DROUGHT OF 1980-82 IN SOUTHEAST FLORIDA WITH COMPARISON TO THE 1961-62 and 1970-71 DROUGHTS

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By Bradley G. Waller

ABSTRACT

The Kissimmee Basin in south-central Florida experienced a severe drought during 1980-82. Lake Okeechobee, the largest water storage area in south Florida, reached its lowest recorded stage of 9.75 feet above sea level on July 29, 1981. The drought was the result of a prolonged period of deficient rainfall extending from June 1980 to March 1982.

Drought conditions on the southeast coast of Florida were mitigated on August 16, 1981, when rainfall from Tropical Storm Dennis replenished the coastal aquifers and filled the water-conservation areas to near scheduled levels. South Dade County was the only area in south Florida not affected by the drought. Rainfall in the southeast coastal areas had a statistical recurrence ranging from 5 to 20 years. The recurrence intervals for some stations in south-central Florida were in excess of 100 years.

The 1980-82 drought in southeast Florida was not as severe as the 1961-62 or the 1970-71 droughts in terms of rainfall conditions or the effect on water levels. Water-management practices further mitigated the effect of the drought on the southeast coast of Florida. Reduction of surface-water runoff and implementation of flow augmentation to maintain ground-water levels in coastal areas, maintenance of higher ground-water levels at the end of the wet season, and water-use restrictions minimized the effects of the drought in this area.

INTRODUCTION

Prolonged below normal rainfall throughout both wet (May through October) and dry (November through April) seasons is a primary cause of water-supply problems in south Florida. This natural phenomenon usually results in an inland migration of saltwater in the coastal water-table aquifers and shortages of irrigation water in the agricultural areas. Water-management practices, such as those implemented by the South Florida Water Management District (SFWMD), can mitigate the effects of droughts. The effectiveness of available water-management practices is affected by antecedent water-storage conditions. Periods of below normal, but not necessarily critically low, rainfall preceding droughts adversely affects water storage and consequently limits the effectiveness of water-management practices. One year of below normal rainfall has only a minimal effect upon the water supply of the region; however, consecutive years or an extended period of below normal rainfall can seriously and, in some cases, permanently affect supplies. Recent severe droughts occurred in 1955-56, 1961-62, 1970-71 (Benson and Gardner, 1974), and 1980-82. These earlier droughts were, however, preceded by several years of normal or above normal rainfall. The 1980-82 drought was preceded by a prolonged period (1970-79) during which only 4 years had average or above average rainfall.

The drought conditions experienced in 1970-71 and 1980-82 were preceded by months of rainfall which provided ample water for storage in Lake Okeechobee, the central Everglades, and the coastal aquifers. In contrast, the dry seasons of 1955-56 and 1961-62 were preceded by long periods of below normal rainfall; thus, there was a deficiency in water available for storage. On July 29, 1981, Lake Okeechobee was at the lowest water level ever recorded (9.75 feet above sea level). The late wet-season rains of September and October 1981 over the lake and the Kissimmee Basin were insufficient to provide adequate water for storage in Lake Okeechobee for the upcoming dry season. Inadequate rainfall in October 1981 and a drop in storage in Lake Okeechobee and the water-conservation areas caused the SFWMD to notify the coastal communities that supplemental water supplies from these areas would not be adequate during the 1981-82 winter season; thus, these communities had to rely on aquifer recharge from local rainfall and water available in aquifer storage to meet their water demands. Increased consumptive use of water since the droughts of 1961-62 and 1970-71 placed an additional stress on the hydrologic system.

The purpose of this investigation was to evaluate effects of the 1980-82 drought on the hydrologic system in southeast Florida and compare it with the previous droughts of 1961-62 and 1970-71. This evaluation will: (1) provide a historic perspective of these droughts; (2) consider the effectiveness of water-management practices to minimize adverse conditions brought about by drought; and (3) examine the interrelation of hydrologic parameters that indicate drought conditions.

The three most recent droughts in southeast Florida were analyzed from the standpoint of antecedent and transient hydrologic conditions and the effect of management practices by the SFWMD to alleviate extreme hydrologic conditions and minimize saltwater intrusion. The following factors were considered in the analysis of these droughts for Dade, Broward, and Palm Beach Counties (fig. 1).

1. Rainfall amounts, frequency, and distribution;
2. Water levels (antecedent and ending);
3. Ground-water recession;
4. Available storage in the water-conservation areas and Lake Okeechobee;
5. Flow augmentation;
6. Discharge to the ocean;
7. Water-management procedures;
8. Saltwater intrusion.

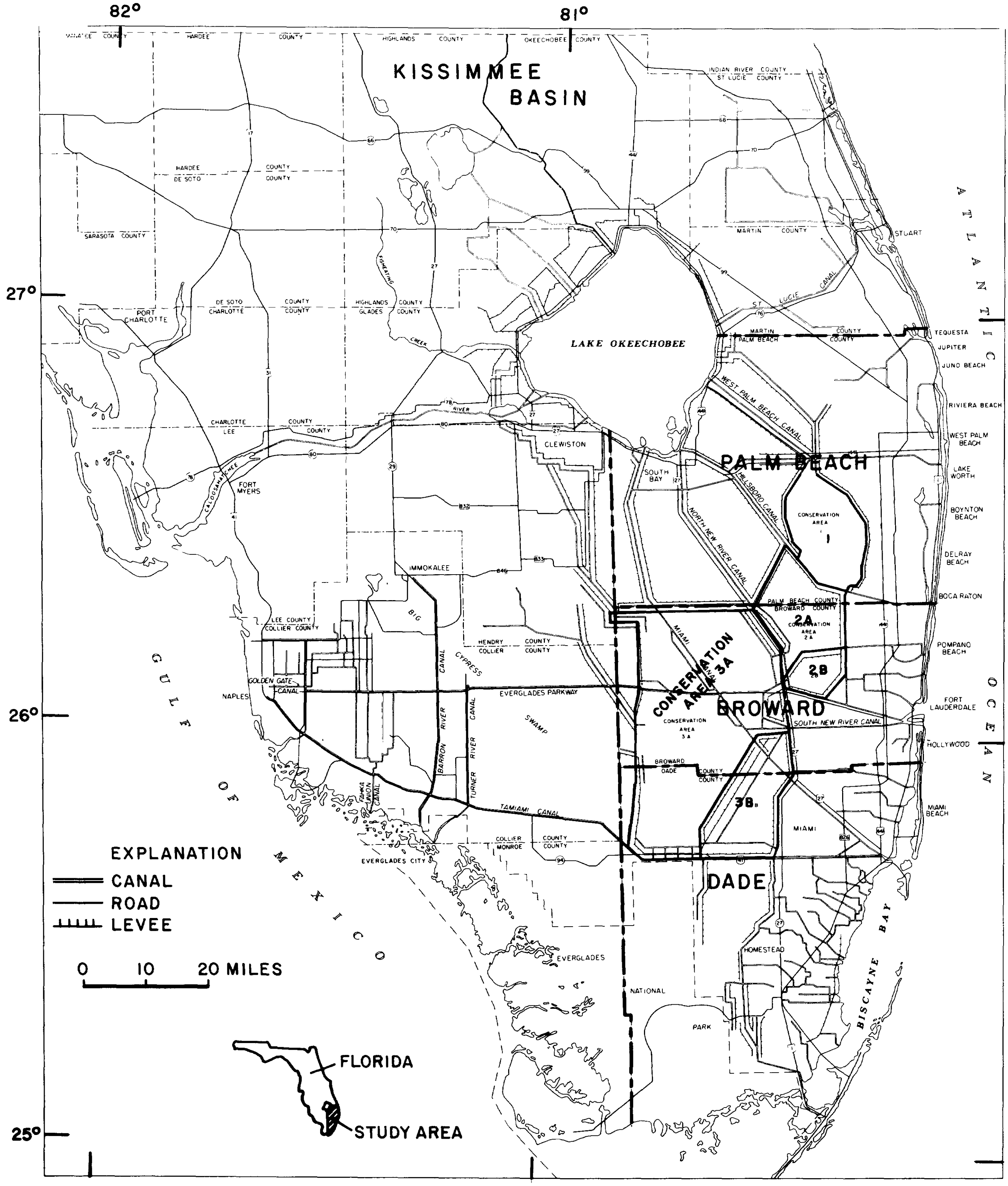

Figure 1.--South Florida showing Dade, Broward, and Palm Beach Counties, Florida.

Graphical and statistical analyses of rainfall, water levels, discharge, and chloride concentrations for selected stations are presented. Data from publications of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, U.S. Geological Survey, and U.S. Corps of Engineers were utilized in preparing the analysis of the droughts and this report.

Primary timeframes used for the drought analysis are November 1961 through June 1962, November 1970 through June 1971, and June 1980 through June 1982. Some analyses include yearly and long-term data and information from the 1955-56 drought.

GENERAL HYDROLOGY AND WATER CONTROL IN SOUTHEAST FLORIDA

The SFWMD manages the water resources in south Florida to minimize the detrimental consequences of extreme hydrologic events, such as droughts and floods. Historic water-level and rainfall data and the normal seasonal rainfalls are considered in the management of the water resources by the SFWMD. Flooding is reduced, or minimized, by discharge of surface water to the oceans through salinity-control structures or by pumping excess water into the three water-conservation areas and into Lake Okeechobee. During periods when rainfall along the southeast coastal area is insufficient to maintain high enough ground-water levels to prevent saltwater intrusion in the aquifer, water is released by gravity from storage in the water-conservation areas and Lake Okeechobee to canals upstream of salinity-control structures to raise water levels in the aquifer and retard saltwater intrusion.

The four primary water-storage areas in south Florida are Lake Okeechobee and Water Conservation Areas 1, 2 (A and B), and 3 (A and B) (fig. 1). These storage areas provide water to the agricultural and urban areas by releases to canals through water-control structures and pumping stations and by way of seepage under levees to coastal aquifers. Excess water enters the storage areas by gravity flow and pumping. Monthly water-level schedules, based on historical records of rainfall in south Florida, have been established for the storage areas. When necessary, releases from the storage areas are regulated during the wet season to prevent water levels in the storage areas from exceeding the scheduled maximum. Peak-scheduled water levels are reached at the end of the wet season, and a steady decline in water levels is scheduled through late winter and spring. This seasonal decline is caused by low rainfall, surface-water releases, seepage, and increased ET (evapotranspiration).

Surface-water discharge in southeast Florida is highly controlled. Over the years, canals, dams, control structures, pumping stations, and levees have been constructed that permit alteration of the natural drainage pattern to control the movement of water on the surface within the system and transferral of surface water to the aquifer along the east coast. Water levels in some coastal wetlands have been lowered, causing a decrease in ET and runoff. Water-storage areas were completed in 1963, causing ET to increase while also providing water for recharging aquifers along the coastal areas, except during periods of extremely deficient rainfall. Water use by both agricultural and urban areas has increased steadily since the early 1960's (Sherwood and others, 1973; Klein and Hull, 1978). Therefore, the resultant runoff records through the years summarize constantly changing conditions, which include both drainage and consumptive use. Taylor Slough is the only discharge station in southeast Florida that represents a rainfall-runoff relation which is unaffected by management practices. In this report, the water-management practices emphasized are storage, flow augmentation for aquifer recharge, and control of surface-water discharge to the ocean.

CHARACTERISTICS AND DEFINITION OF DROUGHTS

Drought is a natural phenomenon that sometimes ranks with floods, hurricanes, tornadoes, earthquakes, tidal waves, and other natural disasters. Droughts are characterized by long duration when compared to the suddenness of other catastrophes, and their beginning and ending times are often difficult to identify. Rainfall deficiency is the basic cause of droughts, but a long time lag may occur between deficiencies and harmful effects, such as crop damage, wildlife stress, and deficient water supply.

In Webster's New International Dictionary (1944), drought is defined as: "(1) a prolonged period of dryness; or (2) a prolonged or chronic shortage." The first definition involves only a condition; the second is more comprehensive and recognizes the needs and failure to adapt to these conditions, thus, being an integral part of the concept of a drought. Meteorologists and hydrologists have defined droughts in many variations; all enhance dictionary definitions by specifically defining dryness or identifying what constitutes a prolonged period or what the shortages may be with respect to selected needs. Types of drought have been defined as follows (Subrahmanyam, 1967):

1. Meteorologic drought--Defined only in terms of precipitation deficiencies in absolute amounts for specific durations.

2. Climatologic drought--Defined in terms of precipitation deficiencies as a ratio to mean or normal values not in specific quantities.

3. Hydrologic drought--Defined in terms of reduction of streamflows, reduction in lake or reservoir storage, and lowering of ground-water levels.

4. Water-management drought--This classification is included to characterize water deficiencies caused by failure of water-management practices or facilities (such as integrated water-supply systems, surface, and subsurface storage) to provide adequate water supplies during the drought.

The U.S. Geological Survey has generally identified droughts on the basis of precipitation records (Thomas, 1962). Hoyt (1938) states:

> "In general, however, in humid and semiarid states there are no serious drought effects unless the annual precipitation is as low as 85 percent of the mean - that is, unless there is an annual deficiency of 15 percent or more."

Hoyt notes, however, deficiencies in annual precipitation are not necessarily good criteria for determining existence of a drought because within-year distribution of rainfall must be considered not to mention antecedent conditions. He concludes that seasonal deficiencies would be a better measure for determining existence of drought conditions or lack of them. In this report, drought conditions are considered to exist if seasonal rainfall is 85 percent, or less, of normal seasonal rainfall.

CLIMATE OF SOUTHEAST FLORIDA

The climate of southeast Florida is essentially subtropical marine, characterized by a long warm to hot wet season from May through October with abundant rainfall followed by a mild to cool dry season from November through April. About 75 percent of the annual rainfall occurs during the wet season.

Rainfall during the dry season occurs mostly during passage of cold fronts, is usually light, and is relatively general in areal distribution. During the wet season, however, rainfall occurs as scattered convective thunderstorms, easterly waves, or tropical depressions and hurricanes. The convective thunderstorms and easterly waves often yield more than 1 inch of rain. Tropical depressions and hurricanes commonly yield more than 5 inches of rain and occasionally more than 20 inches. May is generally a transition month between the wet and dry seasons.

HYDROLOGIC EFFECTS OF THREE DROUGHTS IN SOUTHEAST FLORIDA

Recent major droughts affected southeast Florida in 1961-62, 1970-71, and 1980-82. The drought of 1980-82 is unusual in that it lasted 2 years. Normally abundant wet-season rainfall did not occur throughout the area in 1981, and the effect of the drought carried over into 1982. The following evaluation of these droughts will concentrate primarily on data collected in the dry season.

The following sections describe various hydrologic components used in analyzing the drought of 1980-82 in Dade, Broward, and Palm Beach Counties. This drought is given historical perspective, comparing it with droughts in 1961-62 and 1970-71. A complete analysis of the drought of 1980-82, concentrating primarily on rainfall and storage throughout the jurisdiction of the SFWMD, is presented by Lin and others (1984).

Rainfall

The location of the 12 rainfall stations used for analyzing the drought and the area each represents are shown in figure 2. Normal annual rainfall for these stations and percent departures from normal for 1980, 1981, 1980-81, and 1982 are given in table 1.

The following stations recorded rainfall which indicated drought conditions:

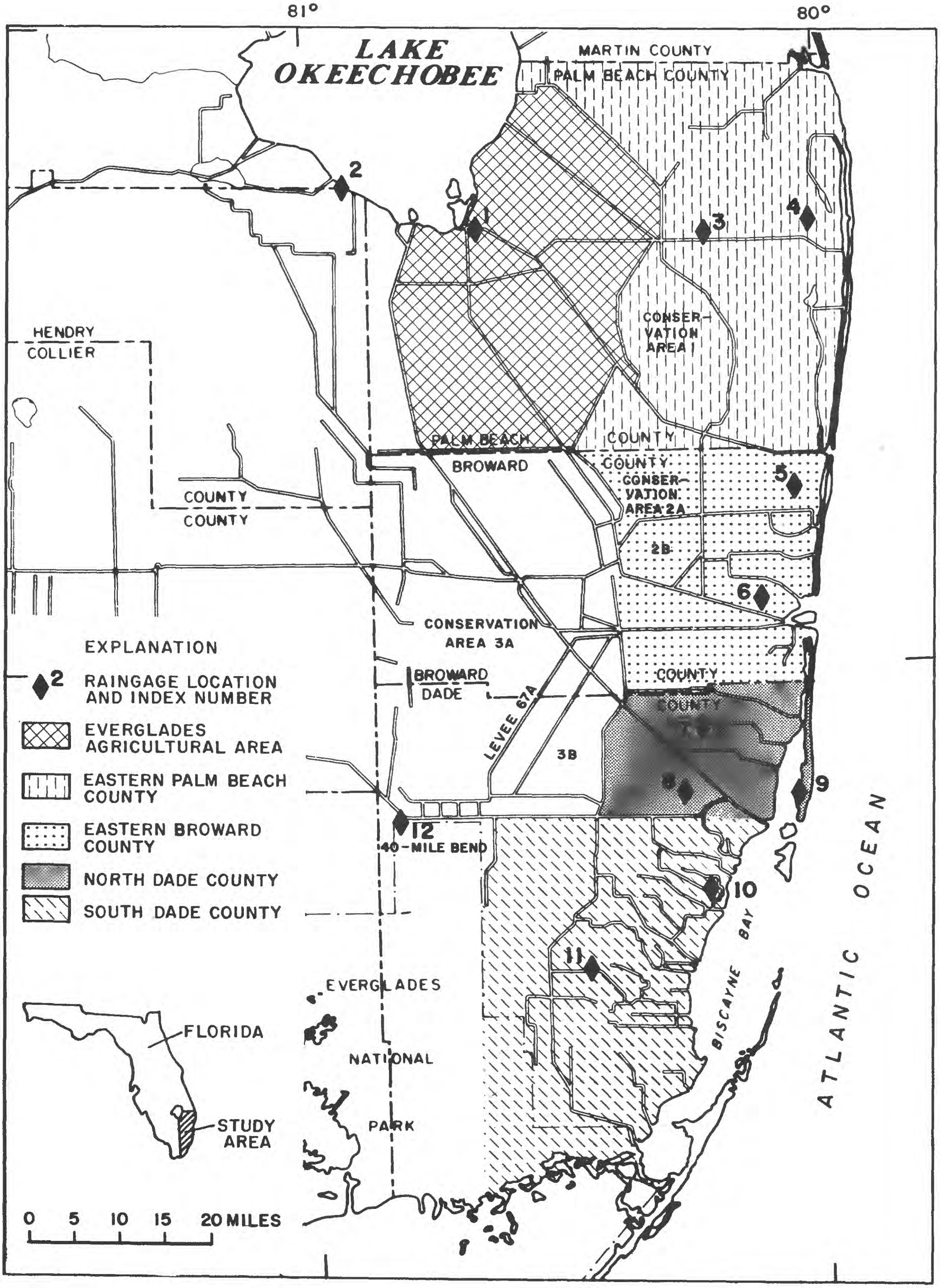

Figure 2.--Location of selected National Weather Service rainfall stations in southeast Florida.

Table 1.--Annual rainfall at selected stations in southeast Florida, 1980-82, and percent departure from normal (1951-80)

[Values are in inches; e, partially estimated record]

Map[1]/ index No.	Station	Normal annual	Annual rain-fall, 1980	Per-cent depar-ture	Annual rain-fall, 1981	Per-cent depar-ture	Average depar-ture (1980-81)	Annual rain-fall, 1982	Per-cent depar-ture
	Everglades agricultural area								
1	Belle Glade agricultural station	58.75	46.18	-21	45.89	-22	-22	55.41e	- 6
2	Clewiston	49.38	39.95	-19	32.25	-35	-27	54.45	+10
	Eastern Palm Beach County								
3	Loxahatchee	64.49	54.04	-16	50.10	-22	-19	75.50	+17
4	West Palm Beach	62.06	56.67	- 9	49.74	-20	-14	80.62	+30
	Eastern Broward County								
5	Pompano Beach	62.50	46.57	-25	50.45	-19	-22	60.08	- 4
6	Fort Lauderdale	60.08	69.67	+16	57.90	- 4	+ 6	82.92	+38
	North Dade County								
7	Hialeah	63.14	61.18	- 3	57.07	-10	- 6	69.42	+10
8	Miami	59.80	57.34	- 4	50.79	-15	-10	67.41	+13
9	Miami Beach	46.54	50.77	+ 9	52.97	+14	+12	53.36e	+15
	South Dade County								
10	Miami 12SSW	59.33	50.23	-15	54.79	- 8	-12	60.90	+ 3
11	Homestead agricultural experiment station.	62.99	74.54	+20	74.72	+19	+20	56.48e	-10
	South-Central Everglades								
12	40-Mile Bend ranger station	57.51	40.78	-29	42.97	-25	-27	58.17e	+ 1

1/ Locations shown in figure 2.

1980	1981	1982
1, Belle Glade 2, Clewiston 3, Loxahatchee 5, Pompano Beach 10, Miami 12SSW 12, 40-Mile Bend	1, Belle Glade 2, Clewiston 3, Loxahatchee 4, West Palm Beach 5, Pompano Beach 8, Miami 12, 40-Mile Bend	None

The greatest rainfall deficiencies were recorded at stations in the northern and western parts of Palm Beach County (1, 2, and 3), northern Broward County (Pompano Beach) (5), and the inland part of the south-central Everglades (40-Mile Bend).

The distribution of rainfall throughout the year is important in analyzing the hydrologic consequences of a drought. Cumulative trends in rainfall from January 1980 through June 1982 for six areas in three counties are shown in figure 3 as the average of the departures from normal of rainfall at stations within each area. Rainfall deficiency in southeast Florida began in June 1980 for most stations. In the Everglades agricultural area, eastern Palm Beach County, and the south-central Everglades, cumulative rainfall continued deficient through February 1982 for a period of 21 months. In November 1980 and August 1981, most stations recorded normal or above normal rainfall, thus, reversing the downward trend in rainfall deficiency. Maximum rainfall deficiencies for this 21-month period were -26.09 inches for the Everglades agricultural area, -22.07 inches for eastern Palm Beach County, and -31.30 inches for the south-central Everglades.

In eastern Broward and north Dade Counties, the trend in rainfall deficiency began in June 1980 (fig. 3) but was erratic with slight recoveries occurring in July through August 1980, November 1980, February 1981, and August through September 1981. Deficient rainfall recurred from October 1981 through February 1982 but, like the other areas, the rainfall in March 1982 marked the decline of deficient rainfall in southeast Florida.

Deficient rainfall in south Dade County began in March 1981 (fig. 3) and continued until August 16, 1981, when Tropical Storm Dennis arrived in the area. South Dade County did not experience the drought conditions of 1980-82 that occurred throughout most of central and south Florida (Lin and others, 1984).

Rainfall Frequency

One indication of the relative severity of a hydrologic event is the frequency at which an event of comparable magnitude can be expected to occur. The severity of a hydrologic event increases as the frequency of occurrence

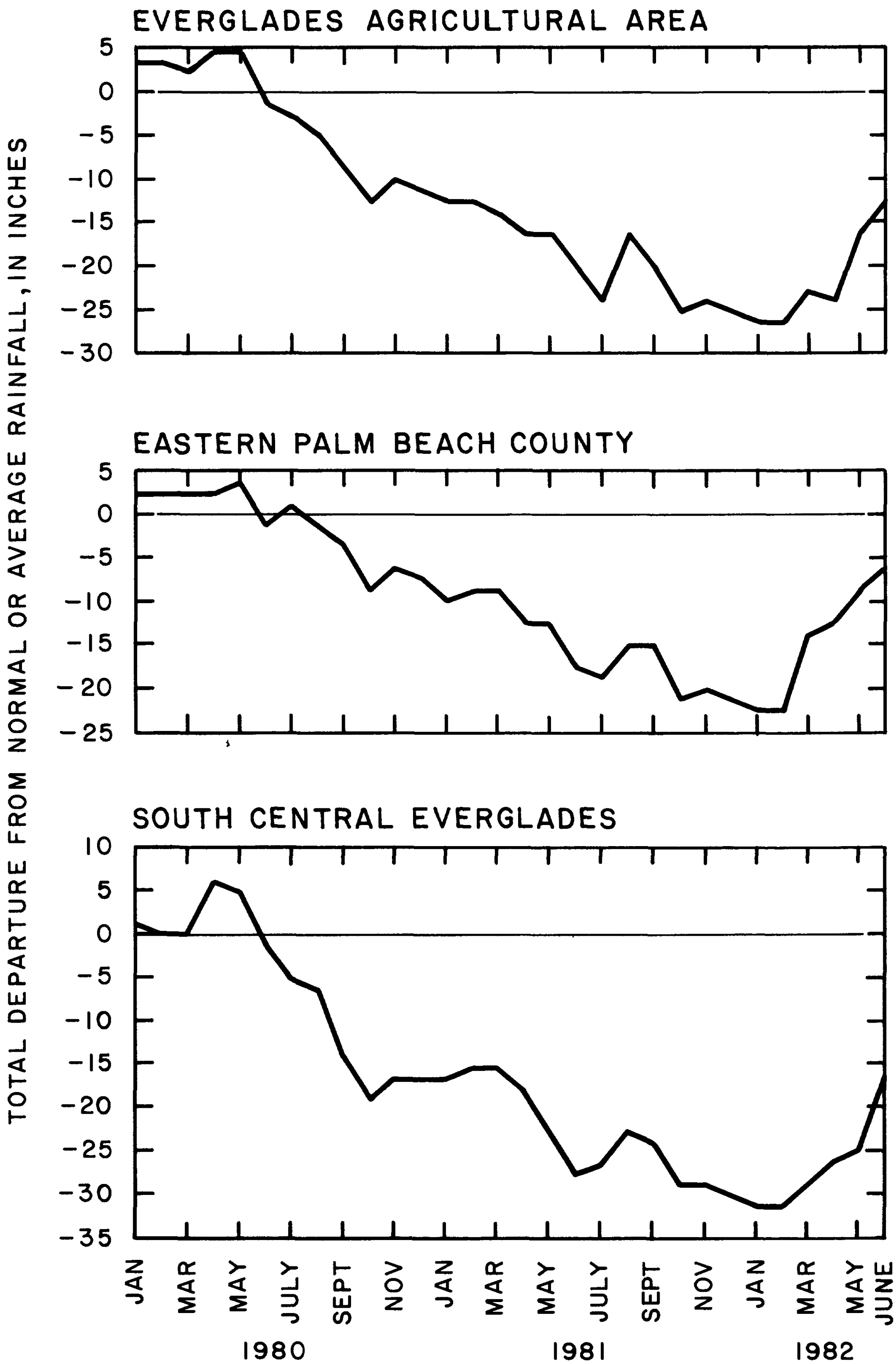

Figure 3.--Cumulative rainfall departures at six areas in southeast Florida, January 1980 through June 1982.

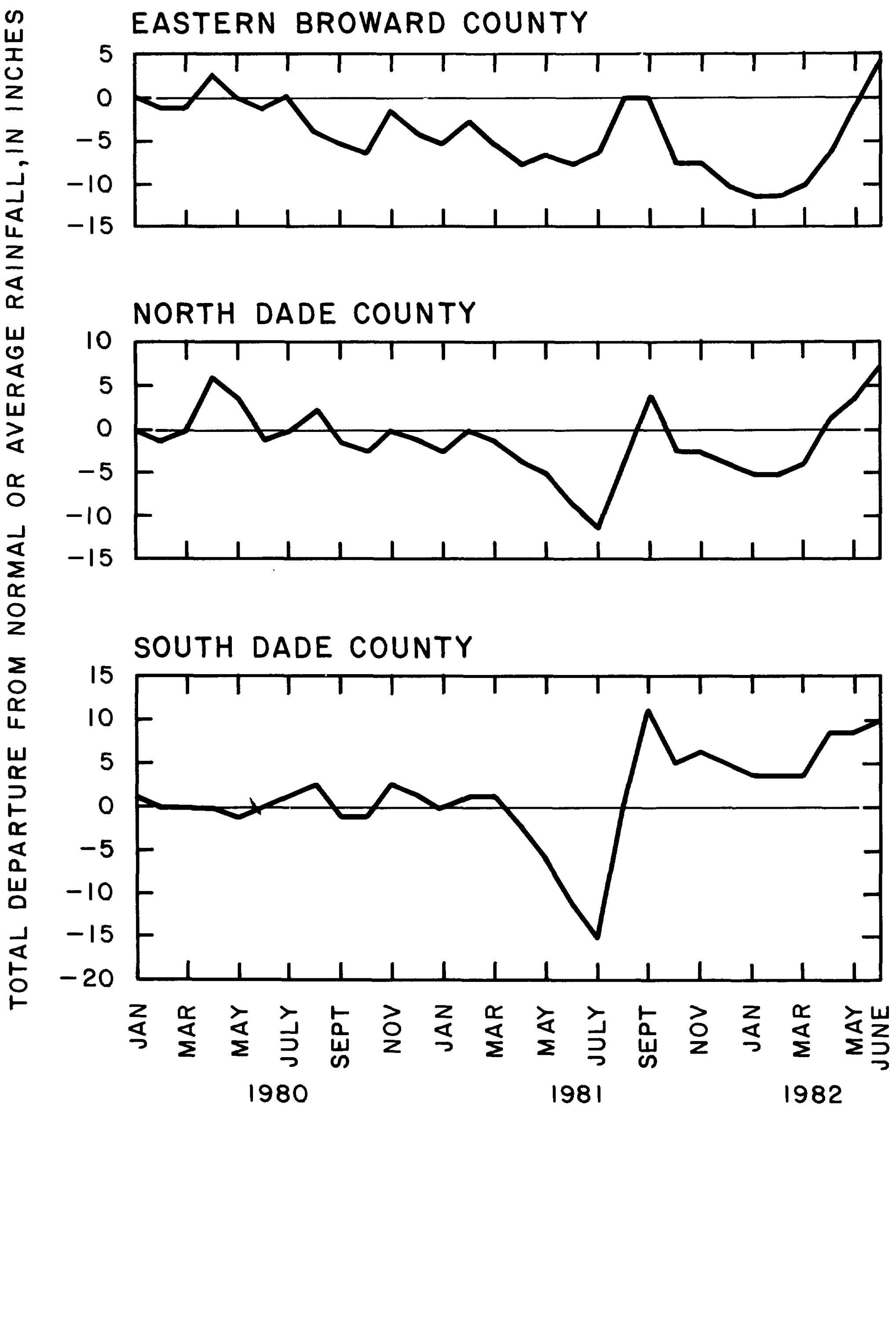

Figure 3.--Cumulative rainfall departures at six areas in southeast Florida, January 1980 through June 1982--Continued.

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of such an event decreases. A common measure of the frequency of occurrence is the recurrence interval designated in average number of years between recurrences. In south Florida, dry-season (November through April) rainfall is a key factor in determining drought conditions. For use in this analysis, May is considered a transition month between wet and dry seasons.

About 25 percent of the annual rainfall occurs during the 6-month dry season, and consumptive use by both agricultural and urban areas increases over wet-season usage. Any deficiency of rainfall during this time can seriously affect the overall water supply in south Florida. A deficiency of rainfall during the wet season is not as critical, because rainfall is generally sufficient to recharge the aquifer and supply the lowered consumptive use during this time. After storage becomes sufficient in the coastal aquifers, most excess rainfall is discharged to the ocean by way of canals.

A summary of the recurrence interval of dry-season rainfall at 12 selected stations (fig. 2) for 5 droughts is shown in table 2. The worst dry-season drought conditions occurred in 1970-71 followed by 1955-56, 1961-62, and 1980-81. The rainfall for the 1981-82 dry season is not considered as below normal because of rain throughout the southeast coast in March and April 1982.

Benson and Gardner (1974, p. 17) report that the recurrence interval of the 1971 drought on the southeast coast exceeds several hundred years. Lin and others (1984) report that the recurrence interval of the 1981 rainfall deficiency on the southeast coast was between 5 and 20 years. Rainfall stations in the Everglades agricultural area near Lake Okeechobee and at stations in the Kissimmee Basin (Lin and others, 1984) recorded rainfall deficiencies in 1981 that had recurrence intervals in excess of 100 years, an extreme drought condition. The dry-season rainfall conditions in 1955-56 and 1961-62 were infrequent events, but the impact of the drought was much less due to less development and consequently less consumptive use of the water resources.

Discharge to the Ocean

The volume of surface runoff flowing to the south and east was evaluated using discharge data in the coastal canals. Ground-water outflow, consumptive use, ET, and surface-water discharge through the control structures account for the freshwater loss. Control structures are automatically operated during periods of normal rainfall to lessen the chance of flooding. Freshwater is discharged at a minimum to conserve as much water as possible for use.

Sixteen major surface-water discharge stations along the eastern coast and southern perimeter of the water-conservation areas (fig. 4) were evaluated. All discharges through these stations are controlled, except for Taylor Slough (station 16) which is uncontrolled. The runoff data from these stations, which is considered loss of freshwater from storage, were analyzed for December through May for drought periods.

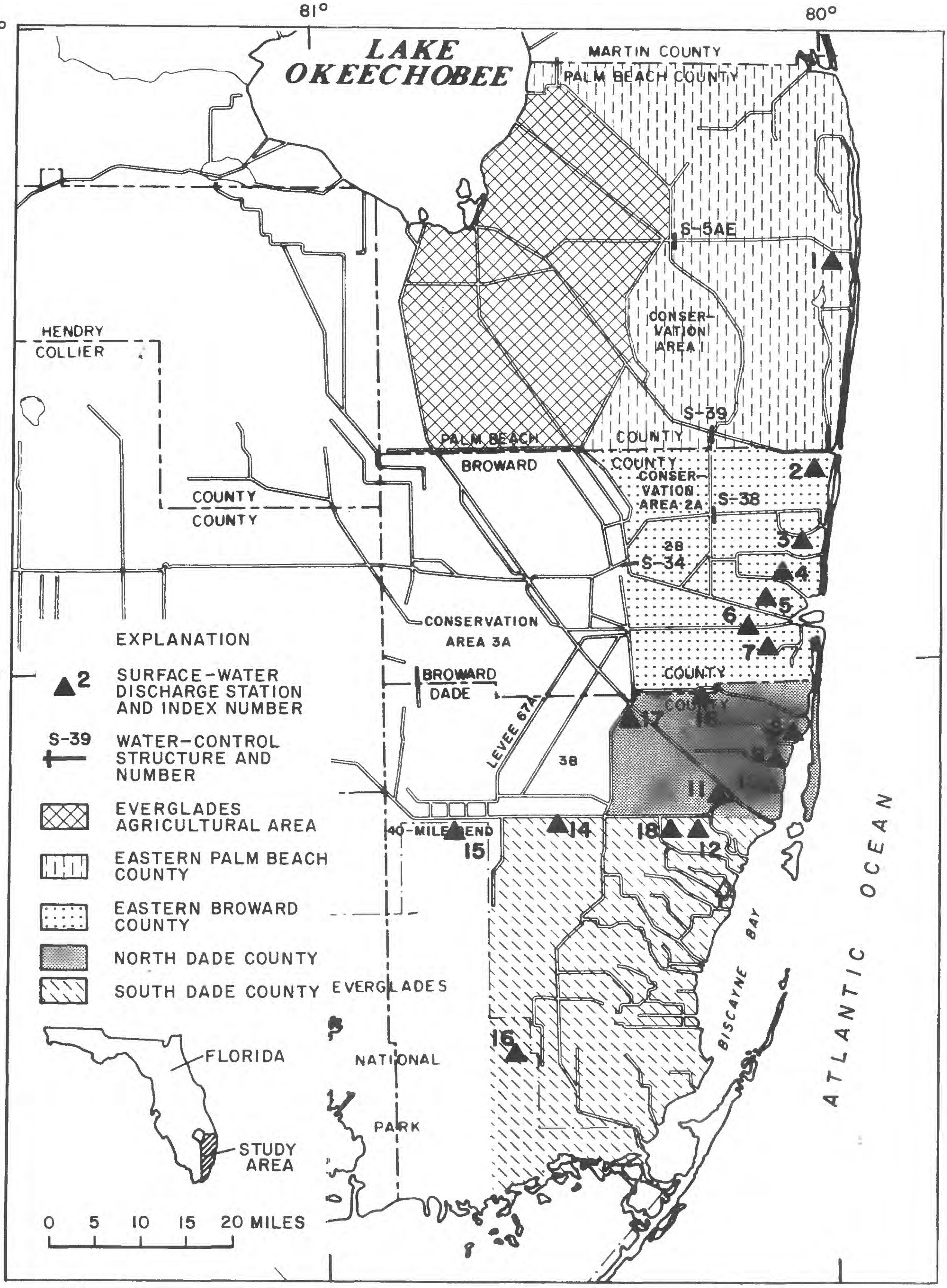

Figure 4.--Location of selected discharge stations in southeast Florida.

Table 2.--Recurrence interval of dry-season rainfall (November through April) at selected stations in southeast Florida for 1955-56, 1961-62, 1970-71, 1980-81, and 1981-82

[Values are shown in years]

Map1/ index No.	Station	Period of record	1955-56	1961-62	1970-71	1980-81	1981-82
1	Belle Glade agricultural station	34	<5	<5	15 - 20	<5	<5
2	Clewiston	32	5 - 10	<5	>100	5 - 10	<5
3	Loxahatchee	34	15 - 20	<5	>100	<5	<5
4	West Palm Beach	34	15 - 20	<5	>100	<5	<5
5	Pompano Beach	30	5 - 10	<5	>100	<5	<5
6	Fort Lauderdale	33	15 - 20	10 - 15	>100	<5	<5
7	Hialeah	34	10 - 15	30 - 35	>100	<5	<5
8	Miami	34	30 - 35	15 - 20	>100	<5	<5
9	Miami Beach	33	<5	<5	>100	<5	<5
10	Miami 12SSW	24		<5	>100	<5	<5
11	Homestead agricultural experiment station	33	5 - 10	<5	>100	<5	<5
12	40-Mile Bend ranger station	34	<5	5 - 10	>100	<5	<5

1/ Locations shown in figure 2.

Map index No.	Station
1	West Palm Beach Canal at West Palm Beach
2	Hillsboro Canal at Deerfield Locks
3	Cypress Creek Canal at S-37A
4	Middle River Canal at S-36
5	Plantation Road Canal at S-33
6	North New River Canal at Sewell Lock
7	South New River Canal at S-13
8	Snake Creek Canal at S-29
9	Biscayne Canal at S-28
10	Little River Canal at S-27
11	Miami Canal at S-26
12	Tamiami Canal near Coral Gables
13	Snapper Creek Canal at S-22
14	Tamiami Canal Outlets, L-30 to L-67A
15	Tamiami Canal Outlets, L-67A to 40-Mile Bend
16	Taylor Slough near Homestead

Discharge deficiency of the selected stations in southeast Florida are used as an index of the severity of the four droughts as shown in the following table:

	Dry-season discharge to the ocean during 1961-62, 1970-71, 1980-81, and 1981-82				
	Average (period of record)	1961-62	1970-71	1980-81	1981-82
Discharge (ft^3/s)	130	28	21	56	71
Percent of average	100	21.5	16.2	43.1	54.6
Total volume (acre-ft)		3,660	3,250	9,340	11,800

Surface-water discharge in 1961-62 and 1970-71 was lower than during 1980-81 or 1981-82, although the average discharge to the ocean during each of the four dry seasons was well below average.

Some discharge occurs during rainfall deficits as a result of normal structure operations and maintenance and during rainstorms which may cause localized flow in canals. Discharge to Everglades National Park from Conservation Area 3A through Tamiami Canal Outlets L-67A to 40-Mile Bend (station 15 in fig. 4) was also low during the last two droughts when discharge ranged from 46 to 54 percent of average (table 3). Discharge at Taylor Slough (station 16 in fig. 4) is a key indicator of conditions in south Dade County because it is a natural, uncontrolled drainage basin. During the dry seasons of 1961-62 and 1970-71, no flow occurred at Taylor Slough; in the 1980-81 and 1981-82 dry seasons, flow was 92 and 115 percent of average, indicating near normal flow conditions in this area.

Table 3.--Runoff at selected discharge stations in southeast Florida for December through May during 1961-62, 1970-71, 1980-81, and 1981-82

[Discharge values are in cubic feet per second; NA: No data available--control structure construction not completed]

Map[1]/ index No.	Station name	Long-term average discharge (Dec-May)	Years	1961-62 Discharge	1961-62 Percent of average	1961-62 Serial rank	1970-71 Discharge	1970-71 Percent of average	1970-71 Serial rank	1980-81 Discharge	1980-81 Percent of average	1980-81 Serial rank	1981-82 Discharge	1981-82 Percent of average	1981-82 Serial rank
1	West Palm Beach Canal	378	30	160	42	7	28	7	1	48	13	2	227	60	11
2	Hillsboro Canal	134	30	53	40	5	35	26	2	63	47	6	189	141	26
3	Cypress Creek Canal	67	20	NA	--	--	1.5	2	1	19	28	3	61	91	15
4	Middle River Canal	52	21	.8	2	3	.0	0	1	30	58	13	14	27	13
5	Plantation Road Canal	15	20	NA	--	--	.0	0	1	1.6	11	3	9	60	7
6	North New River Canal	216	30	20	9	2	15	7	1	87	40	11	36	17	6
7	South New River Canal	153	25	29	19	2	19	12	1	153	100	14	92	60	9
8	Snake Creek Canal	192	23	.0	0	1	68	35	3	164	85	12	102	53	9
9	Biscayne Canal	52	20	NA	--	--	.8	2	1	31	60	7	34	65	9
10	Little River Canal	96	18	.2	0	1	NA[2]/	--	--	70	73	6	46	48	6
11	Miami Canal	214	23	11	5	2	29	14	4	10	5	1	24	11	3
12	Tamiami Canal	116	23	38	33	2	71	61	7	98	84	11	103	89	14
13	Snapper Creek Canal	94	23	.0	0	1	.2	0	2	0	0	1	43	46	9
14	L-30 to L-67A	47	21	.0	0	1	8	17	3	9	19	4	16	34	7
[3]/15	L-67A to 40-Mile Bend	402	19	NA	--	--	216	54	10	207	51	8	187	46	5
[3]/16	Taylor Slough	2.6	22	.0	0	1	.0	0	1	2.4	92	14	3	115	17

1/ Locations shown in figure 4.
2/ No discharge data available for Little River Canal.
3/ Not included in calculations of normal flow or freshwater loss to the ocean.

Water Storage

Water storage at the onset of the dry season is very critical to the coastal areas in southeast Florida and the agricultural areas south of Lake Okeechobee. When storage is well below scheduled capacity, these areas must depend upon local rainfall or conservation to meet water-supply requirements. At the beginning of 1981, the water level was below schedule in three of the four storage areas (figs. 5 and 6) because most of south Florida had been experiencing deficiencies in rainfall since June 1980 (fig. 3).

Between January and May 1981, water levels and available storage declined in Water Conservation Areas 1 (fig. 5) and 3A (fig. 6). These conservation areas were filled to scheduled storage capacity after intense rains from Tropical Storm Dennis in August 1981 (figs. 5 and 6). This is the first time that Conservation Areas 1 and 3A reached scheduled water levels in over 1 year. Storage in these two conservation areas again were below schedule between October 1981 and March 1982.

In Water Conservation Area 2A, the decline ended in May 1981 (fig. 6), and scheduled storage was generally maintained through July 1982. It should be noted that Conservation Area 2A was under a "dry down" operating schedule during 1980-82 for ecological purposes and was not operated under the normal schedule which would call for more storage throughout the year.

The water level in Lake Okeechobee declined steadily from November 1980 until the lowest water level ever recorded (9.75 feet above sea level) was reached on July 29, 1981 (Lin and others, 1984). Because of the tremendous storage capacity (5.106×10^6 acre-ft at an elevation of 17.5 feet), the water level in Lake Okeechobee is a key indicator of how severe a drought has become. During this drought and the previous droughts (1956, 1962, and 1971), the water level remained low for long periods (fig. 7), thus, limiting the ability for flow augmentation to drought-stressed areas throughout south Florida. The stage-duration curves for the 1981 water year and January 1981 through June 1982 are plotted with the curves for previous droughts to show the relative severity of conditions that were faced.

Water levels in Lake Okeechobee for the 1981 water year were low throughout the year and were very similar to the water levels recorded in 1962 and 1971, except that in 1981 Lake Okeechobee was at an elevation of 10.0 feet or less for over 32 consecutive days. At a stage of 10.0 feet, there is nearly 2 million acre-ft of storage in the lake, but it is virtually unusable because of low gradients and lack of pumping capabilities. The 18-month period between January 1981 and June 1982 was the worst period of available storage in the lake with over 400 days when the water level was at a stage of 12.0 feet or less (fig. 7)--a level where there is little usable storage.

From January 1980 through July 1981, water levels in Lake Okeechobee declined (fig. 5). During this period, water levels not only declined but remained 3 to 6 feet below schedule. The lake remained well below scheduled water levels until May 1982, when the wet-season rains began to fill the lake from the contributing basins. By August 1982, the lake was near scheduled water levels, and the effect of the 1980-82 drought on Lake Okeechobee had subsided.

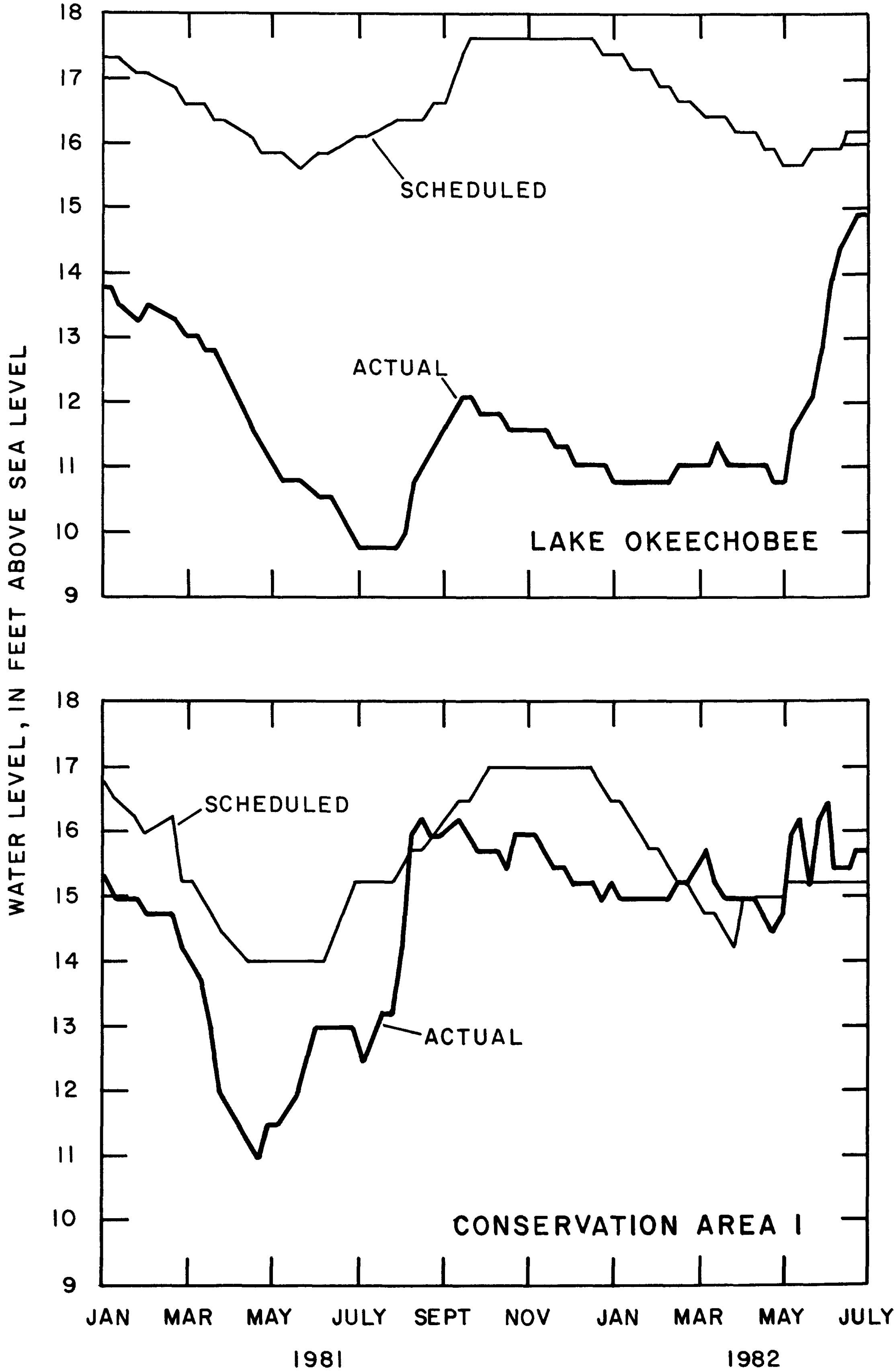

Figure 5.--Scheduled and actual water levels for Lake Okeechobee and Water Conservation Area 1, January 1981 through July 1982.

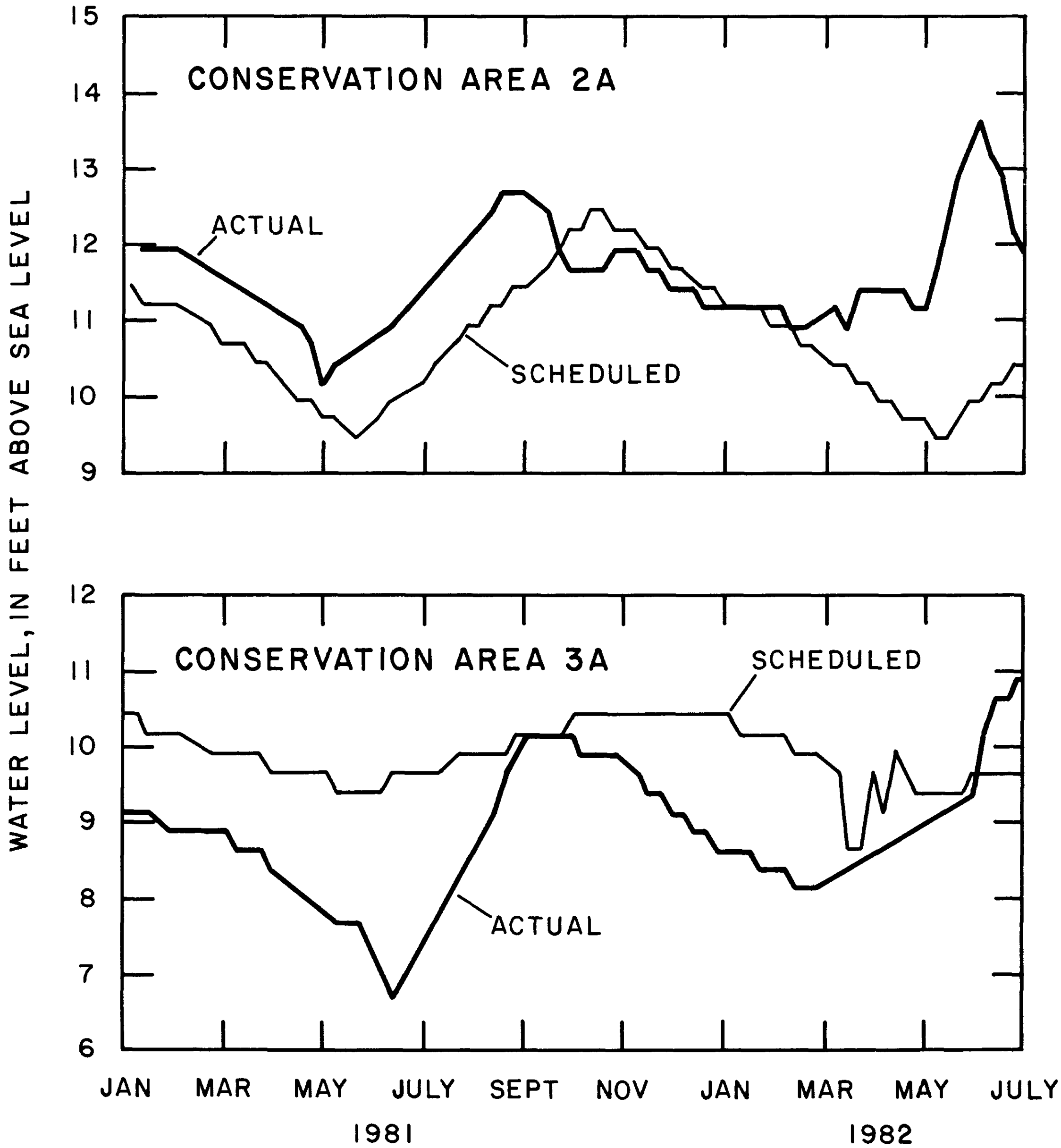

Figure 6.--Scheduled and actual water levels for Water Conservation Areas 2A and 3A, January 1981 through July 1982.

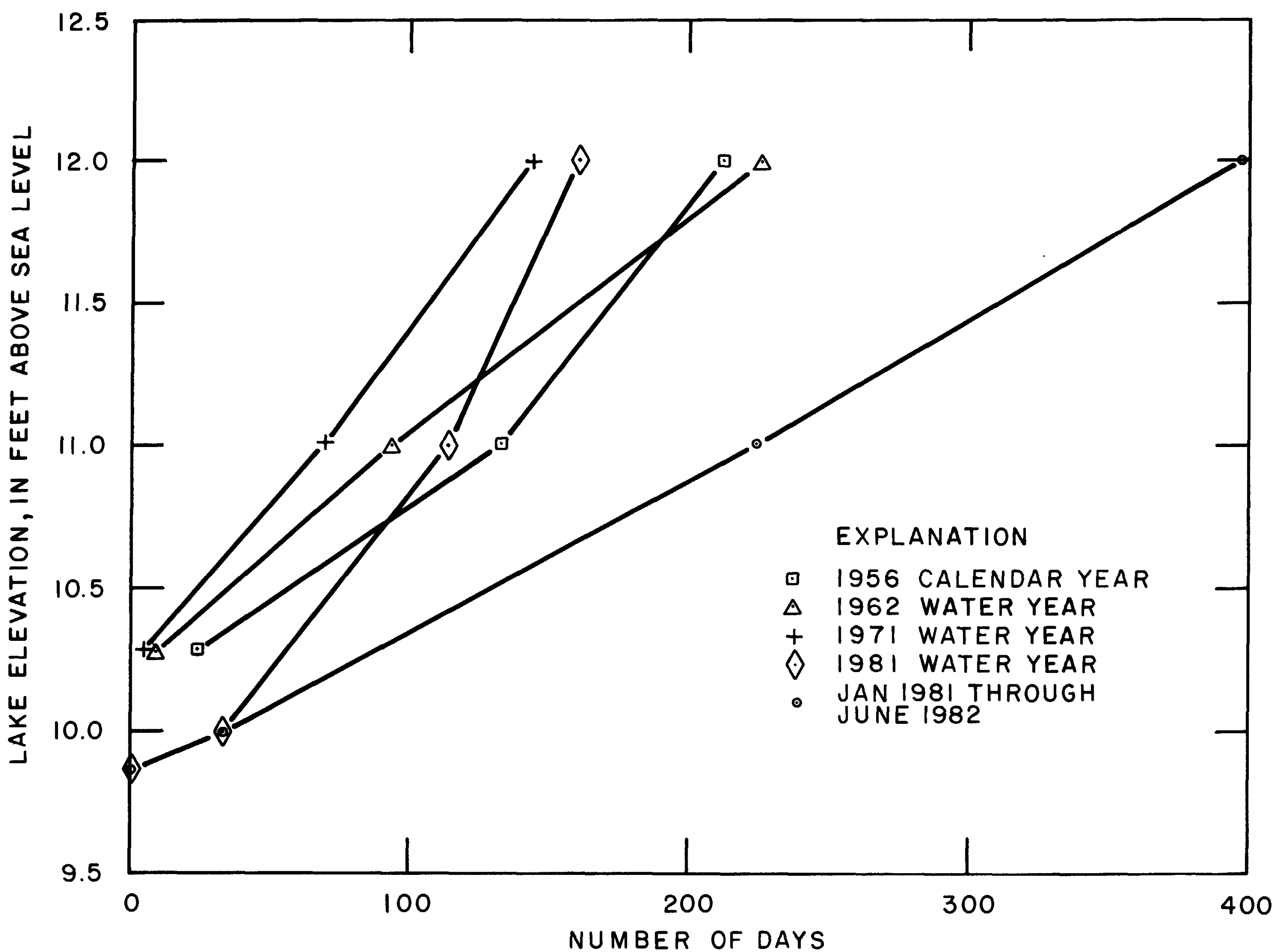

Figure 7.--Number of days water-surface elevation in Lake Okeechobee was at or below indicated elevations in 1956, 1962, 1971, 1981, and January 1981 through June 1982.

A complete analysis of the water levels in Lake Okeechobee from 1980-82 is found in Lin and others (1984). The report discusses the cause and effect of low water levels in the lake which include inflow and outflow from the various basins, rainfall, and evaporation and provides the reader with a water budget for the 2-year period.

Ground-Water Levels

Ground-water levels in coastal areas respond to rainfall, pumpage, ground-water outflow to the ocean, seepage from the water-storage areas, flow augmentation from the canal system, and ET. The level of the water table in the coastal areas is also a key indicator of the hydrologic conditions. The total recession of the water table during a dry period is an indicator of the severity of the dry period and can possibly indicate drought conditions. As the water table declines, resistance to saltwater intrusion into the aquifer decreases so that inland movement of the saltfront occurs. If conditions favorable to advancement of the saltfront persist, it may become necessary to curtail pumping from certain coastal well fields.

Ground-water levels in the coastal areas during the last three droughts were analyzed by using data from the following long-term water-level stations in the three counties (locations shown in fig. 8).

Ground-water levels declined between November and May along the coastal areas in Dade, Broward, and Palm Beach Counties during the droughts of 1961-62, 1970-71, and 1980-81 (table 4). During the 1981-82 dry season, ground-water levels generally rose or remained approximately the same due to above average rainfall at the end of the 1982 dry season. The average decline in water levels for the three counties during 1961-62, 1970-71, 1980-81, and 1981-82 is as follows:

County	1961-62	1970-71	1980-81	1981-82
Palm Beach	-0.48	-2.39	-1.85	1.70
Broward	- .69	- .66	- .93	- .55
Dade				
North	- .65	- .55	- .79	- .19
South	-2.01	-2.89	-2.09	-1.14

The 1970-71 drought was the worst in Palm Beach and south Dade Counties. The 1980-81 dry season had the same pattern of ground-water level decline, except the decline was less. The 1961-62 drought seemed to be most severe in Broward and Dade Counties. It should be noted that during the beginning (November) of both the 1980 and 1981 dry seasons, ground-water levels were above or near average; in 1961 and 1970, overall ground-water levels were generally below average (table 4). Declining water levels since 1961 at well G-616 (map number 5) are due to increasing urbanization and less flood irrigation in the area and are not attributable to drought conditions. No ground-water levels in the three counties were below sea level in 1981 or 1982,

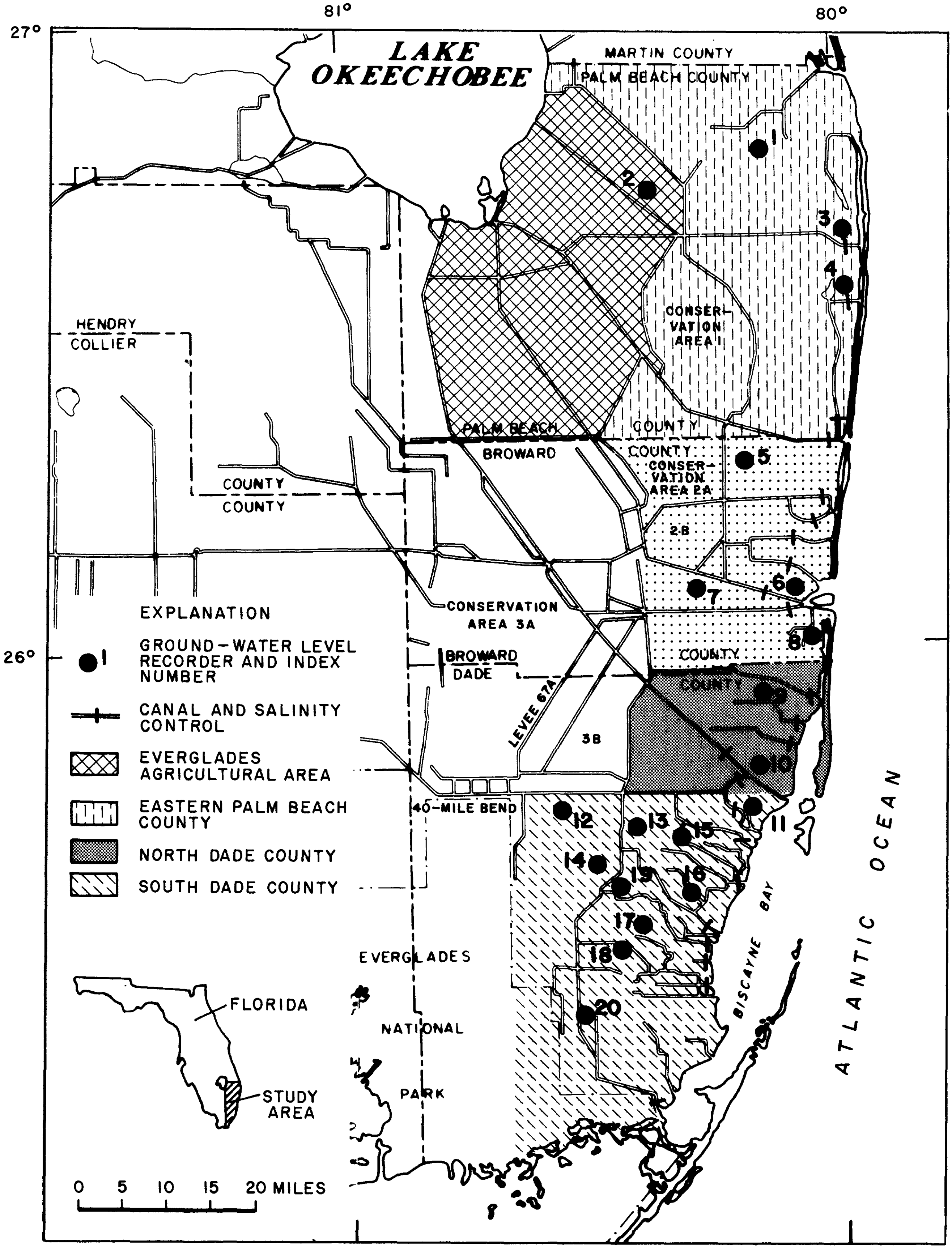

Figure 8.--Location of selected long-term ground-water level recorders and salinity-control structures on canals.

Table 4.--Minimum ground-water levels at selected stations in southeast Florida during November and changes between November and May minimums for 1961-62, 1970-71, 1980-81, and 1981-82 dry seasons

[Values are in feet above (+) or below (-) sea level]

Well No.	Month	Map[1] index No.	1961-62	Water-level change[2]	1970-71	Water-level change[2]	1980-81	Water-level change[2]	1981-82	Water-level change[2]	Average monthly minimum
					Palm Beach County						
PB-109	November	1	17.90		17.85		17.51		18.14		18.43
	May		--	--	14.65	-3.20	15.17	-2.34	18.32	+0.16	16.68
PB-110/831	November	2	19.45		18.65		19.64		19.41		
	May		--	--	16.20	-2.45	17.17	-2.47	19.06	- .35	
PB-99	November	3	6.00		6.60		7.11		7.36		8.49
	May		5.80	-0.20	5.25	-1.35	6.20	- .91	9.71	+2.35	7.13
PB-88	November	4	4.81		5.40		4.08		3.83		
	May		4.05	- .76	2.85	-2.55	2.40	-1.68	8.45	+4.62	
					Broward County						
G-616	November	5	9.60		8.90		5.91		--		
	May		9.10	- .50	7.35	-1.55	4.87	-1.04	9.44	--	
G-561	November	6	1.30		1.15		1.59		1.44		2.12
	May		.80	- .50	1.35	+ .20	.72	- .87	.93	- .51	1.72
G-617	November	7	3.65		3.70		3.18		3.56		4.10
	May		2.55	-1.10	3.05	- .65	2.68	- .50	2.78	- .78	3.85
F-291	November	8	1.50		1.10		1.67		1.42		1.65
	May		.85	- .65	.45	- .65	.36	-1.31	1.07	- .35	1.92

1/ Locations shown in figure 8.
2/ November minimum to May minimum.

Table 4.--Minimum ground-water levels at selected stations in southeast Florida during November and changes between November and May minimums for 1961-62, 1970-71, 1980-81, and 1981-82 dry seasons--Continued

[Values are in feet above (+) or below (-) sea level]

Well No.	Month	Map[1/] index No.	1961-62	Water-level change [2/]	1970-71	Water-level change [2/]	1980-81	Water-level change [2/]	1981-82	Water-level change [2/]	Average monthly minimum
					North Dade County						
S-18	November	9	1.90		1.75		2.20		2.30		2.17
	May		.95	-0.95	1.15	-0.60	1.38	-0.82	1.77	-0.53	2.05
F-45	November	10	1.75		1.70		2.20		2.18		
	May		1.20	- .55	1.15	- .55	1.43	- .77	2.10	- .08	
F-179	November	11	1.85		1.89		2.49		2.21		2.24
	May		1.40	- .45	1.40	- .49	1.71	- .78	2.25	+ .04	1.94
G-618	November	12	5.80		6.90		6.47		6.61		
	May		2.55	-3.25	3.50	-3.40	3.52	-2.95	4.27	-2.34	
					South Dade County						
G-866	November	13	3.83		4.34		4.48		4.81		
	May		1.68	-2.15	1.04	-3.30	2.53	-1.95	3.29	-1.52	
G-596	November	14	4.08		4.33		5.30		5.60		5.44
	May		1.63	-2.45	.58	-3.75	2.70	-2.60	3.45	-2.15	1.73
G-553	November	15	2.45		3.10		3.56		3.69		3.62
	May		.95	-1.50	.85	-2.25	1.92	-1.64	3.01	- .68	3.21
S-182A	November	16	1.80		1.50		2.64		2.88		2.53
	May		.70	-1.10	.35	-1.15	1.54	-1.10	2.38	- .50	2.21
G-614	November	17	2.40		2.40		3.30		3.09		3.20
	May		.35	-2.05	-.50	-2.90	.83	-2.47	2.17	- .92	1.09
S-196A	November	18	1.90		1.90		3.48		3.48		
	May		-.30	-2.20	-1.30	-3.20	1.02	-2.46	2.24	-1.24	
G-757A	November	19	3.50		3.30		3.97		4.18		4.05
	May		1.25	-2.25	.00	-3.30	1.75	-2.22	2.71	-1.47	2.37
G-613	November	20	1.35		1.75		2.43		2.25		2.15
	May		1.00	-2.35	-1.50	-3.25	.15	-2.28	1.62	- .63	.92

1/ Locations shown in figure 8.
2/ November minimum to May minimum.

although levels in some areas declined more than 2 feet. In 1971, some of the ground-water levels in south Dade County were below sea level (Benson and Gardner, 1974). The lesser decline in water levels at the end of the 1981 dry season as compared to the end of 1971 is attributed to periodic rainfall (although deficient) and flow augmentation from storage areas. Rainfall during the beginning of the 1981 wet season was sufficient to raise ground-water levels to average, although it was insufficient to maintain average runoff in the coastal areas of the three counties.

Ground-water levels in the coastal areas are maintained as high as possible to prevent saltwater intrusion in the coastal well fields. To maintain high levels during droughts, surface-water releases at the salinity-control structures are minimized and flow augmentation from the water-storage areas is implemented. Water losses when the salinity-control structures are closed are primarily limited to ET, ground-water outflow to the ocean, and consumptive use.

Surface-water releases to the coastal areas are controlled at gates and culverts on the eastern edge of the water-conservation areas. Seepage under the levees of the conservation areas, although uncontrolled, is a major factor in maintaining desirable ground-water and surface-water levels in the coastal areas. Surface-water releases from the three water-conservation areas toward the east during the period of the lowest ground-water levels, November 1980 through August 15, 1981, are given in table 5. Flow from some of these stations (Snake Creek at 67th Avenue, Miami Canal east of Levee 30, and Tamiami Canal near Coral Gables; map numbers 16-18, fig. 4) is a combination of both surface-water releases and ground-water seepage; flow from other structures, such as S-5AE, S-34, S-38, and S-39 (fig. 4), are direct surface-water releases from the water-conservation areas.

From November 1980 through June 1981, a total monthly release of about 30,000 acre-ft was adequate to maintain acceptable water levels in the coastal aquifer except in April, when it was necessary to release more than 60,000 acre-ft from the storage areas. Rains along the coast in July and early August made it possible to maintain adequate water levels in the aquifer with the release of slightly less than 30,000 acre-ft during this period. The total flow from the inland areas was over 300,000 acre-ft, or nearly 98 billion gallons, during the 10 1/2-month period of deficient rainfall in 1980-81.

Saltwater Intrusion

Saltwater intrusion along the coastal areas has been a concern in southeast Florida since development began and has been monitored, especially near major coastal well fields, periodically for over 40 years. When the head of freshwater along the coast decreases, saltwater will generally move inland along the base of the aquifer and have a configuration of a wedge. Canals that cut into the aquifer also provide a path for the inland migration of saltwater. Saltwater intrusion has caused some well fields to be abandoned and parts of others to be closed down--an obvious economic burden to utilities and municipalities. Mitigation of the inland migration of saltwater is considered a primary goal in the management of coastal well fields, especially during droughts or extended dry periods.

Table 5.--Volume of water released from the three water-conservation areas at major discharge stations from November 1980 through August 15, 1981

[Values are in acre-feet]

Map No.[1]/	Canal	Volume of water released									
		1980		1981							
		November	December	January	February	March	April	May	June	July	Aug 1-15
S-5AE	West Palm Beach	1,080	0	2,660	980	1,290	11,750	3,410	0	256	0
S-34	North New River	6,160	8,880	12,170	6,230	10,870	11,000	1,750	0	350	0
S-38	Cypress Creek	770	1,760	1,490	1,050	2,330	7,070	3,700	0	0	0
S-39	Hillsboro	0	0	0	0	0	7,330	3,590	0	1,320	0
16	Snake Creek[2]/	13,000	7,000	3,280	14,280	5,550	4,000	4,200	14,940	9,800	3,400
17	Miami[2]/	0	0	2,060	2,990	726	18,700	10,550	13,130	6,780	26
18	Tamiami[2]/	11,000	10,760	7,550	6,560	5,330	1,940	3,280	3,840	4,820	2,510
Monthly total		32,010	28,400	29,210	32,090	26,096	61,790	30,480	31,910	23,326	5,936
Total = 301,248											

1/ Includes undetermined amount of seepage under levee.
2/ Locations shown in figure 4.

As the ground-water levels are lowered by outflow, consumptive use, and ET, surface-water flow augmentation is implemented and the water-conservation areas are tapped for their available storage. When storage is low, as was the case in 1981, water-use cutbacks are implemented to conserve as much freshwater as possible in the inland areas and decrease the rate of movement of seawater toward the coastal well fields.

The movement at the saltwater front along the coast is monitored by analyzing water samples collected from wells that penetrate the aquifer. Saltwater intrusion is considered to have occurred if the analysis shows a chloride concentration of at least 1,000 mg/L (milligrams per liter) at the base of the aquifer. Rapid inland movement of the saltfront from the coastline can be caused by canal construction or more gradually by long-term lowering of the water table. Whatever the cause, the inland movement of the saltfront tends to be accelerated by low water or drought conditions.

After the deficient rainfall conditions experienced throughout south Florida in the latter part of 1980, sampling of wells along the saltfront became more frequent. Sampling was usually made on a monthly basis, but as the 1981 wet season began with more deficient rainfall, it increased from a biweekly to a weekly basis as Lake Okeechobee approached its lowest recorded water level at the end of July 1981. Monitoring of saltfront movement continued until August 18, when Tropical Storm Dennis hit south Florida and caused extensive flooding along the coast.

The saltfront in Broward and Palm Beach Counties has been stabilized by installation of salinity-control structures on the coastal canals. Little saltfront movement was detected during the last three droughts. This lack of movement is primarily due to the maintenance of sufficient freshwater head behind the salinity-control structures. Ground-water levels (table 4) remained above sea level inland from these structures (fig. 8), thus, preventing movement of the saltfront. Only at the center of some well fields did the water levels decline below sea level.

In north Dade County, the saltfront has stabilized even during drought conditions, but the saltfront in south Dade County moves inland when extended dry periods occur. Klein and Hull (1978) reported that during the 1970-71 drought, the saltfront moved inland nearly 1 mile in south Dade County. However, during the 1981 dry season, the saltfront had a configuration shown in figure 9 and remained stationary. This is primarily because water levels in south Dade County remained above sea level during 1981 whereas in May 1971, many of the wells in the county recorded water levels below sea level. Maintenance of water levels above sea level in south Dade County in 1981 can be attributed to greater dry-season rainfall, better water-management practices, and more efficient canals and water-control structures for augmenting flow from the storage areas.

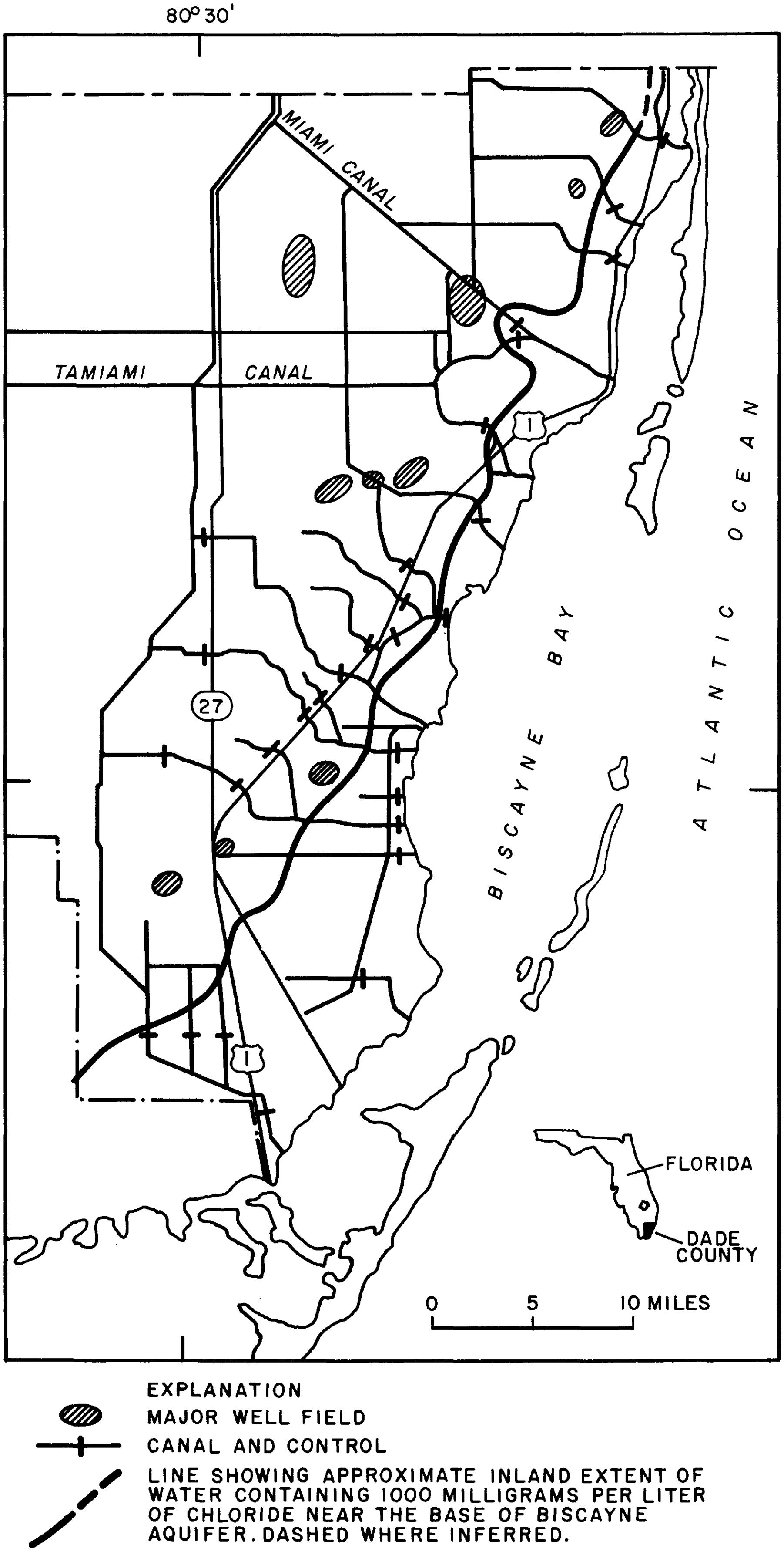

Figure 9.--Saltfront location in Dade County, Florida, March and May 1981.

SUMMARY OF HYDROLOGIC INDICES OF DROUGHT IN SOUTHEAST FLORIDA

No single component of the hydrologic system can be measured to indicate drought conditions in south Florida. Although rainfall deficiencies are a good indicator of drought conditions, south Florida receives more than enough rainfall on an annual basis to supply all of its consumptive use and normal outflow and ET. Even during an extended period of deficient rainfall, such as 1980-81, periodic rainfall along the coast caused ground-water levels in the coastal aquifers to remain high enough during 1981-82 to prevent any inland migration of saltwater. The most serious drought condition is a long period of no rainfall, not just deficient rainfall. This was the case in the 1970-71 drought on the southeast coast and the 1980-82 drought in the Kissimmee Basin which, in turn, affected the amount of storage in Lake Okeechobee and the conservation areas.

Surface-water discharge to the ocean in southeast Florida can be virtually stopped by operation of controls during extended dry seasons or under drought conditions. Evaluation of the runoff records for the last four droughts indicates that when runoff is 25 percent of average runoff, the drought conditions are then fairly severe as in 1961-62 and 1970-71. When the runoff is about 50 percent of average runoff, such as in the 1980-81 and 1981-82 dry seasons, the drought is then only moderate, and some surface-water discharge to the ocean occurs to prevent high water levels in localized areas. Discharge of freshwater to the ocean is a poor index of drought in south Florida because it is highly controlled and will remain so to prevent water loss and saltwater intrusion. The percentiles of average runoff are a relatively poor indicator of drought, because they are so highly controlled and dependent on local conditions. The recession or low flow conditions that can be observed and measured for a natural stream to indicate drought cannot be applied to the analysis of discharge in south Florida canals.

Available storage in Lake Okeechobee and the three water-conservation areas seems to be a good, although not absolute, indicator of drought conditions. Storage in the conservation areas, although below the scheduled or optimum conditions, was sufficient during 1980-81 to provide flow augmentation to the coastal areas and aid in maintaining ground-water levels, but usable storage in Lake Okeechobee was inadequate to provide water for use in the coastal areas or the Everglades agricultural area. This inadequate storage was due to the severe drought experienced in the contributing basins north of Lake Okeechobee (Lin and others, 1984). Because the SFWMD network of canals and storage areas is very highly interconnected, a drought in an upgradient area greatly affects the downgradient areas where water supplies are limited.

Control of ground-water levels in the coastal areas is probably the key to moderating the consequences of drought conditions in south Florida coastal areas. There has always been enough rainfall during previous wet seasons to bring the coastal areas to scheduled water levels at the end of the wet season (October). It is very important for ground-water levels to be average or above at the beginning of a dry season because of uncertainty in ensuing hydrologic conditions. Flow augmentation is an important management practice for prevention of excessive decline of ground-water levels during the dry season. Flow augmentation is essential in areas near major well fields and in south Dade County where major water losses occur every dry season. Ground-water levels in south Dade County decline 2 to 3 feet during the dry season even under moderate drought conditions, such as in 1980-82. Recharge of the aquifer by flow through the south Dade County canal system is necessary to maintain ground-water levels during the dry season to prevent saltwater intrusion. The greatest threat of saltwater intrusion under drought conditions is in south Dade County because of high permeability of the aquifer, increasing water use, and the great distance from water-storage areas.

Consumptive use of freshwater was restricted in south Florida during the 1970-71 and 1980-82 droughts to minimize the recession of ground-water levels and, thus, inhibit saltwater intrusion. A reliable index of drought conditions in south Florida is the inland movement of the saltfront. The monitoring of this saltfront is necessary when evaluating the immediate effects of a drought. This movement combines all the hydrologic components discussed above: rainfall, storage, runoff, ground-water levels, flow augmentation, consumptive use, ET, and ground-water outflow.

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