the Biscayne aquifer at proper depths.



1000 : CHLORIDE, IN MILLIGRAMS PER LITRE.

Water under high pressure from the Floridan aquifer might be injected into shallow wells near the coast to retard sea-water intrusion during dry periods.

A profile of chloride content of water in the Biscayne aquifer at the coast near Miami shows that the zone of diffusion extends inland about 12,000 feet. Highly saline water (more than 10,000 mg/l chloride) extends inland about 9,000 feet. If the inland movement of the highly saline water could be impeded or the water diluted, the threat of contaminating a municipal well would be reduced.

Water in the Floridan aquifer is under artesian pressure. Water levels in wells penetrating the aquifer are about 40 feet above mean sea level. Water from these wells could be discharged into the high-chloride zone of the Biscayne aquifer along a line of effectively spaced injection wells. The continuous discharge of this water of comparatively low salinity (about 2,000 mg/l chloride) would increase the head in the Biscayne aquifer and tend to decelerate the inland movement of saline water (more than 10,000 mg/l).

Deep wells in the Floridan aquifer could be connected directly to shallow wells (at proper depths) in the Biscayne aquifer. Flow to the Biscayne would be controlled by valves so that the system could be deactivated during the wet season, when it would not be needed, and reactivated during dry periods.

Water discharged into the Biscayne aquifer would be under approximately the same pressure as the water from the Floridan aquifer measured at the land surface. The only pressure reductions in the system would be friction losses in the well casings. The turbulence associated with the injection would reduce salinity by mixing, and the cyclic flow patterns within the system would result in the continuous discharge of the mixed saline water to the sea (Sherwood and Klein, 1963).

Water Management for Southwest Florida

Water management in southwest Florida is different from that in southeast Florida because in the southwest, management can generally be planned before rather than after major development. Managers may take advantage of this difference in determining optimum methods of land preparation and land use zoning in the remainder of the coastal area and particularly in the Big Cypress, to minimize environmental degradation. Drainage, of course, would affect water resources and the aquatic environments most drastically.

The drainage-canal network in the Golden Gate-Fahka Union Canal system, east of Naples, has lowered water levels 2 feet or more to protect against flooding and to insure that septic tanks operate properly during the rainy season. Before drainage, this area was inundated several months during and after the rainy season. After drainage, although some biota has changed or is changing, water supplies have not been seriously affected because of control by a series of weirs in canals.

As urbanization continues to expand in this area, secondary canals may be required. Unless these also are controlled, runoff of fresh water will be accelerated. A paradox could then evolve similar to that on the urban east coast--accelerated loss of fresh water through canals would conflict with increased water demand caused by population growth. Building houses above flood levels in areas not directly served by drainage systems may help minimize fresh-water runoff.

Water management in the future will probably consider methods of water treatment and disposal of wastewater as a matter of course. In early stages of scattered residences, septic tanks will probably be the prime method of disposal. In later stages of dense housing, sewage treatment and disposal that conform to State, Federal, and local standards will be required. Advanced wastewater treatment may be required if effluent is to be discharged into controlled canals and reused. Such treatment may not be required if effluent is disposed through deep wells. The disposed effluent might ultimately be recovered and reused--depending on improvement in quality during its residence in the subsurface and intended use.

The water resources in the inland areas of the Big Cypress are particularly important, as they may be the ultimate supply for the entire lower Gulf Coast in future years. Long water-distribution lines, of course, will be required, so the cost of developing inland water supplies will be weighed against that of producing desalinated water near the municipalities.

Water needs for Naples are approaching the capacity of its present source of supply. As Naples grows, so will its water supply. The remainder of the Big Cypress, east of the Fahka Union basin is virtually a wilderness--only scattered truck farms in the north and small isolated residences in the central and south parts. Planning officials have been requested to consider permitting development in the area. The Department of the Interior, supported by the State, is considering acquisition of that area because of its unique character and because biota of the western part of Everglades National

Park depend on its waters.

If the eastern Big Cypress were to be developed, the methods of land treatment and the type and intensity of land-use would determine the magnitude of environmental changes. Restricted land-use with no canal drainage would cause local changes but would have little effect on the overall character of the area or the park. Regional development through canal drainage would cause regional lowering of water levels and changes in periods of inundation, which, in turn, would destroy or, at least, change the biota of the Big Cypress. The resultant change in the pattern and character of runoff to the park would change biologic communities in the park, although the changes might be slower and more subtle than those in upland areas of the Big Cypress.

Development by methods other than drainage would minimize freshwater losses and, thereby, more nearly maintain the aquatic environment. Although such methods protect the environment and conserve water, they are more costly than development by canals. Development would be slower but, perhaps, more orderly.

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