

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY EVALUATION OF
INFILTRATION FROM THE MIAMI CANAL
TO WELL FIELDS IN THE MIAMI SPRINGS-HIALEAH
AREA, DADE COUNTY, FLORIDA

By

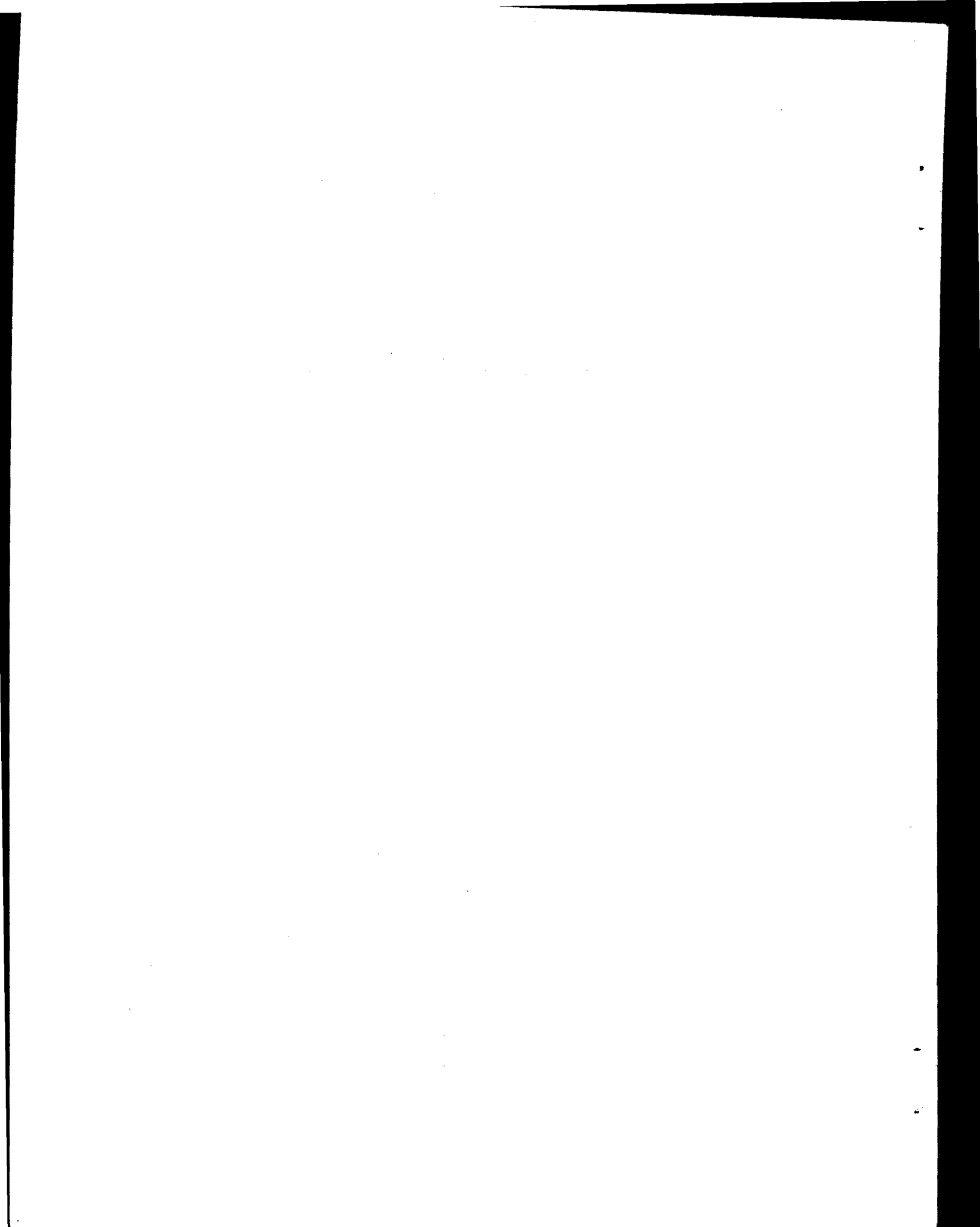
Frederick W. Meyer

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Prepared by
UNITED STATES GEOLOGICAL SURVEY
in cooperation with
CENTRAL AND SOUTHERN FLORIDA FLOOD CONTROL DISTRICT
DADE COUNTY
and the
CITY OF MIAMI

Tallahassee, Florida

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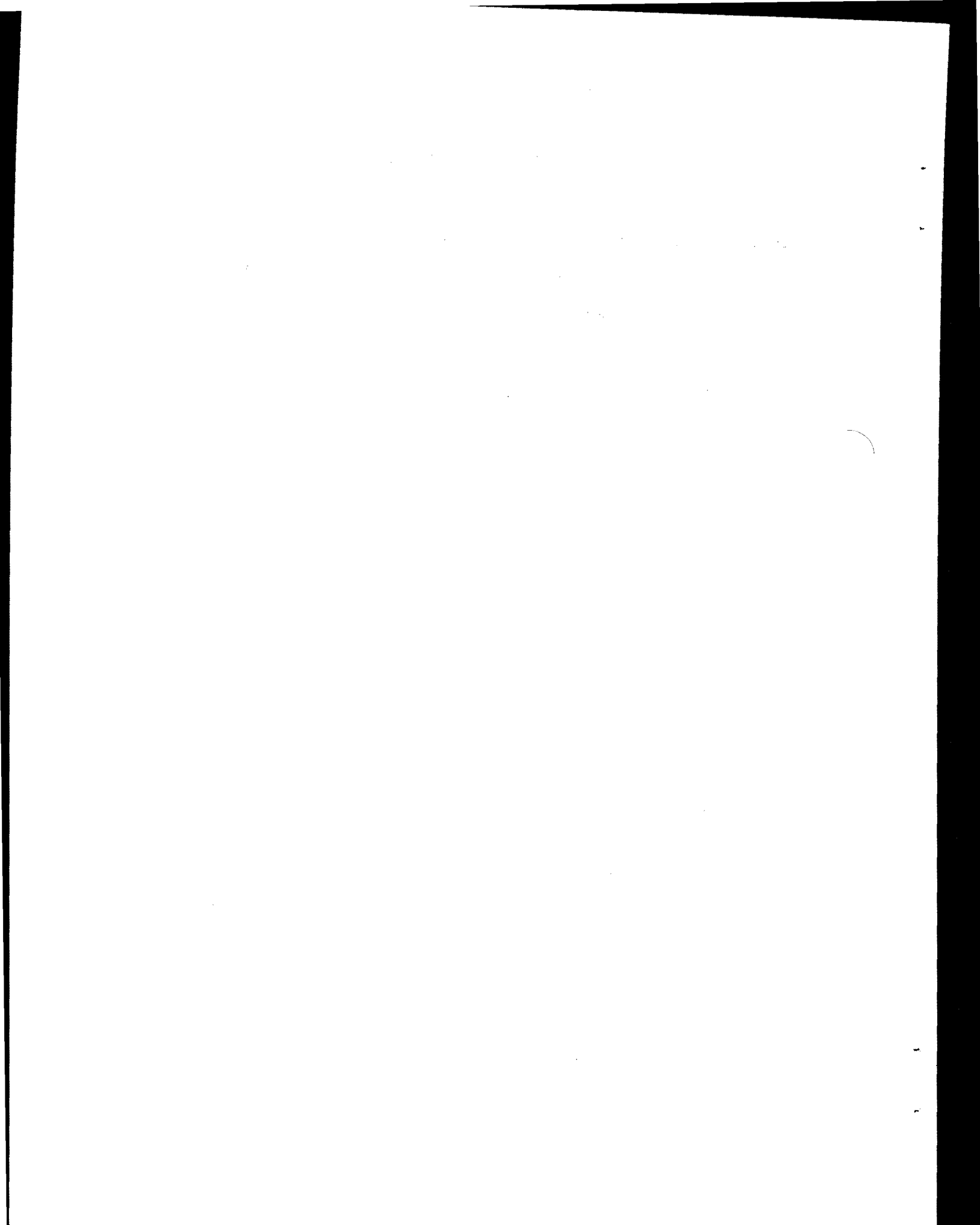
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ABSTRACT

Infiltration from controlled canals minimizes the depth and extent of the cone of depression about the well fields in the Miami Springs-Hialeah area and prevents sea-water intrusion. In the 1940's the controlled canals contributed 78 to 100 percent of the dry-season pumpage. Average pumpage has increased from 67 to 92 million gallons per day during 1961-71 without significantly affecting the quality of well-field water. Water demands since 1961 have caused the cone of depression to expand beyond the limits of the recharging canals; therefore, the percentage of dry-season contribution from the canals has decreased. In April 1971, the cone of depression expanded southward and caused deep salty ground water in the vicinity of the Tamiami Canal to move northward beneath the airport toward the well fields, forcing a reduction in pumpage. A temporary dam was installed in the Tamiami Canal in September 1971 as a stopgap measure to minimize the threat of sea-water intrusion.

INTRODUCTION

Infiltration from the Miami Canal and its tributaries has long been recognized by water managers and hydrologists as a major source of recharge to the Biscayne aquifer in the city of Miami well fields in the Miami Springs-Hialeah area (fig. 1). Recharge from the canals tends to stabilize the cone of depression about the well fields and prevents sea-water intrusion. In recent years (1970-71), especially during the 1971 drought, the depth of the cone of depression has increased because of increased pumpage, and the cone of depression has expanded southward toward tidewater in the Tamiami Canal. The chloride concentration of water in the aquifer beneath the Miami International Airport also has increased in response to peak pumpage. Water officials are concerned over a recurrence of sea-water intrusion, which has historically been the chief threat to Miami's water supply.

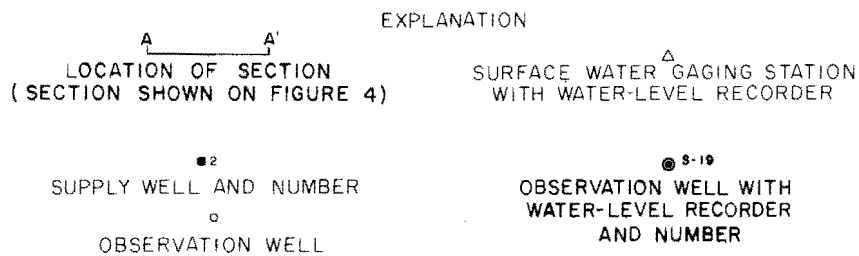
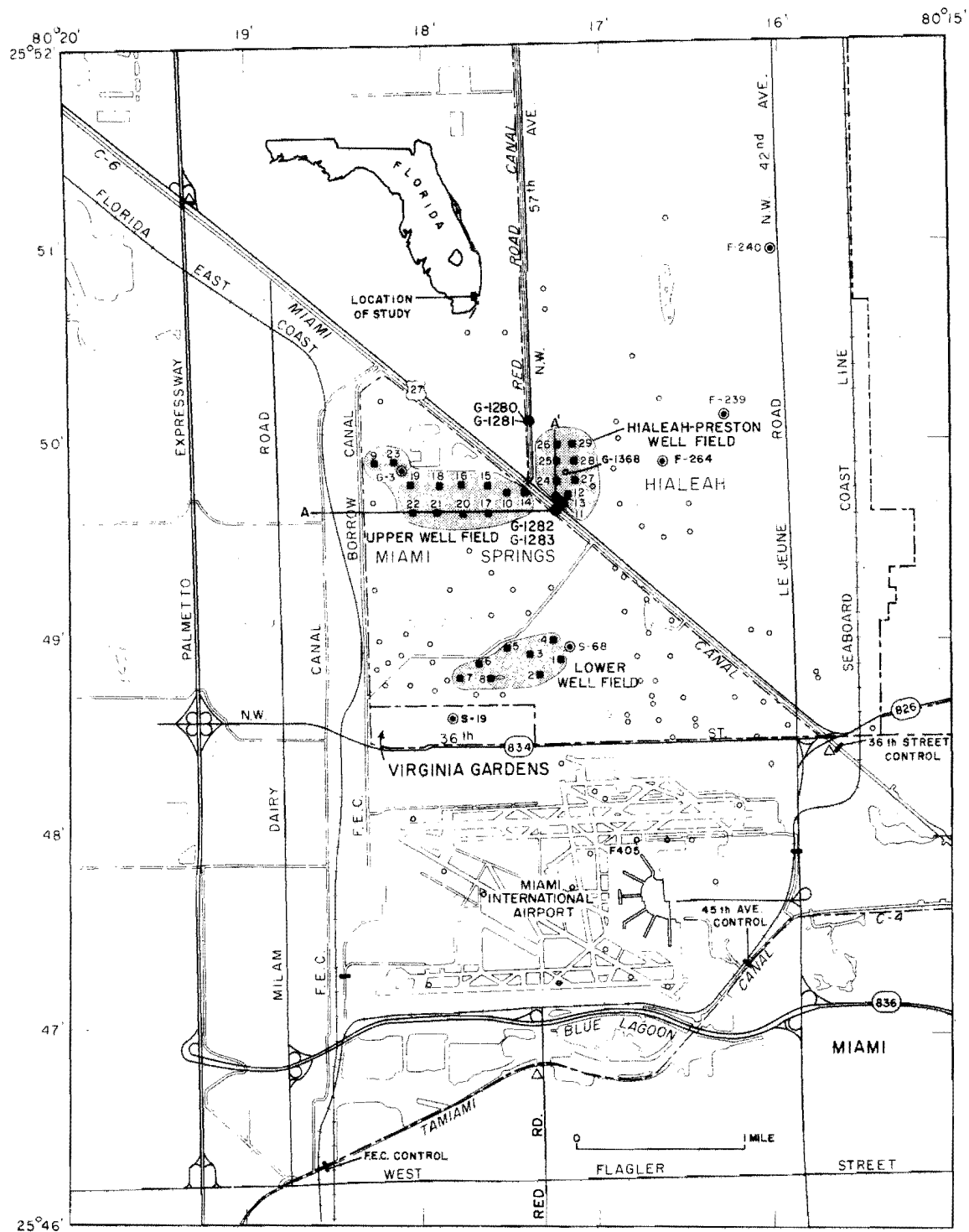


Figure 1.--Location map showing well fields, principal hydrologic features, and data-collection sites.

Purpose and Scope

The purpose of this investigation is to evaluate the capability of the Miami Canal system to supply sufficient recharge to the Biscayne aquifer where it underlies the city's Miami Springs-Hialeah well fields to meet future water demands and to prevent a recurrence of sea-water intrusion. The report, based on historical data, covers (1) the relation between the size of the cone of depression and the rate and areas of infiltration from the canals, (2) changes in quality of well-field water, and (3) the adequacy of the canal system to supply increasing pumpage.

The information should be helpful to local officials in planning water-supply and water-management facilities to meet future requirements of Dade County's expanding urban area.

Acknowledgments

This report was prepared by the U.S. Geological Survey as part of the cooperative water-resources program with the Central and Southern Florida Flood Control District, the city of Miami's Department of Water and Sewers, and the Water Control Division of the Metropolitan Dade County Department of Public Works.

The author thanks the following people for providing data for the study: Mr. William V. Storch, Chief Engineer of the Central and Southern Florida Flood Control District; Mr. Garrett Sloan, Director of the Department of Water and Sewers, city of Miami; and Mr. F.D.R. Park, Chief Engineer of the Dade County Water Control Division.

The work was done under the supervision of T.J. Buchanan, subdistrict chief, Miami, and C.S. Conover, district chief, Tallahassee, both of the U.S. Geological Survey.

HYDROLOGIC SETTING

Biscayne Aquifer

The Biscayne aquifer (Parker, 1955, p. 160-162; Schroeder, 1958), a section of highly permeable limestone strata, ranging in age from late Miocene to Pleistocene, underlies most of Dade and Broward Counties (fig. 2). The aquifer is about 110 feet thick in the Miami Springs-Hialeah area and is the source of fresh water for the city of Miami's wells. The aquifer overlies a relatively impermeable bed of green shelly marl in the Tamiami Formation.

Locally, the principal formations included in the aquifer (from oldest to youngest) are: the upper part of the Tamiami Formation (Parker, 1951, p. 823), of late Miocene age; the Fort Thompson Formation (Cooke and Mossom, 1929, p. 211-215), of Pleistocene age; and the Miami Limestone^{1/} of Hoffmeister and others (1967), of Pleistocene age. The highly permeable Fort Thompson Formation, however, constitutes about 80 percent of the total thickness of the aquifer.

1/ The Miami Limestone refers to the formation which has been called the Miami Oolite by previous writers.

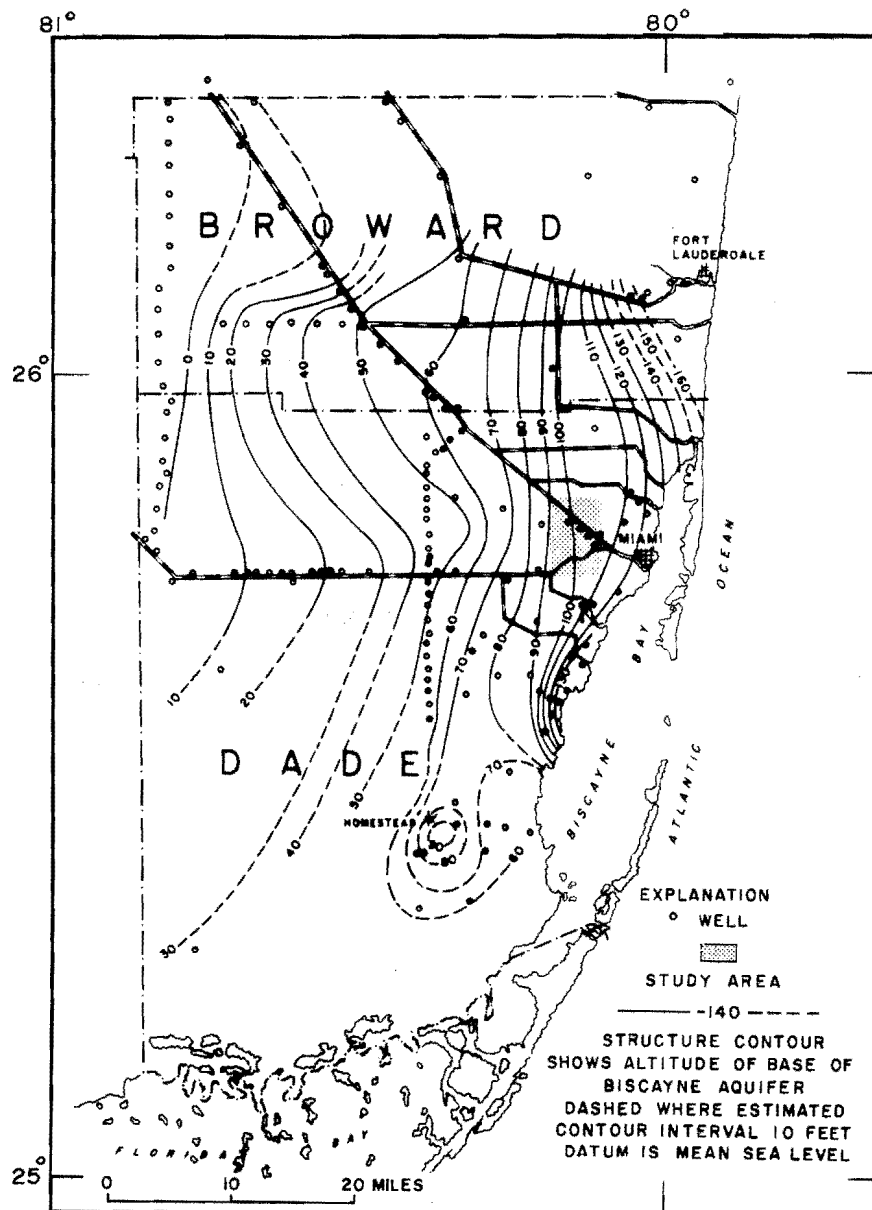


Figure 2.--Map of Dade and Broward Counties showing contours on the base of Biscayne aquifer.

Drainage

The region is drained chiefly by the primary canal system of the Central and Southern Florida Flood Control District (fig. 3). Canals and related works are designed to furnish flood protection to urban and agricultural areas during rainy seasons and to provide facilities for storing fresh water for replenishment of the aquifer along the coast during dry seasons. Coastal reaches of most canals are protected from sea-water intrusion by salinity controls. The water-management system is designed around the water-storage capabilities of Lake Okeechobee and the Conservation Areas. Seepage and regulated releases from the lake and the Conservation Areas to the canal system sustain water levels along the coast, replenish well fields, and prevent sea-water intrusion. The canal system is also designed to discharge excess water to the sea or for backpumping excess water to storage in the lake and Conservation Areas.

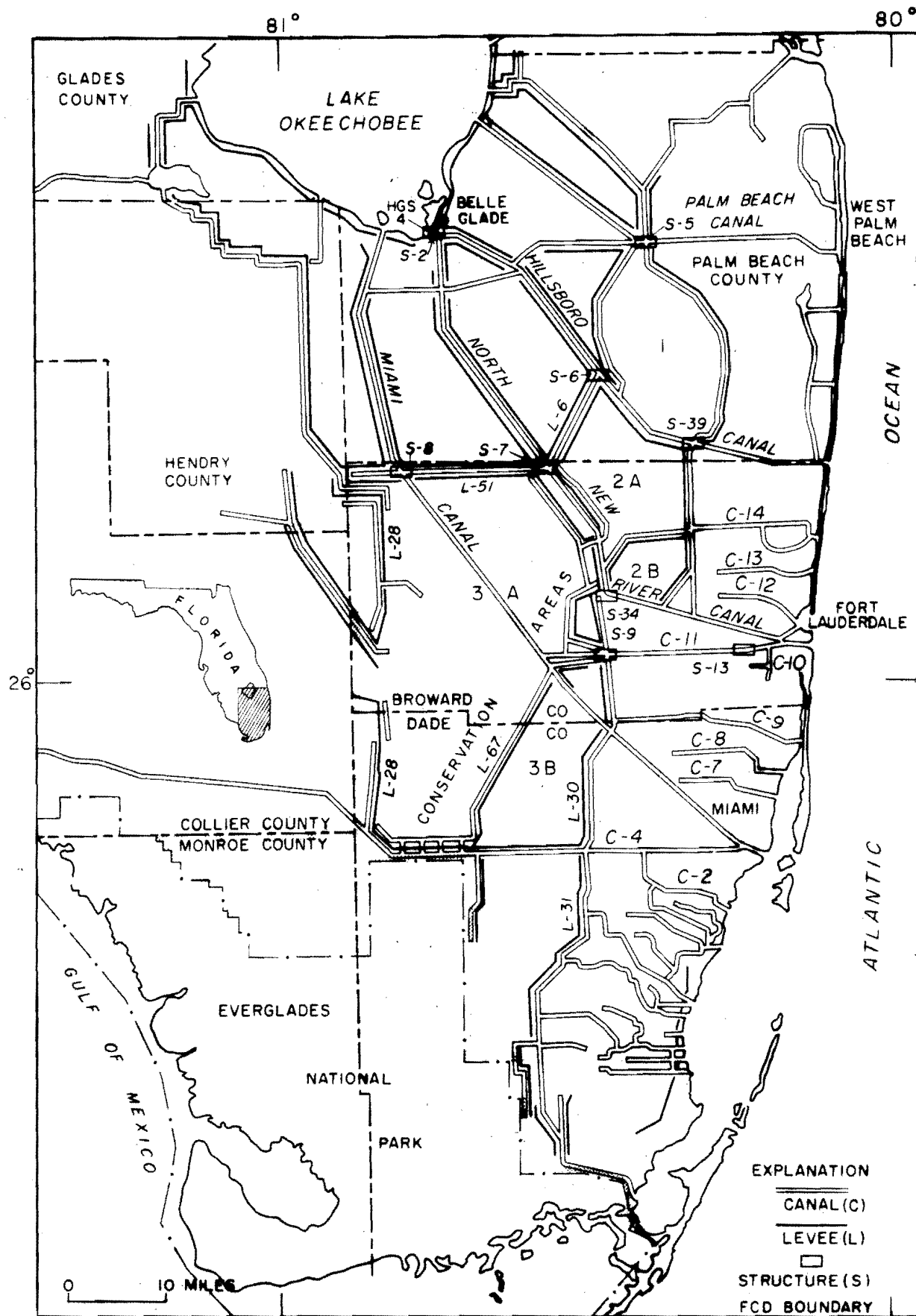


Figure 3.--Map of southeastern Florida showing the Central and Southern Florida Flood Control project and hydrologic features in 1968.

Plans by the U.S. Corps of Engineers and the Central and Southern Florida Flood Control District call for construction of permanent salinity-control structures in the Miami and Tamiami canals to replace temporary controls and for construction of secondary controls in the Miami Canal (C-6), Snake Creek Canal (C-9), Biscayne Canal (C-8), Little River Canal (C-7), Tamiami Canal (C-4), Coral Gables Canal (C-3), and Snapper Creek Canal (C-2), so that part of the storm water that normally flows eastward from low areas west of Miami to tidewater will be backpumped into Conservation Area 3B (Kohout and Hartwell, 1967). When implemented, the plan, called the Area B Backpumping Plan, will add to the conservation of fresh water for future use in Dade County.

Relation Between Ground Water and Surface Water

The hydraulic connection between the controlled canals and the highly permeable Biscayne aquifer is good in the Miami area. The success of overall water management to a great degree depends upon the ability of the system to: (1) lower ground-water levels by discharging excess water to the canals and then to the ocean for flood control in the urban and agricultural areas during wet periods; (2) furnish adequate water from the storage system to recharge the well-field areas during times of peak pumpage; (3) prevent sea-water intrusion during prolonged drought. The rate of infiltration from canals to aquifer, however, is expected to diminish with time, as fine sediment accumulates on the bottom of the canals. The principal areas of concern are the reaches of the coastal canals opposite large well fields. There, the gradual accumulation of bottom sediment would be most harmful because canals within these reaches supply most of the recharge to aquifers.

Sea-Water Intrusion

Sea-water intrusion has historically been the chief threat to the water resources of southeastern Florida. Parker, Ferguson, Love, and others (1955, p. 571-711) described in detail the history and causes of regional sea water intrusion, 1907-50. Generally, sea-water intrusion is related to uncontrolled canals. In early years of development, several large uncontrolled canals were constructed from the Everglades eastward to the coast to drain low-lying lands for agriculture; other canals were constructed to provide flood protection to urban areas developing along the coast. The net result of uncontrolled drainage was overdrainage. During dry periods, sea water moved several miles up the uncontrolled canals and contaminated nearby fresh-water supplies. For example, sea-water intrusion from the Miami River caused the city of Miami to move its well fields progressively westward. During the 1940's and 1950's salinity controls were placed in the primary canals near the coast to halt the advancing salt front and to reduce fresh-water losses.

The effectiveness of the salinity controls is indicated by the fact that intrusion has been significantly reduced by maintaining adequate water levels upstream from the controls during dry periods. However, sea water may again advance inland unless more water is made available to the coast during dry periods to offset future water demands.

MIAMI SPRINGS-HIALEAH WELL FIELDS

History and Description

Miami's municipal water supply system began in 1898 with the sinking of a well at the Royal Palm Hotel near the mouth of the Miami River. In 1900, increased water demands and sea-water intrusion forced the city-franchised Miami Water Company to construct the Spring Gardens well field about 2 miles upstream near Northwest 10th Avenue and 11th Street, present site of Miami's Civic Center. By 1924, further demand and evidence of sea-water intrusion caused the city to purchase 184 acres in Miami Springs for a well field, and about 20 acres in Hialeah for a water-treatment plant.

In 1925 the 10-mgd (million gallons per day) capacity Hialeah water-treatment plant was constructed, and 8 supply wells in the south part of Miami Springs were drilled (wells 1 through 8, fig. 1). At that time the system was jointly owned and operated by the city of Miami and the Miami Water Company.

By 1932 the capacity of the Hialeah plant had increased from 10 to 20 mgd, and three additional wells were drilled at the plant site in Hialeah (wells 11, 12, 13, fig. 1); by 1938 the plant capacity had increased to 40 mgd, and four additional wells were drilled in the northern part of Miami Springs (wells 14 through 17, fig. 1).

Early in 1939 sea water moved up the Miami Canal to contaminate four nearby wells in Miami Springs. As a result, the city constructed a pumping station at the Hialeah plant to skim fresh water from the canal and a temporary sheet-piling dam in the Miami Canal at N.W. 36th Street to prevent further intrusion of sea water into the reach adjacent to the well fields and to reduce fresh-water losses. The temporary dam was removed later that year because of strong objections from upstream residents, who contended that the control would cause local flooding.

In 1941 the operation of the system was delegated to the newly formed Department of Water and Sewers under the direction of the city's Water and Sewer Board. During 1942-43 efforts to reinstall a control at N.W. 36th Street were thwarted; however, in 1943, a pneumatic dam was installed to prevent upstream movement of sea water during that dry season. It was washed out in the spring of 1945, and a temporary sheet-piling dam was installed shortly thereafter. The city installed the present removable sheet-piling dam in 1946. The responsibility for operating the 36th Street dam was taken over by the Dade County Department of Public Works, who operated the structure until 1966, when responsibility was assumed by the Central and Southern Florida Flood Control District.

By 1947 the treatment capacity of the Hialeah plant had increased from 40 to 60 mgd (maximum output of 80 mgd) and five additional wells were drilled in the upper well field (wells 18 through 22, fig. 1). Increased demands in the southwest part of the county gave impetus to planning the construction of another city-owned water supply system near S.W. 87th Avenue and 72nd Street, the present Alexander Orr treatment plant and related well fields.

In 1948 two additional wells were drilled in the upper well field (wells 23 and 9, fig. 1), and in 1954 another well (well 10, fig. 1) was added to the system, bringing the total number of wells supplying the Hialeah plant to 23.

In 1958 the city prepared a report on expansion of the water-supply system to meet future needs in the northwestern part of the county. As a result, construction of the Preston plant (third city-owned plant) began in 1963 on 18 acres just north of the Hialeah plant (fig. 1).

In 1964 wells 6 and 14 in the Miami Springs well field (fig. 1) were replaced by two larger capacity wells drilled nearby. The replacement wells retain the number designations of the replaced wells.

In 1968 the 60-mgd capacity Preston plant served by six 10-mgd wells (wells 24 through 29, fig. 1) became operational, and the Preston and Hialeah plants were interconnected with the other well fields in the area.

In 1972 the combined treatment capacity of the Hialeah and Preston plants is 120 mgd, according to the city of Miami Department of Water and Sewers. The number of wells in each well field and their aggregate capacity is as follows: Preston well field, 6 wells, 54 mgd; Hialeah well field, 3 wells, 10 mgd; the lower Miami Springs well field, 8 wells, 29.5 mgd; and the upper Miami Springs well field, 12 wells, 42 mgd. The combined capacity of all the 29 wells is 135.5 mgd.

Present (1972) water needs call for immediate construction of a 9-mgd well near the Hialeah plant to supply the Preston plant, and future needs call for expansion of the Preston plant to treat 100 mgd by 1980, according to the city of Miami Department of Water and Sewers. Plans call for drilling new wells to the west and north as needed.

Wells in Miami Springs -Hialeah fields tap the highly permeable limestone strata that constitute the Biscayne aquifer. See section A-A' on fig. 4, located on fig. 1. Locally the aquifer is about 110 feet thick and the city wells range in depth from about 60 to 110 feet. The Miami Limestone underlies the area to a depth of about 17 feet. Beneath it lies a bed of fine to medium sand that retards the vertical movement of water within the aquifer.

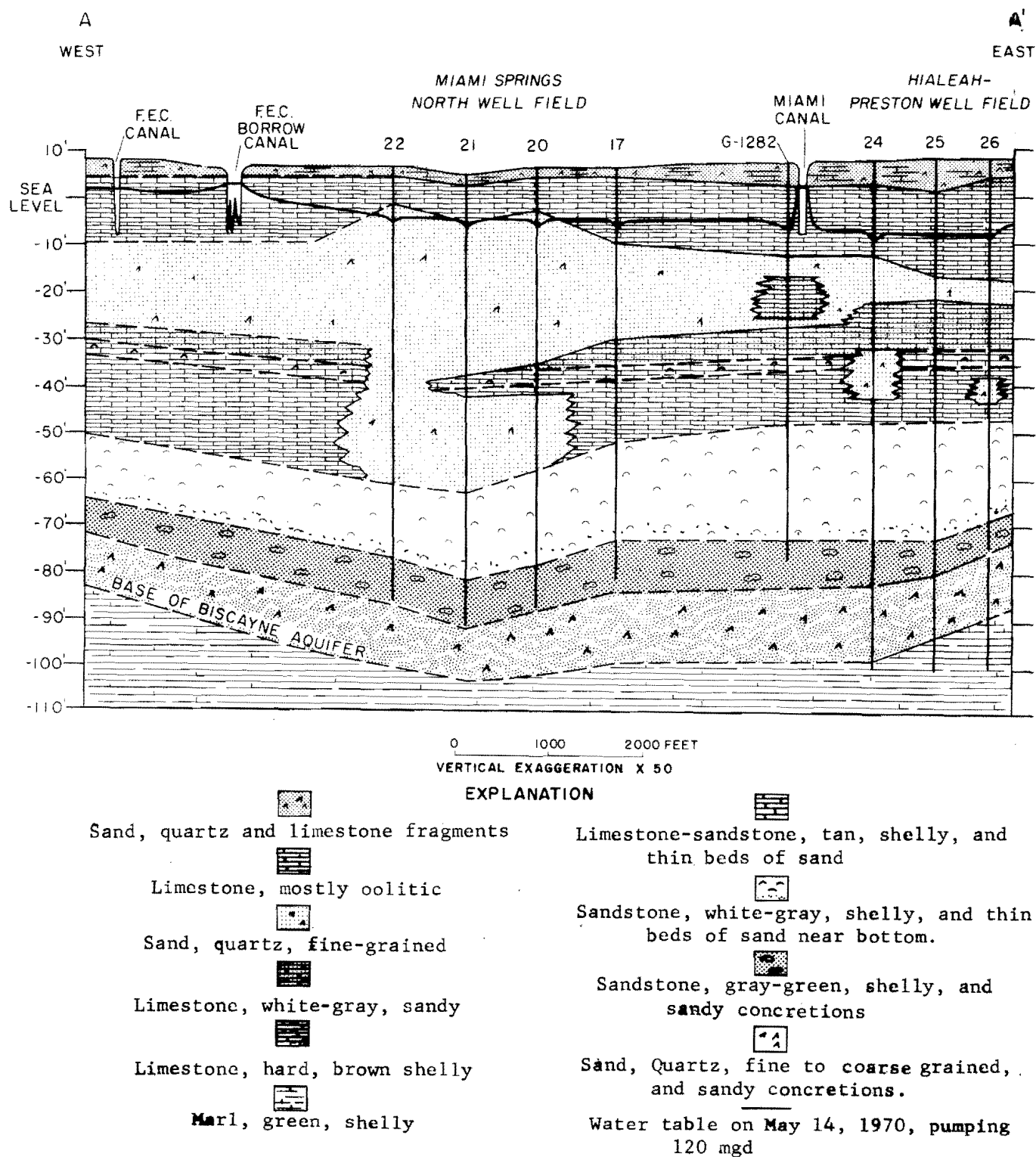


Figure 4.--Section A-A' in the Miami Springs-Hialeah well fields.

Beneath the sand is a 60-foot section of limestone and interbedded sandstone, tentatively identified as the Fort Thompson Formation. Beneath the Fort Thompson is a bed of shelly medium to coarse sand, which is tentatively identified as part of the Tamiami Formation, or the Pinecrest Beds described by A. A. Olsson (1964). Olsson applied the name Pinecrest to a unit overlying the Tamiami Formation. A bed of green shelly marl tentatively identified as the Tamiami Formation of undetermined thickness underlies the sand and forms the base of the Biscayne aquifer. The city supply wells pump from a highly permeable zone between 60 and 90 feet below msl (mean sea level datum of 1929). An aquifer test (S1) in the lower well field indicates that the transmissivity is about 3,200,000 gpd/ft (gallons per day per foot), according to an analysis by John Ferris, research hydrologist for the U.S. Geological Survey (Schroeder 1958, p. 39). The storage coefficient of the aquifer was estimated by Parker (1955) to be about 0.20, based on fluctuations of the water table. The permeability of the Miami Limestone and the sand in the shallow part of the aquifer is generally lower than that of the underlying cavernous Fort Thompson Formation; therefore, the aquifer response to pumping resembles that of an artesian aquifer with a leaky roof.

Pumpage and Pumping Effects

The high rate of increase in pumpage from the Miami Springs-Hialeah well fields reflects the rapid development of the Miami area. Average pumpage increased from 23 mgd in 1941 to 92 mgd in 1971. Pumpage usually increases during drought years, as shown by the peak-day pumpage of 1952, 1963, and 1970 on fig. 5. Peaks were suppressed during the 1945, 1955, and 1971 droughts due to water-use restrictions.

Pumpage fluctuates seasonally and is greatest during December-May. The peak day pumpage usually is maximum during April or May. Peak day pumpage from the Miami Springs-Hialeah well fields during 1970 and 1971 reached 120 mgd.

Water levels in the Miami Springs well fields, as shown by the hydrograph of well S-68 in the lower well field (fig. 6), have been declining since 1961; and the chloride content of water from well F-405 at Miami International Airport has been increasing since 1961 (fig. 7). These data suggest that during 1944-61 the amount of recharge to the well fields was sufficient to minimize the depth and the extent of the cone of depression, although the average pumping rate increased from 30 mgd in 1944 to 67 mgd in 1961. The data since 1961 indicate that the drawdown in the lower well field has been increasing and that the cone of depression has been expanding southward beneath the airport, thus diverting northward deep salty ground water in the vicinity of the Tamiami Canal.

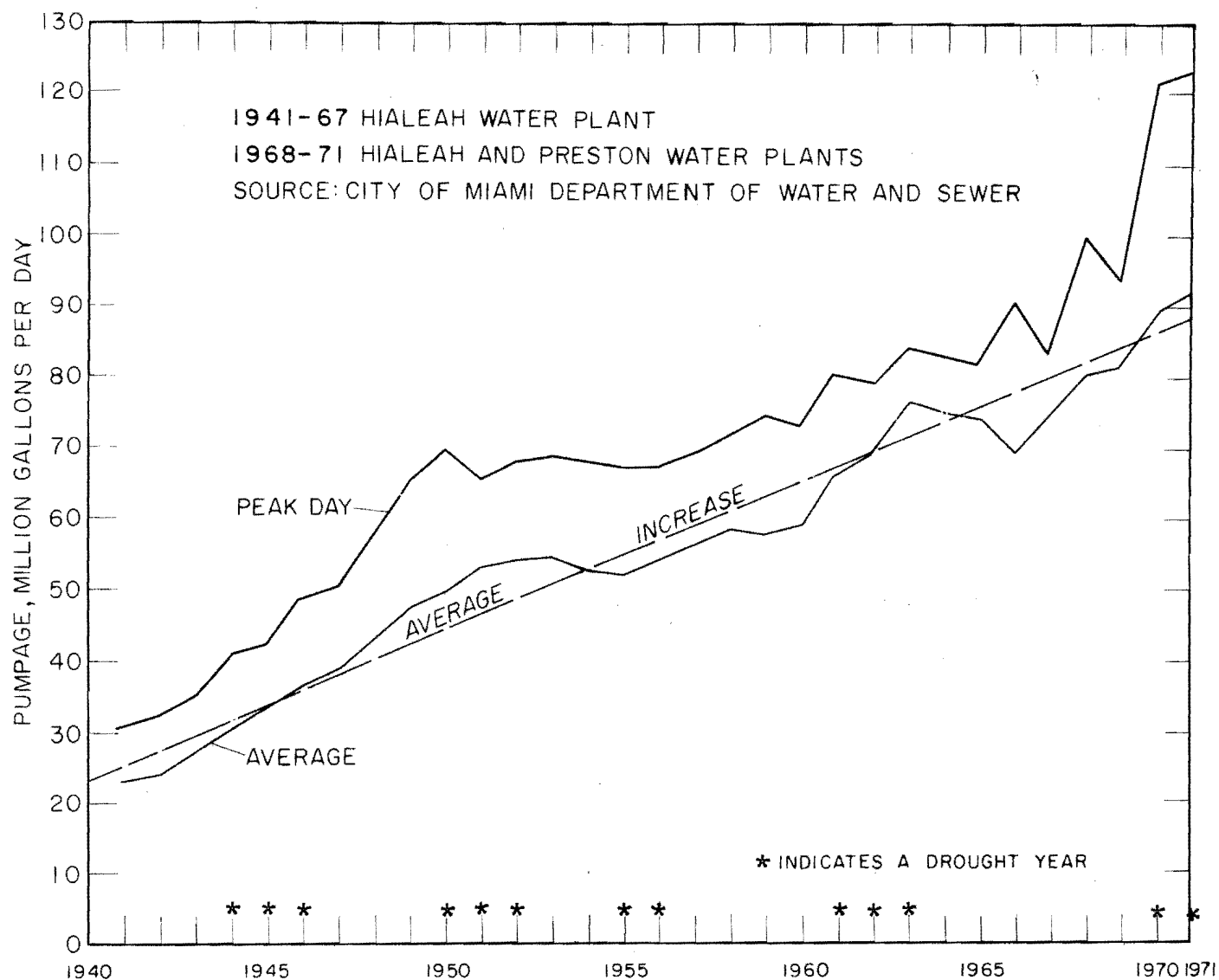


Figure 5.--Graph of the average and peak day pumpage from the Miami Springs-Hialeah well fields, 1940-71.

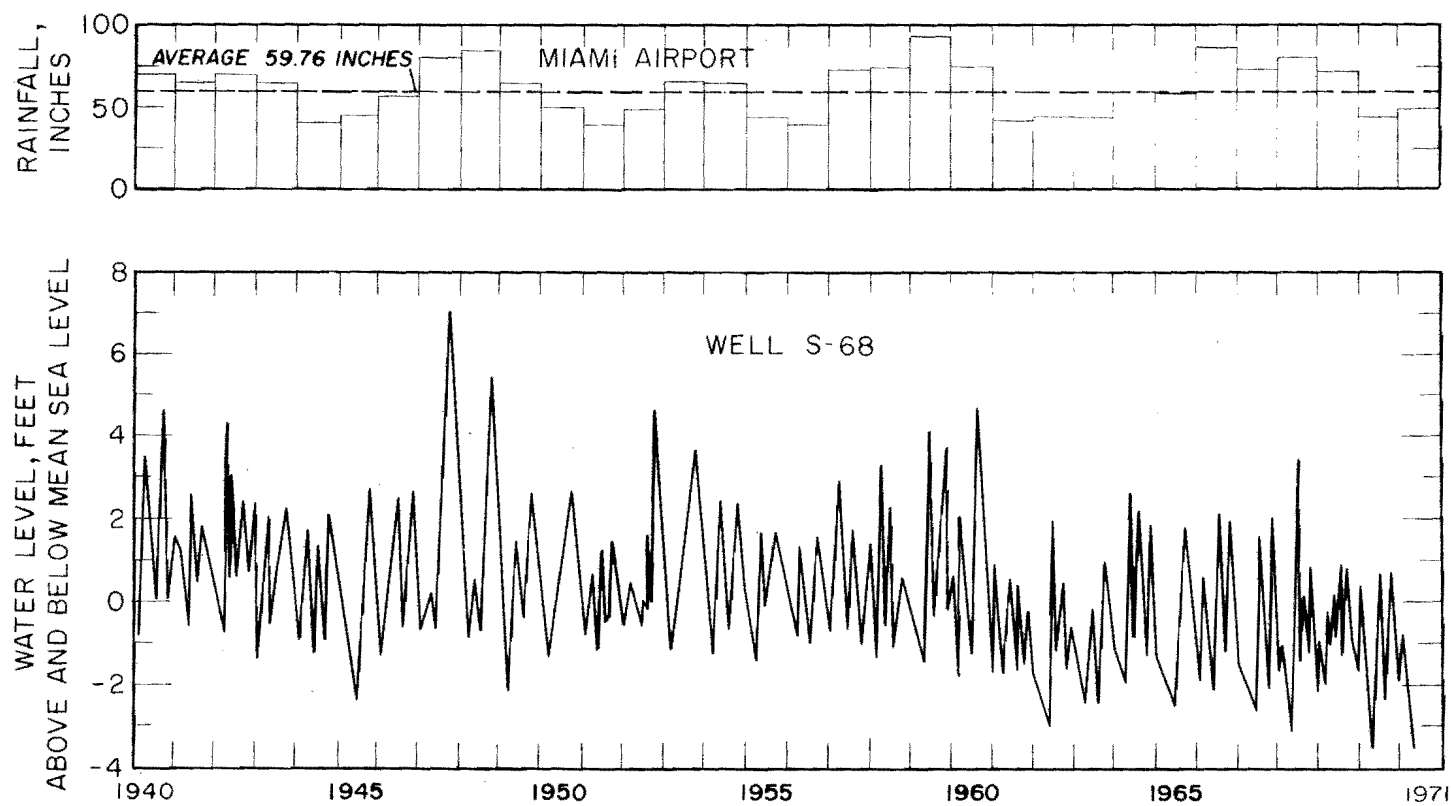


Figure 6.--Hydrograph of well S-68 and rainfall at Miami International Airport, 1940-71.

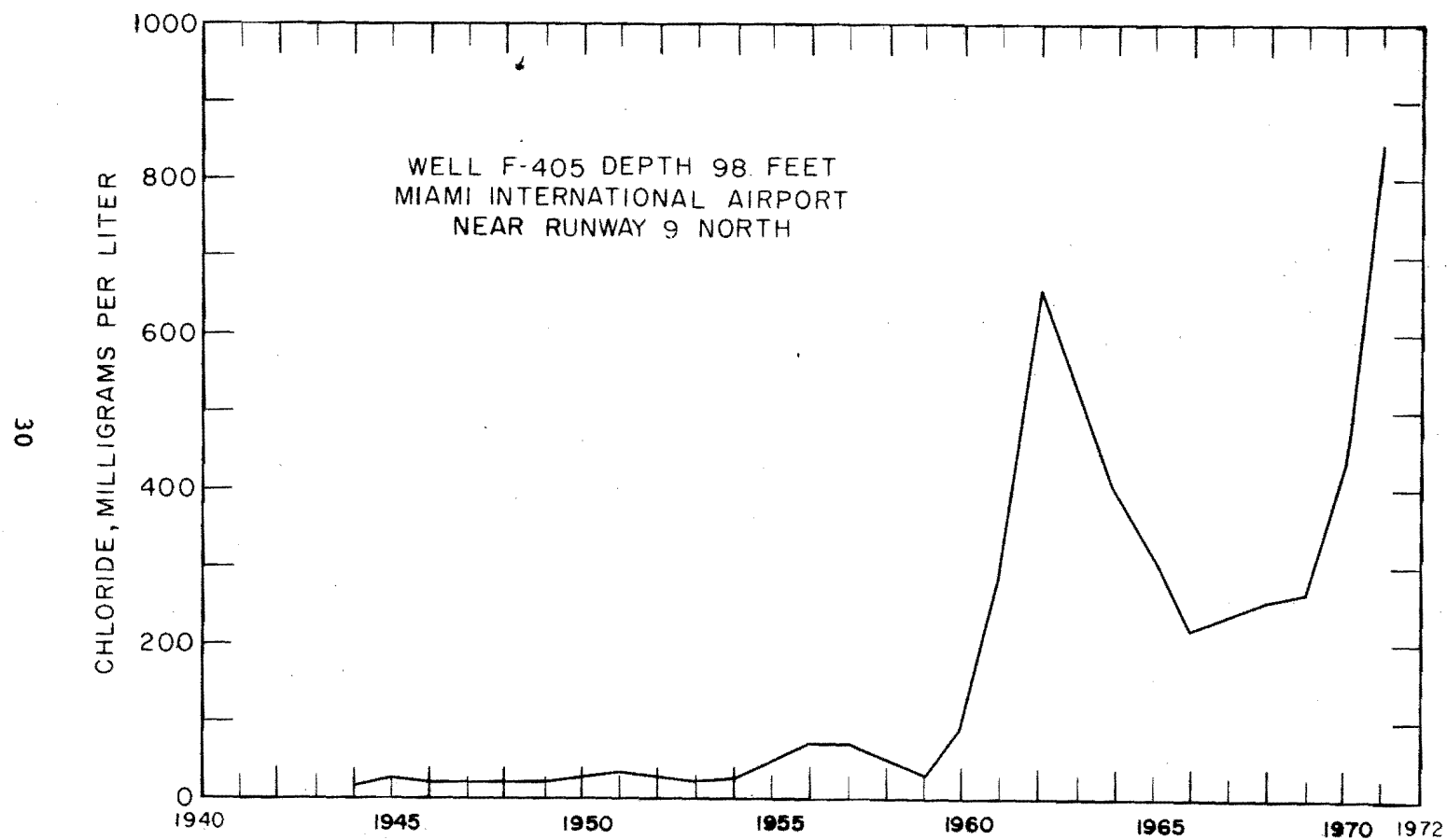
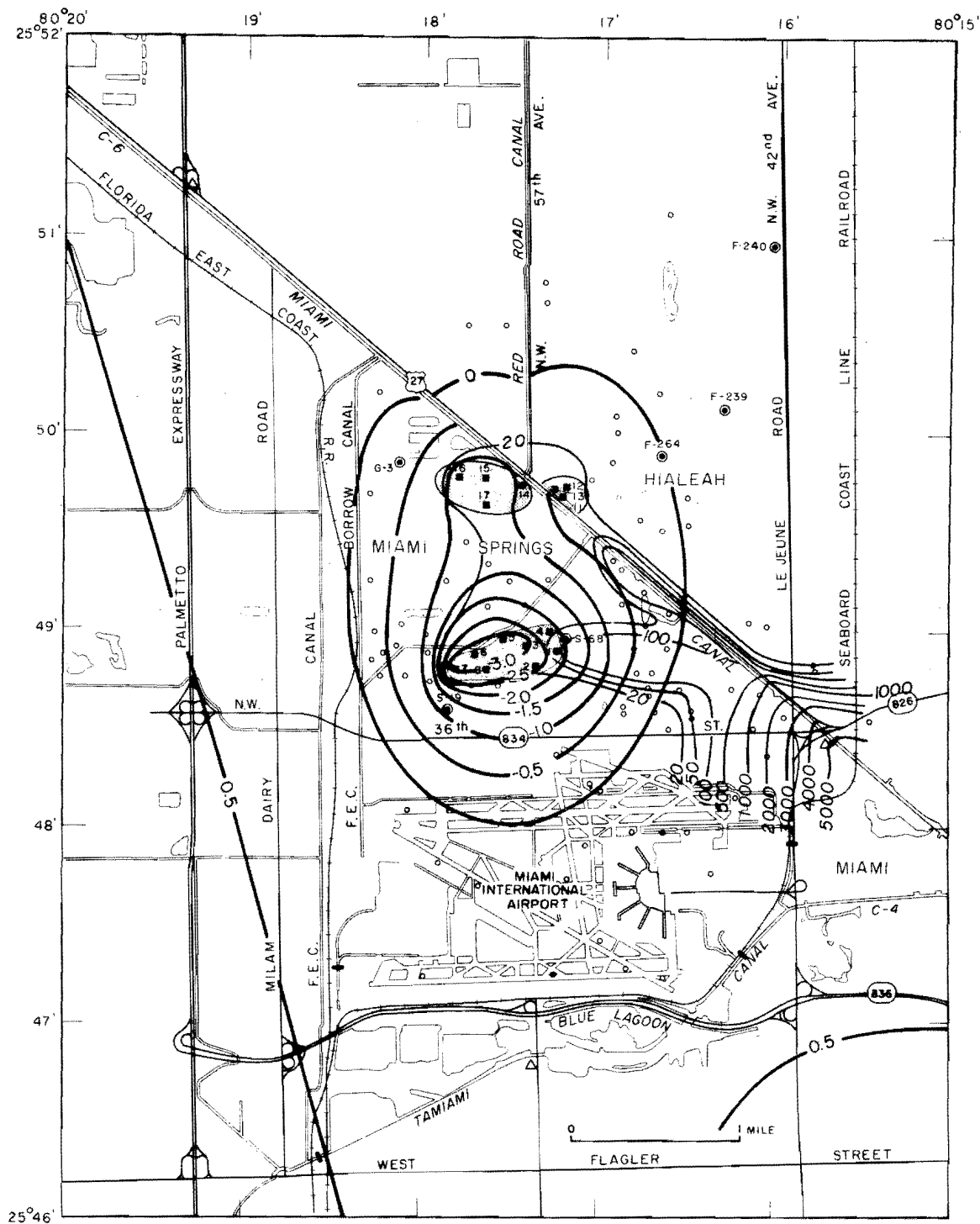


Figure 7.--Graph of chloride content in water from well F-405 at Miami
International Airport, 1944-71.

The effects of increased pumpage on water levels and chloride content are shown best by a comparison of water-table contour maps during progressive stages of development. The contour map in figure 8 for May 31, 1945 (near end of an extreme drought), shows that the water level in the lower well field was 3 feet below msl, and that the zero contour of the cone of depression encompassed an area about 2 miles (east to west) by 3 miles (north to south). Pumpage that day was 38 mgd, 57 cfs (cubic feet per second), from 15 wells. Although the control in the Miami Canal at N.W. 36th Street was closed, the stage of 0.35 foot above msl upstream from the control was insufficient to prevent the salt-water movement through and around the structure; as a result salt water moved upstream along the bottom of the canal to contaminate nearby wells.



EXPLANATION

■ 2
SUPPLY WELL AND NUMBER

○
OBSERVATION WELL

● 5-19
OBSERVATION WELL WITH
WATER-LEVEL RECORDER
AND NUMBER

— 0.5 —
WATER-LEVEL CONTOUR
DATUM IS MEAN SEA LEVEL (1929)
DASHED WHERE ESTIMATED
CONTOUR INTERVAL 0.5 FOOT

— 50 —
LINE OF EQUAL
CHLORIDE CONCENTRATION,
MILLIGRAMS PER LITER

■
WELL FIELD

Figure 8.--Water-table map of the Miami Springs-Hialeah well fields,
May 31, 1945.

The contour map of figure 9 for May 25, 1962 (drought conditions comparable to 1945), shows that the water level was 4 feet below msl in the upper well field and that the area encompassed by the zero contour in the cone of depression was slightly more than 2 miles east to west by $2\frac{1}{2}$ miles north to south. The 23 wells were then yielding 78 mgd, which was about equivalent to the measured flow in the Miami Canal at the Palmetto Expressway. Although the 36th Street control was closed, the upstream stage of 1.06 feet above msl was not sufficient to prevent some salt-water movement upstream. Salt water also moved northward beneath the airport toward the well field, as shown by the position of the 1,000-mg/l (milligrams per liter) chloride line and by the increased chloride content in water from well F-405 (fig.7).

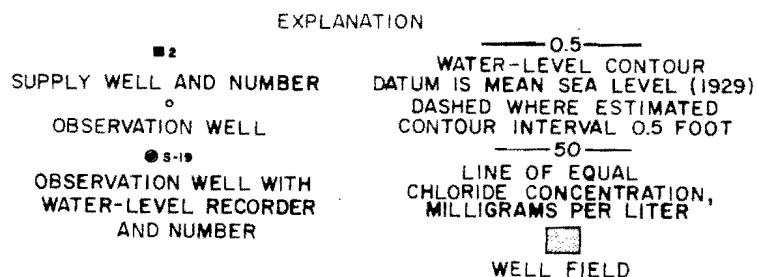
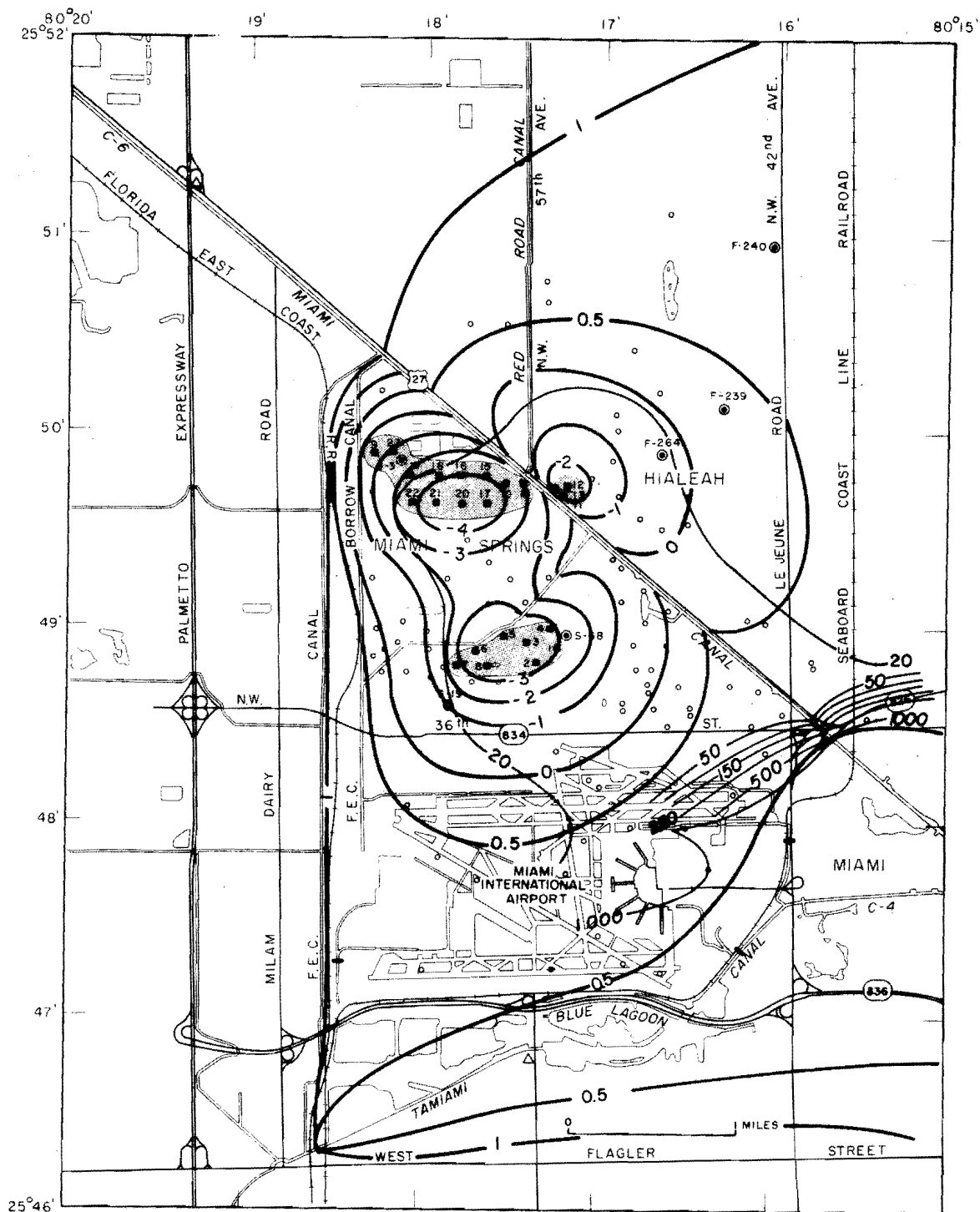
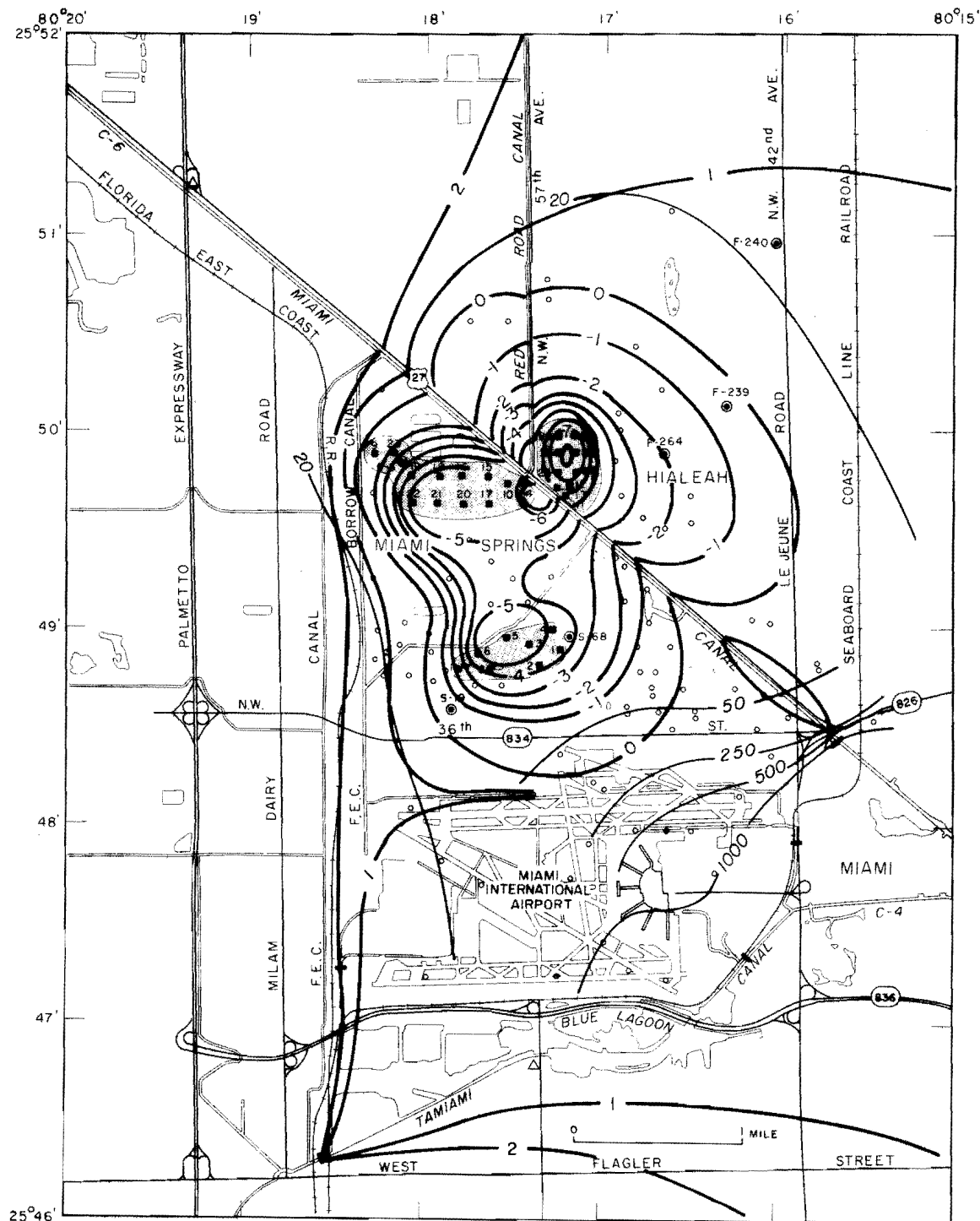


Figure 9.--Water-table map of the Miami Springs-Hialeah well fields,

May 25, 1962.

A comparison of the contour map for May 1945 (fig. 8) with that for May 1962 (fig. 9) shows relatively little change in the size and depth of the cone of depression in the Miami Springs area, although pumpage increased from 38 mgd to 78 mgd. The chief differences between the maps are that in 1962 the water level in the Miami Canal was slightly higher than in 1945 and that in 1945 the well field experienced sea-water intrusion. The rate of infiltration from the canals to the well fields was greater in 1962 than it was in 1945 because hydraulic gradients from the canal were steeper. However, in both cases, the flow in the Miami Canal was insufficient to sustain high fresh-water head above the 36th Street control through the drought to prevent intrusion. As a result, in 1945 salt water moved chiefly upstream in the Miami Canal into the well fields, and in 1962 salt water moved chiefly northward beneath the airport. In 1962, however, the drought was broken by heavy rains in June, which caused water levels to rise and pumpage to decrease; thus, no contamination of supplies occurred.

The contour map for May 14, 1970 (fig. 10), shows that the water level declined to 9 feet below msl in the Hialeah-Preston well fields and that the area enclosed by the zero contour was about 3 miles east to west by 3 miles north to south. Pumpage that day was 120 mg, 186 cfs, from 29 wells. Pumpage was slightly greater in Hialeah (east of the Miami Canal) than in Miami Springs (west of the Miami Canal); however, the separate depressions were about equal in size. The 1,000-mg/l chloride line was located beneath the south part of the airport, and the 36th Street control was partly open and discharging 439 cfs. The stage above the 36th Street control was 1.42 feet above msl. Flow in the Miami Canal at the Palmetto Expressway was 509 cfs, of which about 70 cfs infiltrated the well fields. About 100 cfs flowed northward from the Tamiami Canal through the F.E.C. Canal toward the Miami Canal. Probably most of the flow in the F.E.C. Canal infiltrated the well fields. The position of the 20 and 50 mg/l chloride lines in 1970 suggests that the water entering the well fields contained between 20 and 50 mg/l chloride. The earlier contour maps indicated that the increase in chloride content of the ground water was caused by the northward movement of salt water from the tidal reaches of the Miami and Tamiami canals. However, recent data suggest that the increase in chloride content is partly related to an influx of inferior water from the Everglades.



EXPLANATION

□ 2
SUPPLY WELL AND NUMBER

○
OBSERVATION WELL

● 5-19
OBSERVATION WELL WITH
WATER-LEVEL RECORDER
AND NUMBER

— 1 —
WATER-LEVEL CONTOUR
DATUM IS MEAN SEA LEVEL (1929)
DASHED WHERE ESTIMATED
CONTOUR INTERVAL 1 FOOT

— 50 —
LINE OF EQUAL
CHLORIDE CONCENTRATION,
MILLIGRAMS PER LITER

□
WELL FIELD

Figure 10.--Water-table map of the Miami Springs-Hialeah well fields,

May 14, 1970.

A comparison of the 1945 and 1962 contour maps (figs. 8 and 9) with that for May 1970 (fig. 10) shows that the additional pumpage from the 60-mgd Preston well field in Hialeah caused the cone of depression to expand northeastward toward the Little River Canal (C-7), about 2.5 miles north of the water plant. Although pumpage from the well fields increased from 1945-70, the configuration of the cone of depression in Miami Springs remained about the same. Releases from Conservation Area 3 in 1970 were sufficient to hold fresh-water head in the canal above the control high enough to prevent sea-water intrusion and to supply the necessary recharge to the well fields.

The contour map for April 16, 1971 (fig. 11), during a drought comparable with those of 1945 and 1962, shows that the area encompassed by the zero contour was about 3 miles east to west, by about 4 miles north to south. Pumpage that day was 118 mg, 182 cfs, from 29 wells. The pumpage from the wells east of the Miami Canal was slightly greater than from the wells to the west. For the first time the zero contour overlapped the position of the 1,000 mg/l chloride line, and the chloride content of water from observation wells at the airport began to increase sharply (fig. 7). The 36th Street control was closed but leaking. The daily mean stage above the control was 1.33 feet, but during high tides small amounts of salt water moved upstream through the control. The net leakage downstream through the control was estimated to be 50 cfs.

In order to minimize this obvious threat to the well fields, pumping from 7 of the 8 wells in the lower well field was curtailed, and for the first time water was pumped down the Miami Canal from Lake Okeechobee to raise water levels in the well-field area. The effects of these actions are shown by comparison of the April 16 contour map (fig. 11) with that for May 5, 1971 (fig. 12). The bulge in the zero contour in the vicinity of the airport shown on the map for April 16 (fig. 11) disappeared, and the water level in the center of the lower well field in Miami Springs rose from 5 feet below msl to 2 feet below msl.

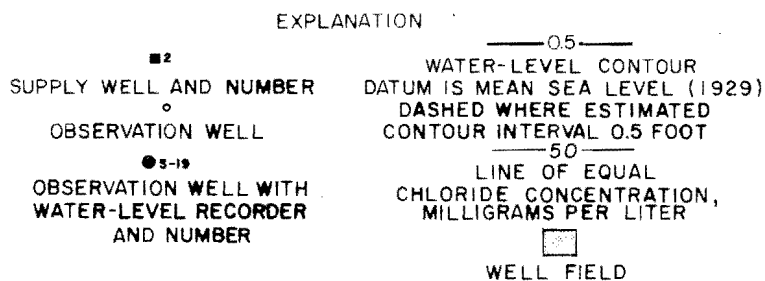
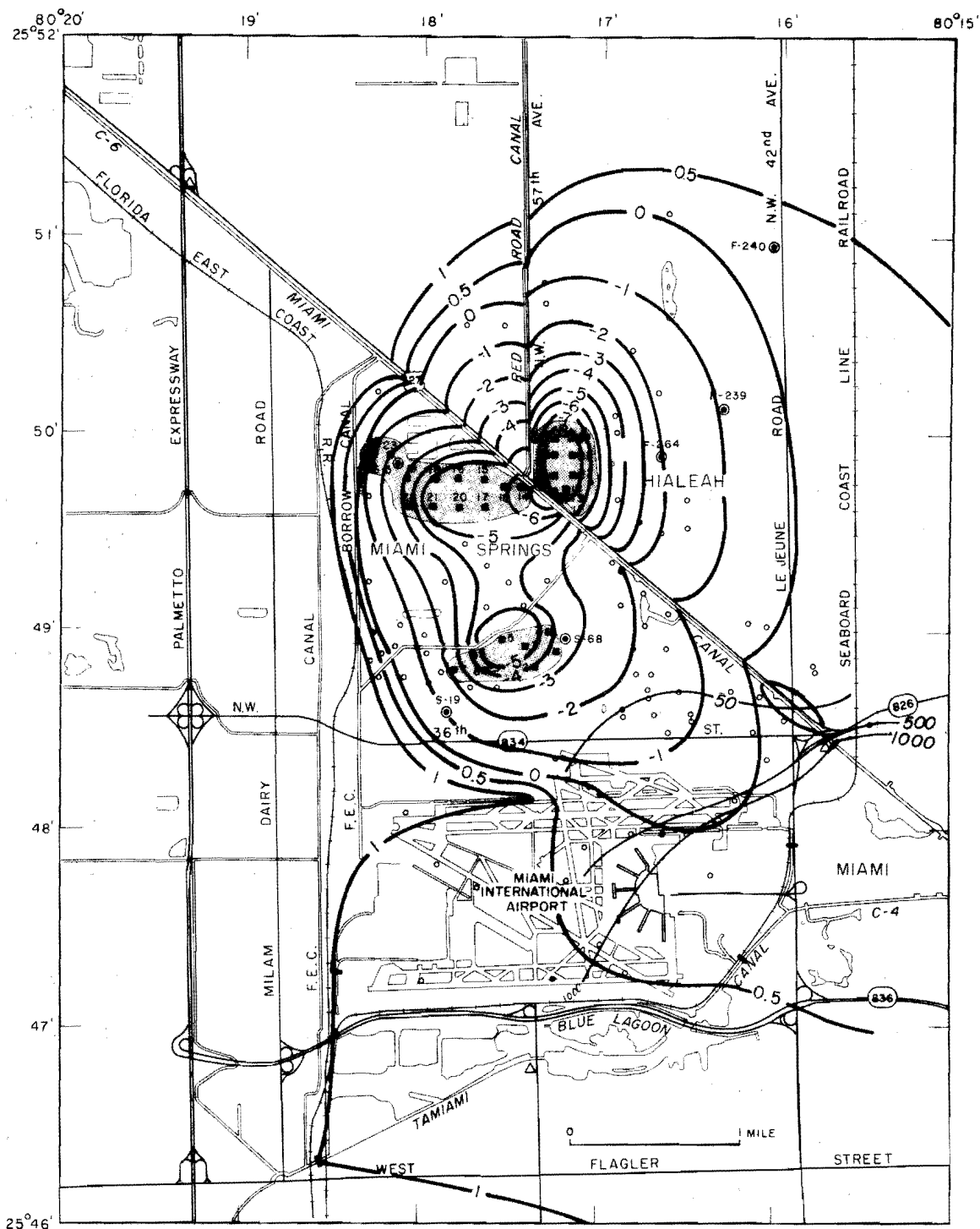
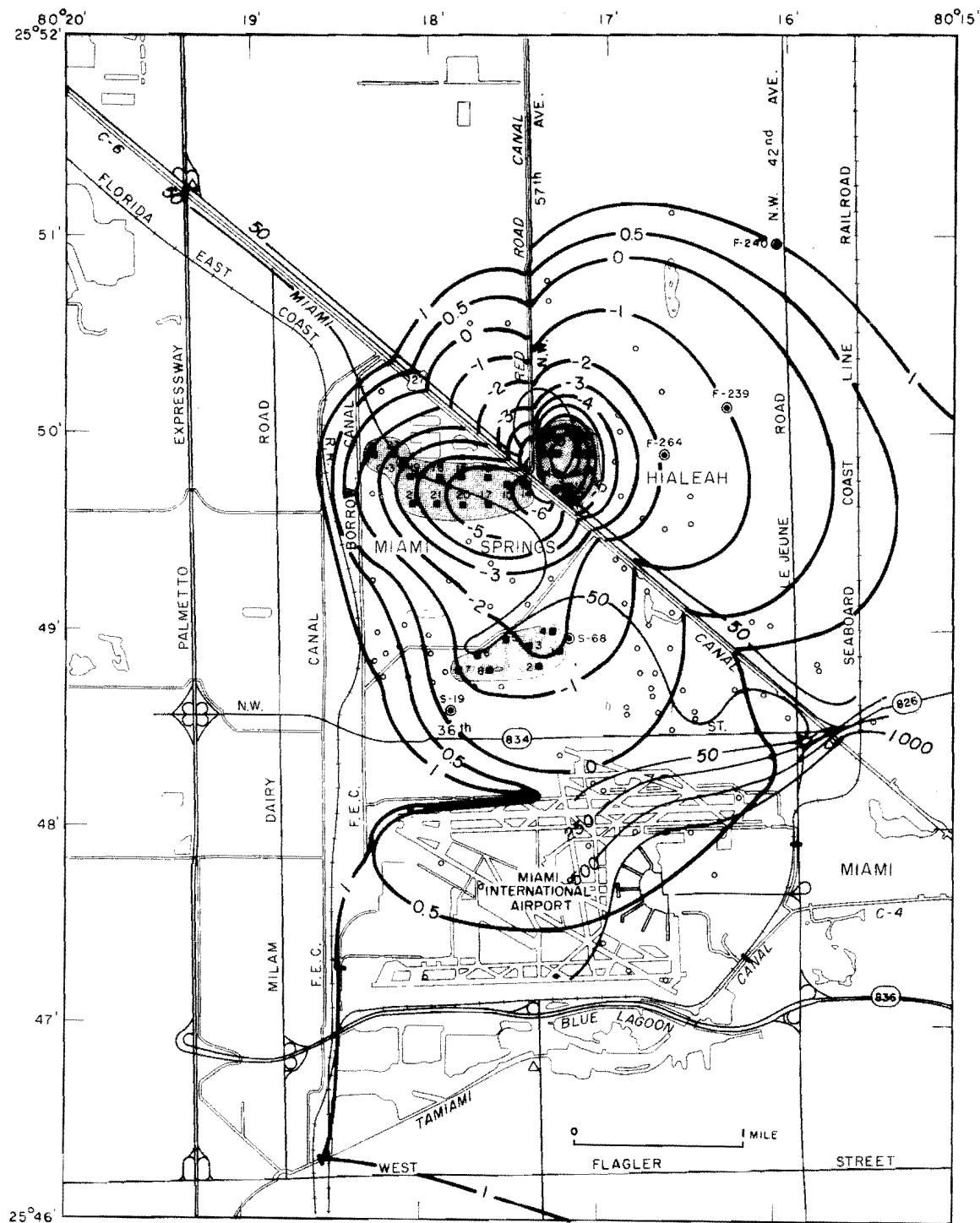


Figure 11.--Water-table map of the Miami Springs-Hialeah well fields,
April 16, 1971.



EXPLANATION

■ 2
SUPPLY WELL AND NUMBER

○
OBSERVATION WELL

● 5-19
OBSERVATION WELL WITH
WATER-LEVEL RECORDER
AND NUMBER

— 0.5 —
WATER-LEVEL CONTOUR
DATUM IS MEAN SEA LEVEL (1929)
DASHED WHERE ESTIMATED
CONTOUR INTERVAL 0.5 FOOT

— 50 —
LINE OF EQUAL
CHLORIDE CONCENTRATION,
MILLIGRAMS PER LITER

■
WELL FIELD

Figure 12.--Water-table map of the Miami Springs-Hialeah well fields,
May 4-5, 1971.

The combined effects of the reduction in pumpage and the increase in fresh-water head above the 36th Street control alleviated the critical drawdown and halted the movement of sea water from the Tamiami Canal toward the well field. The threat of salt-water intrusion will remain until a salinity control is built in the Tamiami Canal southeast of the airport to halt the advance of the salt front permanently. A temporary sheet-pile structure was installed in the canal southeast of the airport in September 1971.

Water Quality

Miami's water supply system yields water of excellent quality. Treatment includes lime-softening, recarbonation, breakpoint chlorination, fluoridation, and filtration. The chief objectionable traits of the raw water from the wells are hardness and color. Treatment reduces the hardness (as CaCO_3) from 230 to 70 mg/l and color from 50 to 10 units (Hazen platinum-cobalt scale).

Sea-water intruding the Miami Canal during 1939-45 caused minor increases in the chloride content of water from the city's wells. For example, in 1945 water from at least one well contained, on the average, 48 mg/l chloride compared with 305 mg/l in the Miami Canal at the Hialeah plant (fig. 13). During May 1945, water from 6 of the 15 wells was affected by the salt water. Chloride content of the canal water at the Hialeah plant reached 6,000 mg/l, and four supply wells nearest the canal were seriously affected by salt-water intrusion and had to be pumped to waste. Detailed accounts of salt-water contamination of the Miami Springs-Hialeah wells and the Miami Canal during 1939-46 were described by Parker, Ferguson, Love and others (1955, p. 631-641 and 691-705).

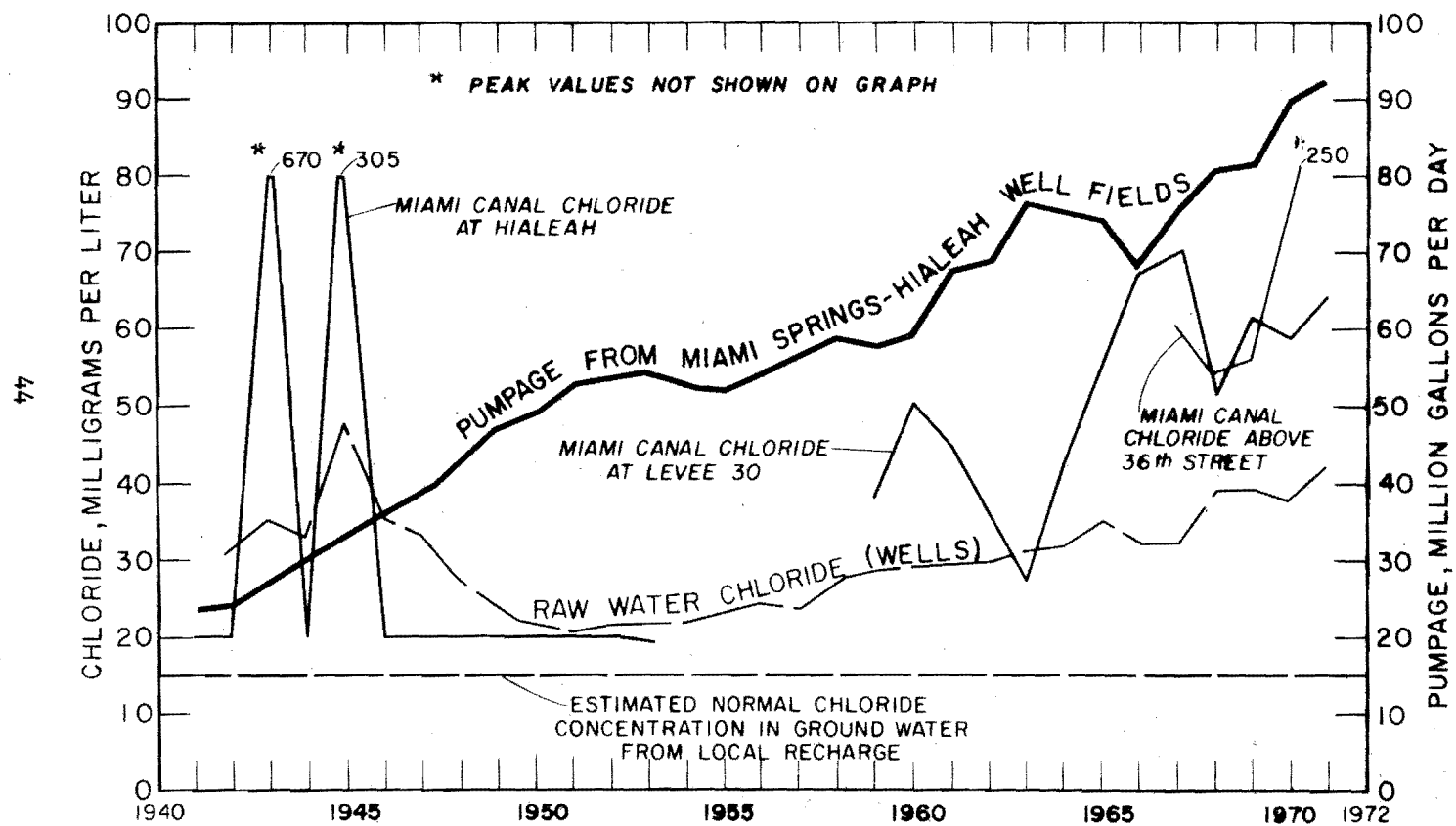


Figure 13.--Graphs of pumpage and chloride content in raw well-field water and canal waters, 1941-71.

The residual effect of the 1945 intrusion on the well-field water is shown by the slow decline in chloride content in the raw water during 1945-50 (fig. 13). Chloride content in the Miami Canal at the Hialeah water plant during 1946-53 was estimated to average 20 mg/l, based on a few samplings. Unfortunately, sampling in the Miami Canal at the Hialeah water plant was discontinued in 1948, and, therefore, long-term data are not available to relate the progressive increase in chloride concentrations in the well-field water to the apparent increases in the chloride content of infiltrating canal water. However, chloride concentrations in the Miami Canal water at Levee 30, 12 miles upstream from the water plant, have generally increased since 1959, which suggests that the chloride content in the canal at the water plant has also increased. Therefore, the increased chloride concentrations in raw well-field water could be due to increased chloride content in the incoming water from Conservation Area 3A and 3B and to upstream migration of salt water from the 36th Street control. Assuming that the chloride concentration in water in the Miami Canal at Hialeah is related to the chloride concentrations in water in the Miami Canal at Levee 30, a comparison of the chloride concentrations in the raw water with estimated concentrations in the normal ground water and with concentrations in the canal at Levee 30 during 1968-71 (fig. 13) suggests that about half the water pumped from the city's wells is contributed by the Miami Canal and its tributaries.

MIAMI CANAL

Description

The Miami Canal is a manmade extension of the Miami River. The Miami River originally extended inland from Biscayne Bay to a point just west of the N.W. 27th Avenue bridge. Dredging of the Miami Canal began in 1909 and proceeded northwestward into the Everglades. The canal was completed in 1932 and extended from Miami to Lake Okeechobee. The lower reach of the Miami Canal was dredged in rock to a depth of about 12 feet below land surface from N.W. 36th Street to its junction with South New River Canal (C-11). The channel of the Miami River was dredged to a depth of 15 feet from Biscayne Bay to the 36th Street bridge.

The upper reach of the Miami Canal was dug in deep mud from Lake Okeechobee 6.5 miles southward through the agricultural area to Bolles Canal. The middle reach of the Miami Canal was dug to only a shallow depth in the thin layer of muck from Bolles Canal 40 miles to South New River Canal (C-11). Because of the poor conveyance capacity of the middle reach, a new conveyance canal (C-123) was constructed parallel to the old Miami Canal during 1967-1969 in order to route water from Lake Okeechobee through the middle and upper reaches to the lower reach of the present Miami Canal.

Excess water in the upper Miami Canal drainage area is pumped into Lake Okeechobee. Pumping station S-8, constructed in the middle reach in 1962, pumps excess water southward into Conservation Area 3A; control structures S-151 and S-31, constructed during 1962-63, regulate flow from the Conservation Areas 3A and 3B to the lower reach of the Miami Canal; and control structures S-32 and S-32A, constructed in 1952, regulate seepage from Conservation Area 3B into the lower reach of the Miami Canal. See location on fig. 3.

The lower reach of the Miami Canal drains Hialeah and Miami Springs and is an important source of recharge to Miami Springs-Hialeah well fields. Details of the Miami Canal drainage before 1950 were presented by Parker, Ferguson, Love and others (1955 p. 406-486).

Flow from the Miami Canal to tidewater has been measured continuously by a gaging station at the 36th Street control since February 1959. Before that time the discharge was measured at a gaging station near the Hialeah Water Plant. Leach and others (1972, p. 53) indicated that little or no discharge occurs when the annual rainfall is less than 37 inches. Their analysis suggests that annual evapotranspiration and seepage from the basin are at least 37 inches and that reductions in discharge at the 36th Street control has been significant since 1955 as a result of completion of levees 30 and 33 on the east side of Conservation Area 3B and operation of the controls S-32 and S-32A in the levee borrow canals. In 1960, a second reduction in flow occurred as a result of construction of levee L-67A, which reduced seepage from Conservation Area 3A. A comparison of the flow-duration curves for 1940-57 and 1959-65 (fig. 14) clearly shows the reduction in flow.

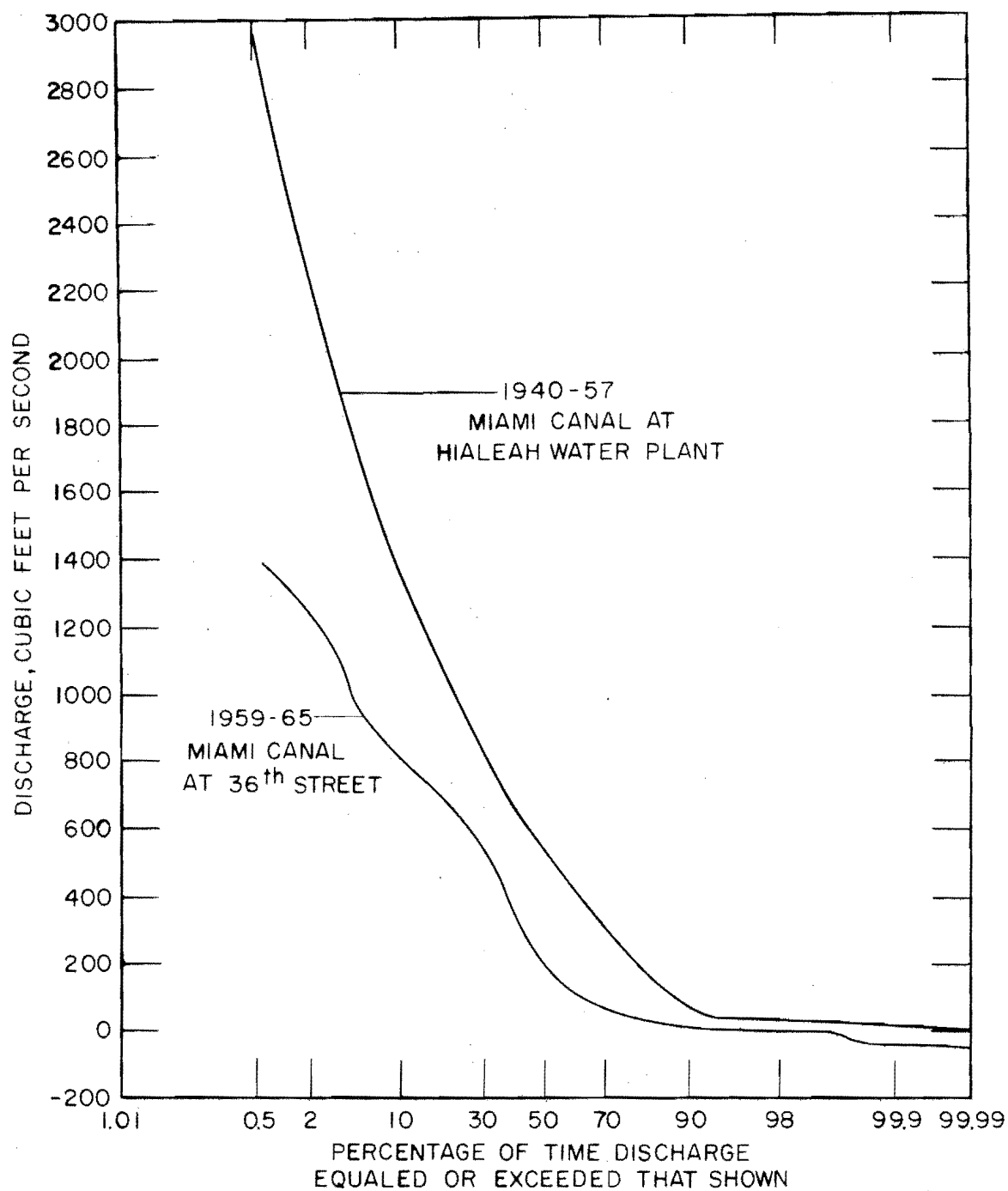


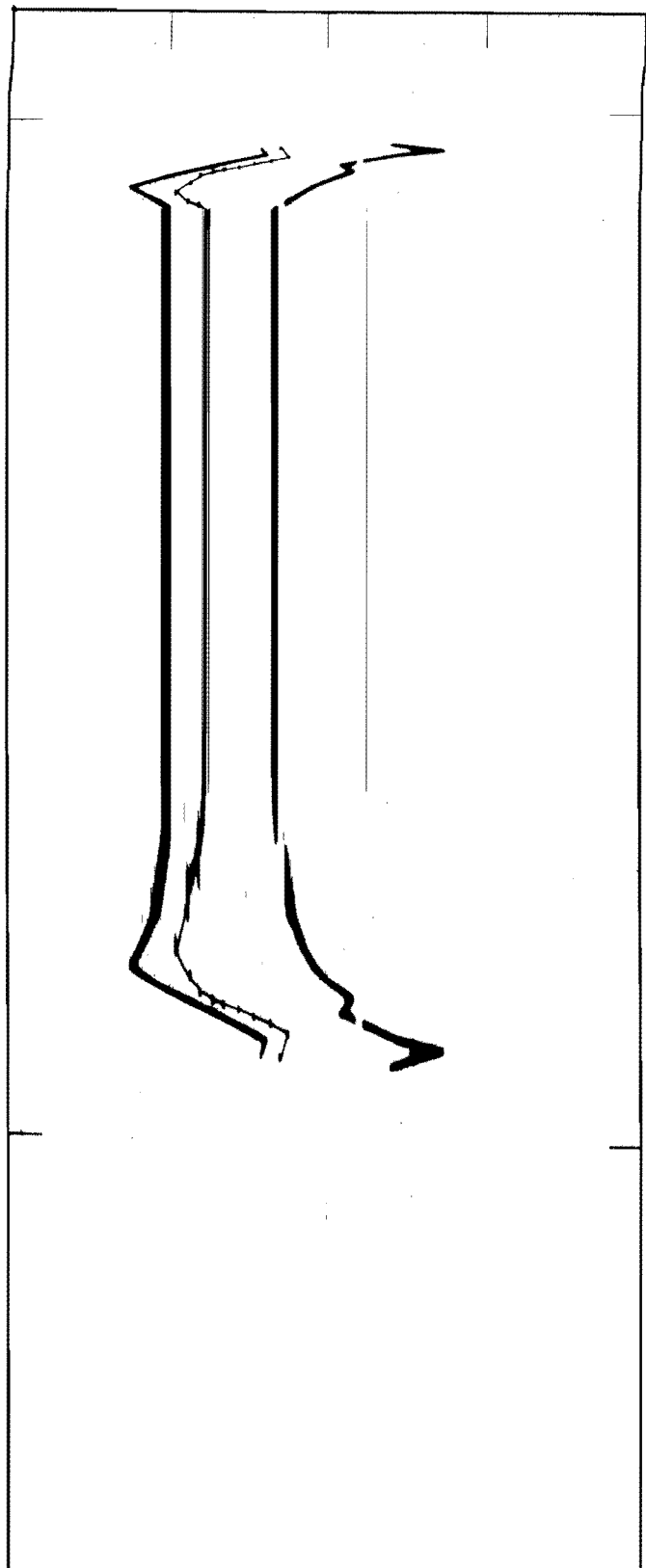
Figure 14.--Flow-duration curves for lower Miami Canal, 1940-57 and 1959-65.

Flow in the reach from Levee 30 to the Palmetto Expressway is distributed as needed to the primary canals, such as Snake Creek Canal (C-9), Biscayne Canal (C-8), Little River Canal (C-7), and the Tamiami Canal (C-4). Flow in the reach from the Palmetto Expressway to 36th Street is distributed to the Miami River, Red Road Canal, F.E.C. Borrow Canal, Southside Canal, and the F.E.C. Canal.

The F.E.C. Canal is connected to the Tamiami Canal and three secondary canals that head to the west. Therefore, the F.E.C. Canal provides a route for exchange of water between the Tamiami and Miami Canals, depending on the stage of each. A comparison of the mean monthly water levels of the Tamiami Canal at Coral Gables Canal with those for the Miami Canal at Palmetto and 36th Street (fig. 15) indicates that water flowed chiefly northward from the Tamiami Canal toward the Miami Canal.







1969 1970

bus CO, and

Water Quality

Parker and others (1955), and Leach and Grantham (1966) documented the movement of salt water in the Miami Canal and Miami River. Their work indicated that the protection of the Miami Springs-Hialeah well fields depends to a great degree on

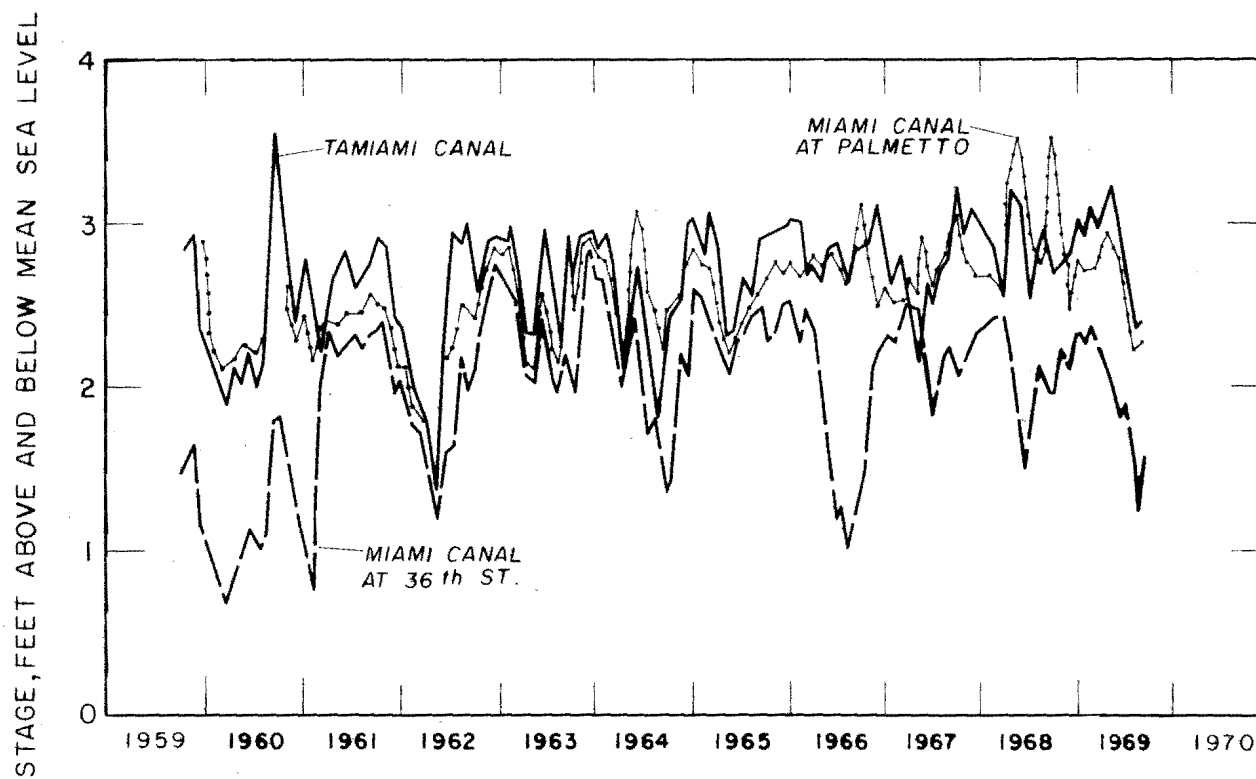


Figure 15.--Hydrographs of Tamiami Canal, Miami Canal at Palmetto, and Miami Canal at 36th Street, 1959-71.

Water Quality

Parker and others (1955), and Leach and Grantham (1966) documented the movement of salt water in the Miami Canal and Miami River. Their work indicated that the protection of the Miami Springs-Hialeah well fields depends to a great degree on operation of the 36th Street control as well as upstream controls (S-151, S-31, S-32 and S-32A). Their studies suggested that the 36th Street control be closed or partly closed when the discharge there falls below 280 cfs and that the necessary controls be regulated to maintain a stage between 2 and 2.5 feet above msl.

The chloride content in the Miami Canal at Levee 30 has increased about twofold since 1959 (fig. 16). During 1959-63 it ranged from 25 mg/l in dry years to 65 mg/l in wet years, averaging about 40 mg/l. During 1964-67 the chloride content increased due to gradual increase in the influx of water from the north and central part of the Everglades, which normally has a ground-water component having high concentrations of residual salt water (Parker, 1955, p.686). Before that time, the drainage at Levee 30 was probably confined to a relatively small area that was salt free except during extremely wet periods; for example, during 1959-60 the canal picked up inferior water from the middle and north reaches and moved it southward to the lower reach, causing the chloride content at Levee 30 to rise sharply.

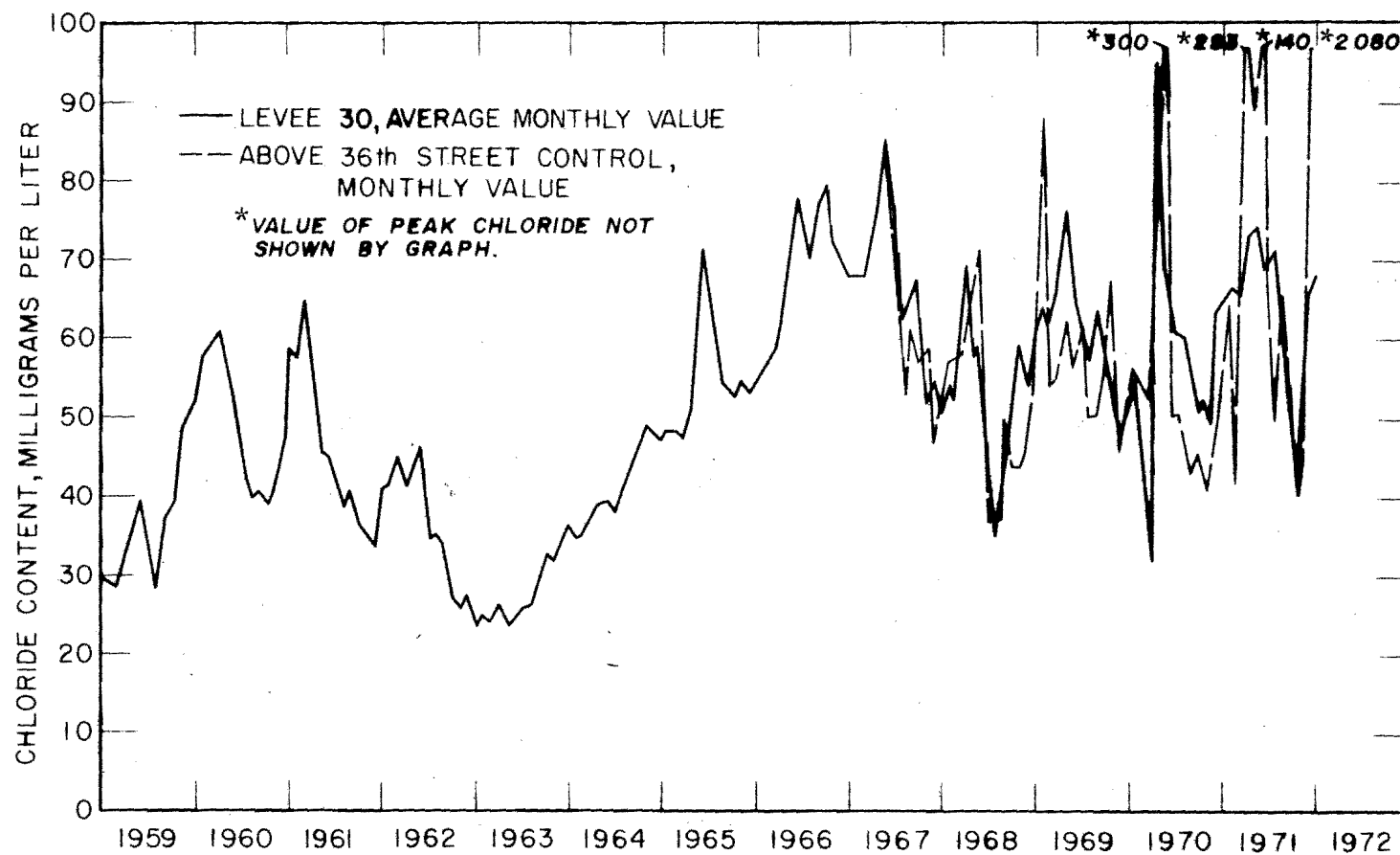


Figure 16.--Graphs of monthly mean chloride content in the Miami Canal
 above the 36th Street control, 1959-71, and at Levee 30,
 1967-71.

During 1967-69, Canal C-123 was constructed parallel to the middle reach of the Miami Canal to transport water from Lake Okeechobee to Dade County. Canal C-123 transects the area of inferior ground water, thereby increasing the flow of chloride-rich waters from the upper and middle reaches to the lower reach. Another factor to be considered in the cause of increased chloride at Levee 30 is the effect that pumping station S-8 has on downstream water quality. Pumping station S-8, completed in 1962, pumps chloride-rich water from the agricultural area near Lake Okeechobee southward into the conservation areas. Therefore, the S-8 pumpage also constitutes a probable source of increasingly high chloride to the downstream reaches of the Miami Canal.

As previously stated in the discussion dealing with water quality in the well fields during the early 1940's, salt water moved up the Miami Canal, and the chloride content in the canal near the Hialeah Plant was in excess of 6,000 mg/l. Operations of the 36th Street control kept the reach above the control relatively salt free until 1962, when abnormally high tides in March topped the control and caused salt water to move upstream. By May 1962 insufficient water was available to raise the fresh-water head upstream from the control and salt water again moved upstream. The chloride concentration of water in the canal was 7,200 mg/l about eight-tenths of a mile upstream (Leach and Grantham, 1966, p. 24).

A comparison of the chloride content of water in the Miami Canal upstream from the 36th Street control with those in the canal at Levee 30 during 1967-71 (fig. 16) indicates that average monthly concentrations during 1967-68 (wet years) were about the same at both sites, which suggests that runoff and seepage from the area upstream of Levee 30 was sufficient to cause a nearly uniform distribution of chloride in the reach between Levee 30 and the control. During 1969 (a wet year) construction of Canal C-123 was completed, so that more inferior water from the central and northern Everglades flowed southward to the lower reach of the Miami Canal. During 1970-71 rainfall was far below average, and inferior water from the middle and upper reaches of the Miami Canal (hence Canal C-123) had to be routed downstream during the winter and spring to help reduce drought effects along the coast.

As a result, chloride was generally higher during the 1970-71 dry seasons at both sampling sites; but it was much higher upstream from 36th Street than at Levee 30, because the water immediately above the control was affected by upstream leakage of salt water from the tidal reach. Thus, the reach between Levee 30 and the control was being invaded by salty water.

The net effect on the chloride content of the water in the canal between the two sites was probably small because the intervening basin, no doubt, contributed some water with lower chloride content. Therefore, the chloride content in canal water near the Hialeah Water Plant would probably have been lower than that above the control and at Levee 30, and the average yearly chloride in the canal water at the Hialeah Water Plant, therefore, would probably have been slightly lower than that above the control and at Levee 30. Chloride concentrations in the lower reach of the Miami Canal should continue to increase slightly as more water is moved southward from the upper and middle reaches to meet increasing urban demands. Likewise, the chloride content in the well-field water should also increase as a result of higher chloride content in the infiltrating canal water.

TAMIAMI CANAL

Description

The Tamiami Canal is tidal from its confluence with the Miami River westward to the F.E.C. Canal. A sheet-pile dam just east of the F.E.C. Canal prevents the westward movement of salt water (fig. 17). East of the F.E.C. dam, secondary canals and ditches drain the southern part of Miami's International Airport and several large deep rock pits (for example Blue Lagoon on fig. 1). A contraction in the canal at Red Road reduces the canal's discharge capability, retards the westward movement of salt water, and dampens tidal effects between Red Road and the F.E.C. dam. The controlled reach of the canal receives drainage from the Levee 30 borrow canal, Snapper Creek Canal Extension (C-2), Coral Gables Canal (C-3), and a few secondary canals.

During dry periods water is diverted northward through the F.E.C. Canal toward the Miami Canal to recharge the Miami Springs-Hialeah well fields. However, flow can reverse, depending upon operations of the F.E.C. and 36th Street dams and the relative stages of the Miami and Tamiami Canals.

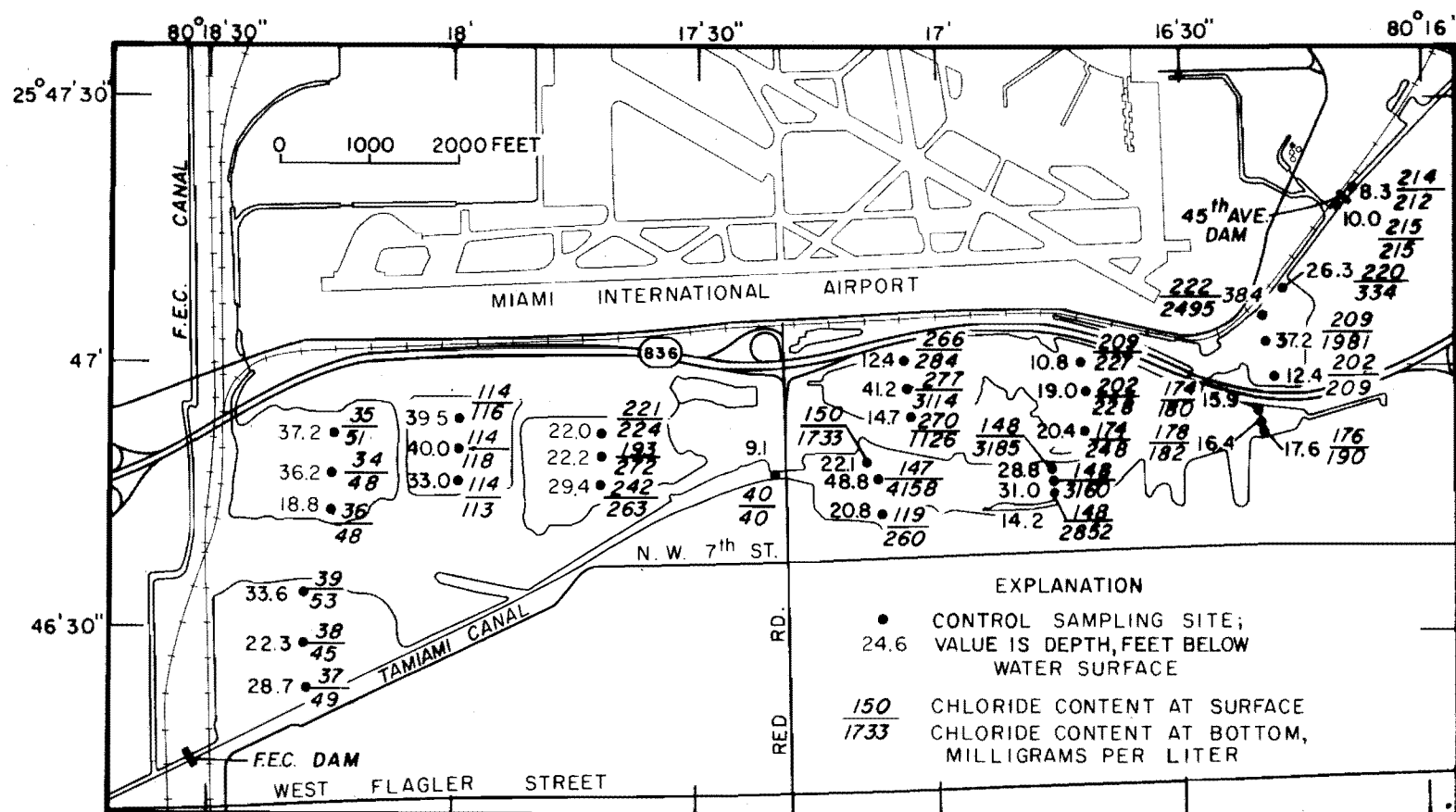


Figure 17.--Map of the Tamiami Canal between the F.E.C. and 45th Avenue dams showing the chloride content on September 28, 1971.

During wet periods part of the flow in the Tamiami Canal upstream from the F.E.C. dam is diverted to the Miami Canal due to the poor conveyance of the Tamiami Canal at Red Road.

In September 1971, a temporary sheet-piling dam was installed in the Tamiami Canal about 2,000 feet west of Le Jeune Road at N.W. 45th Avenue (fig. 17) to stem the threat of sea-water intrusion to the well fields until a planned permanent structure can be constructed near Le Jeune Road.

Water Quality

Salt water occurs in the Tamiami Canal chiefly in the reach from the Miami River to Red Road. Parker (1955 p. 666) concluded that salt water in the deep parts of the canal and associated rock pits posed a significant threat to the well fields. He found that only a low ground-water divide across the airport prevented the movement of salty ground water from the Tamiami Canal area northward into the well fields. Parker also found that in 1942-46 the salt water between the Miami and Tamiami Canals in the Biscayne aquifer advanced northward toward the well fields despite the fact that the 36th Street control was in operation in 1945-46, and he predicted that the well fields would be contaminated by salt water in less than 20 years unless the lower reach of the Tamiami Canal was also controlled. His prediction was almost realized in April 1971, when the effect of pumping expanded southward to breach the low ground-water divide, and salty ground water moved northward from the Tamiami Canal area toward the well fields. Only the timely reduction of pumping in the lower well field prevented a serious problem from developing. The seriousness of the situation gave impetus to the construction of the temporary dam in the Tamiami Canal at N.W. 45th Avenue.

On September 28, 1971, the reach from the F.E.C. dam to the 45th Avenue dam was sampled (fig. 17) to determine the distribution of chloride concentrations in the canal at about the time the 45th Avenue dam was installed. Chloride content ranged from about 40 mg/l at the F.E.C. dam to about 4,000 mg/l in deep parts of the rock pits in the reach from Red Road to the 45th Avenue dam (fig. 17). Flushing of the salt water from this reach is expected to require many months. The increased head in the canal upstream from the 45th Avenue dam should increase the hydraulic gradient toward the lower well field and should, therefore, cause some salty ground water to move into the cone of depression. Ultimately, some of the salt water should reach the wells and blend with the total raw-water pumpage.

INFILTRATION FROM CANALS TO THE WELL FIELDS

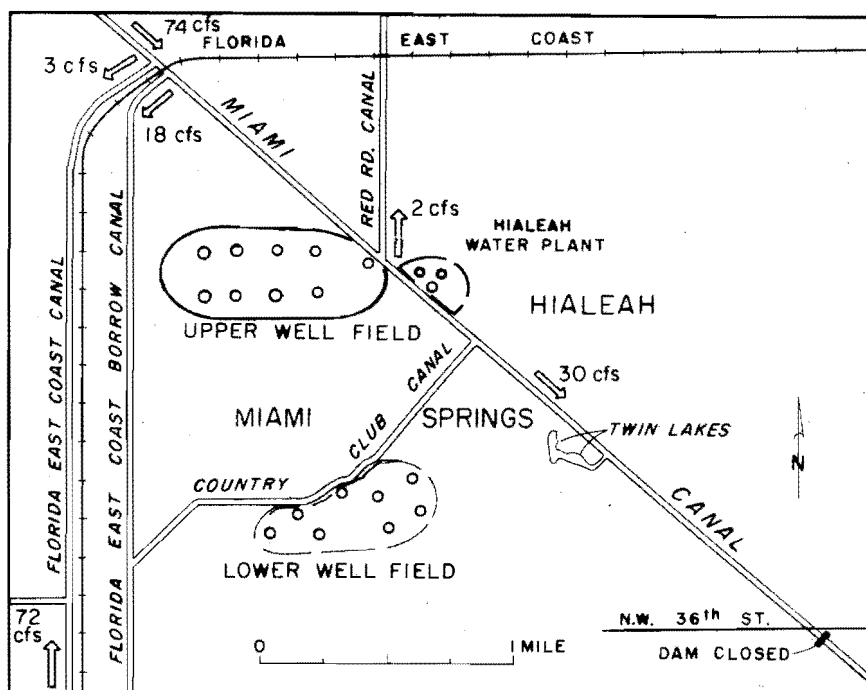
Part of the water pumped from the Miami Springs-Hialeah well fields is obtained from rainfall and part from nearby canals. Infiltration varies with location and time. The part obtained from rainfall is usually greatest during the wet season (June-November), and that obtained from canals is usually greatest during the dry season (December-May). Rainfall infiltration is greatest within the deepest part of the cone of depression, and canal infiltration is greatest where the centers of heaviest pumpage are nearest to canals that cut into the aquifer. Canal infiltration is important to the Miami Springs-Hialeah well fields because pumpage is greatest when rainfall is least, and the part that is obtained from the canals minimizes expansion of the cone of depression into nearby areas that are underlain by salty ground water. If the fresh-water reaches of the nearby canals were capable of supplying all the ever-increasing pumpage, the cone of depression would not increase in size. However, if the nearby canals could not supply the recharge, the cone of depression would expand, and part of the pumpage would be obtained from stored ground water (infiltrated rainfall and water from more remote canals). Therefore, it is important to know whether the rate of infiltration (recharge) from nearby canals is keeping pace with the pumpage. If not, then it is essential to know the cause, so that corrective action can be taken.

Estimates of Infiltration

Estimates of the amount of water that infiltrates the aquifer from nearby canals can be made by: (1) determining loss in flow at selected points in the canals; (2) comparing the quality of pumped ground-water with water from various sources; and (3) analyzing head losses across the sediment in the bottom and sides of the canals. The Miami Canal and tributaries were excavated in rock to depths ranging from 8 to 10 feet below msl. (See section A-A', fig. 4.)

Water-table maps (figs. 8 through 12) and discharge measurements indicate that water from the Miami Canal infiltrates the aquifer tapped by the city's wells, chiefly in the reach of the Miami Canal between the 36th Street Control and the F.E.C. Canal.

Measurements of dry-weather flow in nearby canals during 1946 and 1949 indicated a large infiltration to the Miami Springs-Hialeah well fields. On March 28, 1946, several discharge measurements were made at selected points in the lower reach of the Miami Canal to determine seepage losses to the well fields. See locations on fig. 18. Pumpage that day from the city's wells was 44.4 mgd (69 cfs). On the basis of losses in selected reaches of canals around the well fields, Parker and others (1955, p. 482-484) estimated that 78 percent of the water pumped from the city's wells came from the canals. They further indicated that the percentage varies seasonally; that is, during droughts the canals probably contribute more than 78 percent of the pumpage, and during floods they probably contribute little or no water.



EXPLANATION

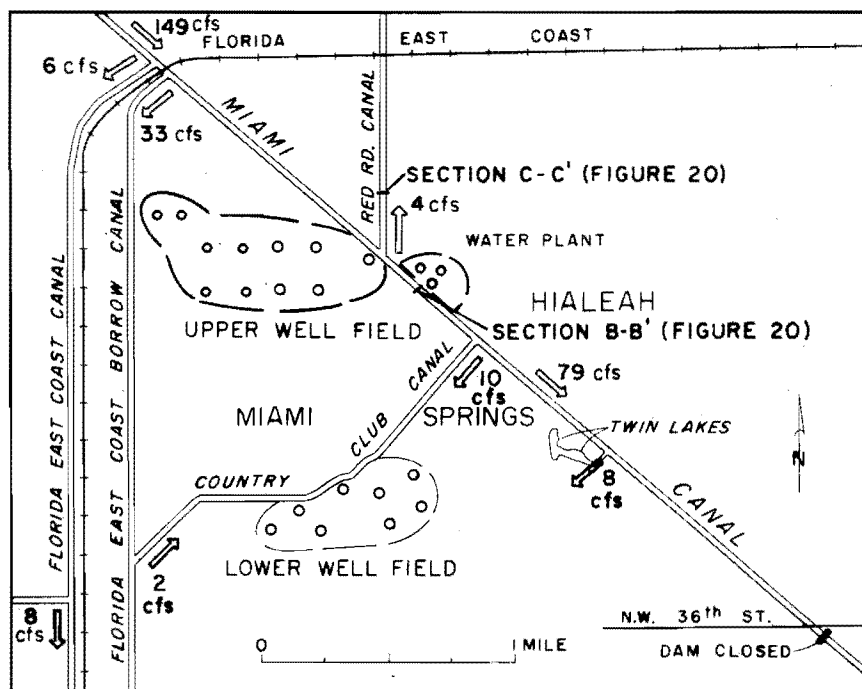
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ARROW INDICATES DIRECTION
OF FLOW OF SURFACE WATER,
CUBIC FEET PER SECOND.

Figure 18.--Map showing locations of discharge measurements in the vicinity of the Miami Springs-Hialeah well fields, March 28, 1946.

On April 13, 1949, another set of discharge measurements was made at selected locations in the lower reach of the Miami Canal. See locations on fig. 19. Pumpage that day averaged 64.4 mgd. Measurements of flow loss suggested that 100 percent of the water pumped by the city was obtained from the canals; the estimated percentage from each canal is shown in table 1.

Numerous measurements would be needed to determine changes in dry weather recharge to the aquifer tapped by the city's wells. Long-term data at previously measured sites are not available, therefore, an evaluation of long-term changes in canal infiltration is not possible. In 1968 the author attempted to evaluate the well-field contributions from canals from discharge measurements at selected sites, but the data were found to be affected by tides. Therefore, any future evaluation by this method would probably require analysis of storage changes and measurements of discharge at each site through at least a tide cycle.



EXPLANATION
 → 30 cfs
 ARROW INDICATES DIRECTION
 OF FLOW OF SURFACE WATER,
 CUBIC FEET PER SECOND.

Figure 19.--Map showing locations of discharge measurements in the vicinity of the Miami Springs-Hialeah wellfields, April 13, 1949, and locations of sections B-B' and C-C.

Table 1.--Estimates of contributions from nearby canals to well fields
in the Miami Springs-Hialeah area, April 13, 1949

<u>Location</u>	<u>Percent</u>
Southside Canal	12
F.E.C. Borrow Canal	32
Red Road Canal	4
Miami Canal (between F.E.C. Canal	
Twin Lakes)	44
F.E.C. Canal	0
Twin Lakes	8

The quality of water often indicates its source. If two or more waters are blended, each of different quality, the quality of the blend indicates the proportion from each source. In the case of the Miami Springs-Hialeah well fields, three water sources are possible, each contributing water of different quality that could affect the quality of the pumped ground water. They are: (1) fresh surface water in nearby reaches of controlled canals, in which average chloride concentrations have apparently increased from less than 20 mg/l in 1950 to about 64 mg/l in 1971; (2) stored fresh ground water that is derived from local rainfall and contains about 15 mg/l chloride; and (3) salty ground water near uncontrolled reaches of the Miami and Tamiami Canals and whose chloride concentration ranges from 1,000 to more than 5,000 mg/l.

The proportional amounts contributed by each source can be expressed by the equation:

$$Q_1C_1 + Q_2C_2 + Q_3C_3 = Q_4C_4 \quad (1)$$

where

Q_1 is the infiltration from nearby canals, mgd

C_1 is the chloride concentration of the water in nearby canals, mg/l

Q_2 is the contribution from rainfall, mg d

C_2 is the chloride concentration in infiltrated rainfall, mg/l

Q_3 is the contribution from salty ground water, mgd

C_3 is the chloride concentration of salty ground water, mg/l

Q_4 is the well field pumpage, mgd

C_4 is the chloride concentration in pumped water, mg/l

As previously discussed, a low ground-water divide across the airport has apparently prevented northward movement of salty ground water into the cone of depression; and the well-field map for May 4-5, 1971 (fig. 12), indicates that most of the municipal wells lie east of a 50 mg/l chloride line that parallels the controlled reach of the Miami Canal. Therefore, the contribution from salty ground water can be considered minimal, and the third term can, therefore, be omitted in equation 1.

The average amount of canal water that recharged the Biscayne aquifer and that was removed from the aquifer by pumping the city wells is computed as follows:

$$Q_1 + Q_2 = Q_4 \quad (2)$$

$$Q_1 C_1 + Q_2 C_2 = Q_4 C_4 \quad (3)$$

Therefore

$$Q_1 C_1 + (Q_4 - Q_1) C_2 = Q_4 C_4 \quad (4)$$

where

Q_1 is the canal infiltration, mgd

C_1 is the chloride concentration of Q_1 , 59 mg/l

Q_2 is the contribution from rainfall, mgd

C_2 is the average chloride concentration of Q_2 ,
assumed 15 mg/l

Q_4 is the average pumpage, 89 mgd.

C_4 is the average chloride concentration of Q_4 ,
38 mg/l

Substituting terms in equations 4 and solving for Q_1

$$Q_1 (59) + (89 - Q_1) (15) = (89) (38)$$

$$Q_1 = 46.5 \text{ mgd.}$$

Thus the canal infiltration during 1970 was about 46.5 mgd, or 52 percent of the pumpage. The contribution for 1971 was computed to be 50.7 mgd, or 55 percent of the pumpage.

The analysis indicates that canal infiltration is increasing in response to increased pumpage, at least on a yearly basis. However, the critical test occurs during droughts, when increasingly higher peak pumpages could exceed the canal's ability to supply adequate recharge to the aquifer to preclude inflow of inferior water from the tidal canals. For example, the peak pumpage during 1971 apparently caused the cone of depression to expand southward and breach the low ground-water divide across the airport; and, as a result, salty ground water in the vicinity of the Tamiami Canal began to move northward beneath the airport toward the well fields.

Induced recharge from the canals is retarded by fine-grained bottom sediments and by beds of fine sand within the Biscayne aquifer. Generalized sections B-B' and C-C' (fig. 20) located on figure 19 show the relative positions of the Miami and Red Road Canals with respect to the retarding beds and the pumped zone.

Fluctuations of water levels are recorded in wells G-1280 through G-1283, adjacent to the canals; in the Miami Canal above the 36th Street control; and in wells G-1368, G-3 and S-19, near the centers of pumpage (fig. 1). A comparison of the water-level fluctuations during 1970 (fig. 21) indicates that the drawdown was greatest in well G-1368 at the Preston-Hialeah well field. During 1970, the water level in well G-1368 ranged from 3.6 to 8.8 feet below msl; the water level in well G-3, near the upper Miami Springs well field, ranged from 1.4 feet above to 2.2 feet below msl; the water level in well S-19, near the lower Miami Springs well field ranged from 3.0 feet above to 1.0 foot below msl; and the canal's water level ranged from 2.7 feet to 0.4 foot above msl. The comparison also shows that the water levels in wells G-1280 - G-1283 are closely related to those of well G-1368. This indicates that the drawdown from the Preston-Hialeah wells extends beneath the recharging canals and that hydraulic gradients are steep adjacent to the channels.

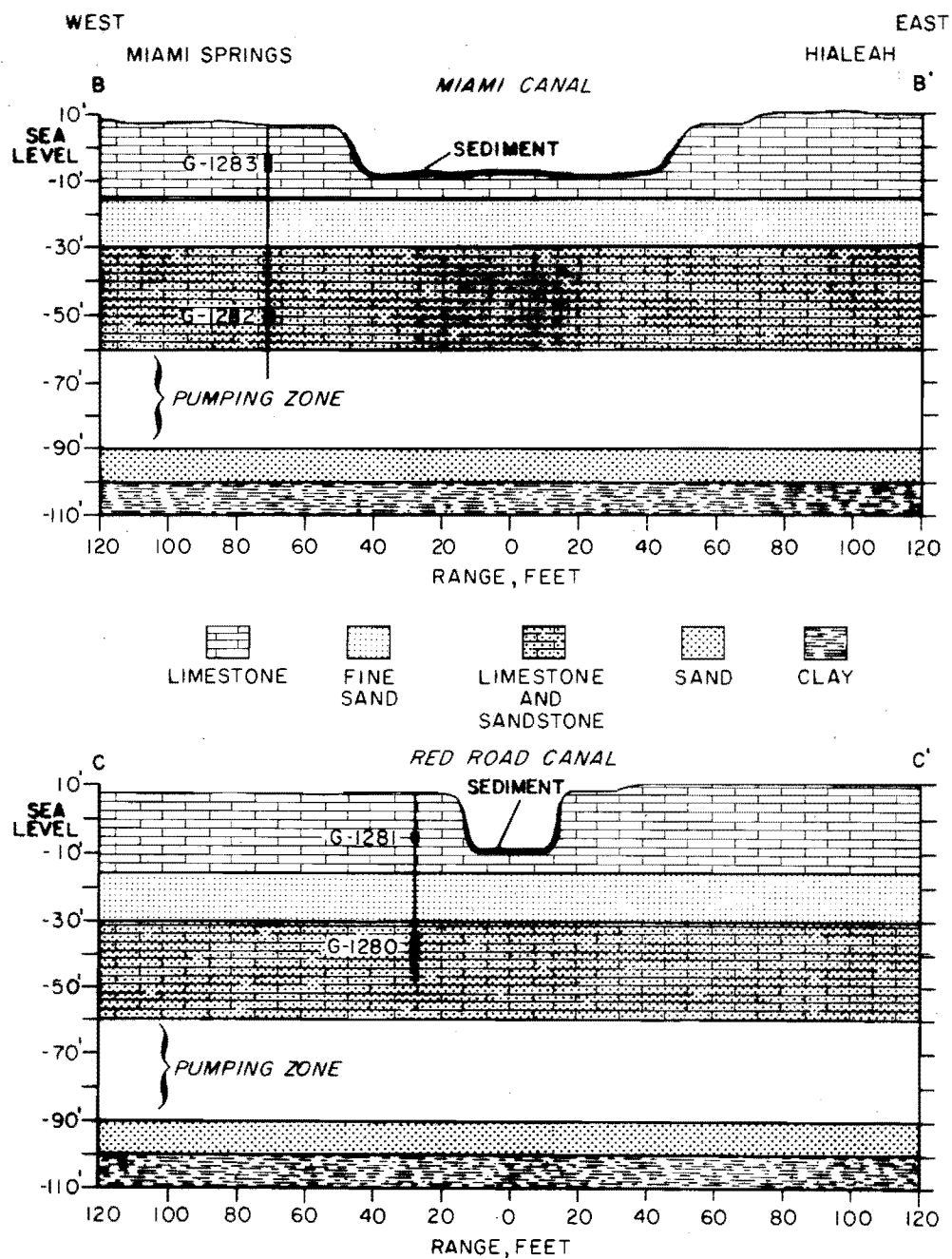


Figure 20.--Generalized sections along B-B' and C-C'.

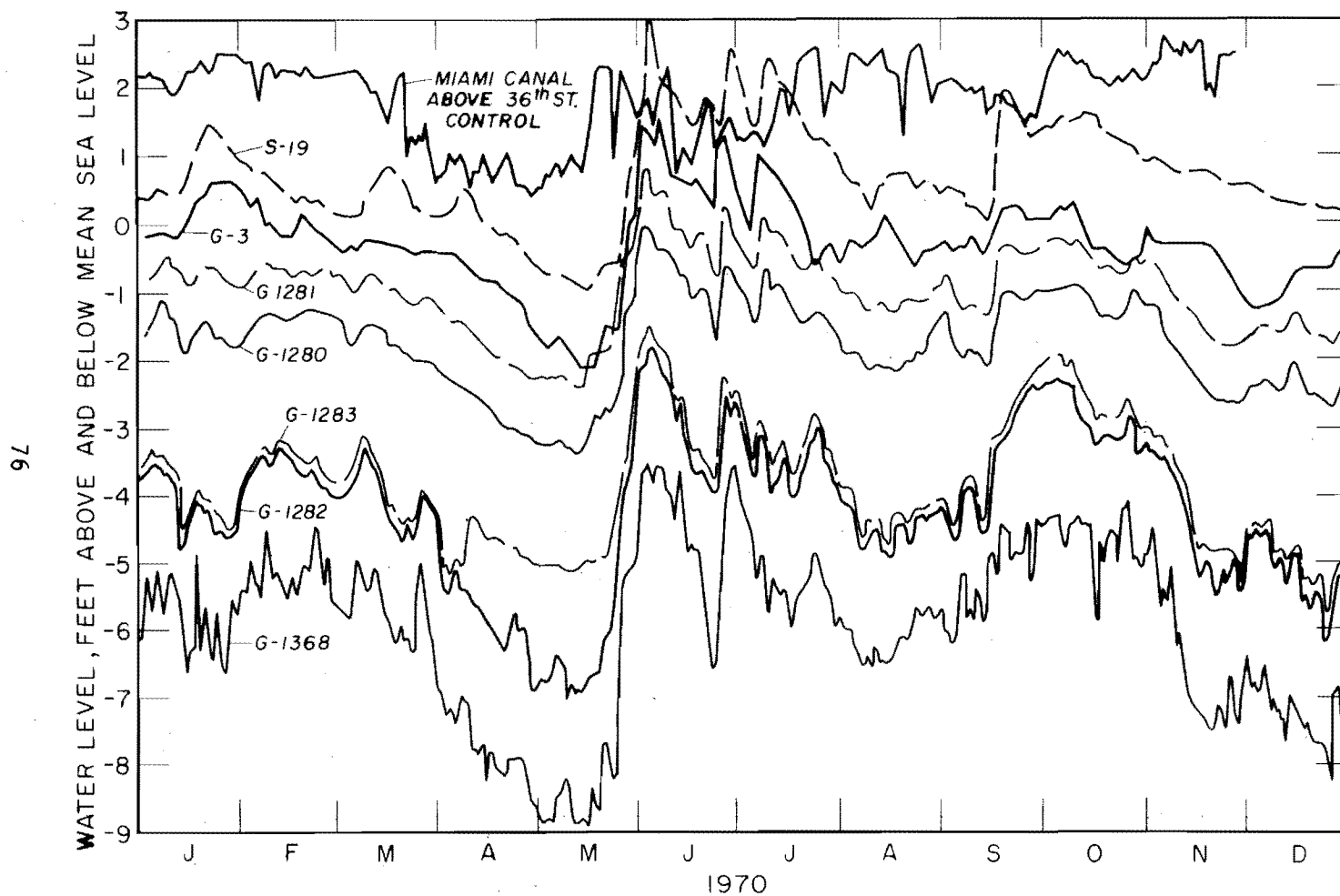


Figure 21.--Hydrographs of wells G-3, S-19, S-68, G-1280-83, and G-1368,
and of the Miami Canal above 36th Street control, 1970.

Figure 22 shows the theoretical distribution of head, as shown by equipotential lines on sections B-B' and C-C', on May 14, 1970. The close spacing of the equipotential lines around the bottom of the canals indicates the steep hydraulic gradients directly beneath the channels. The steep gradients are probably caused chiefly by the relatively less-permeable bottom sediments. Data concerning the permeability of the sediment and the distribution of hydraulic gradients along the reaches of infiltration recharging canals are lacking; therefore, direct computation of infiltration is not possible.

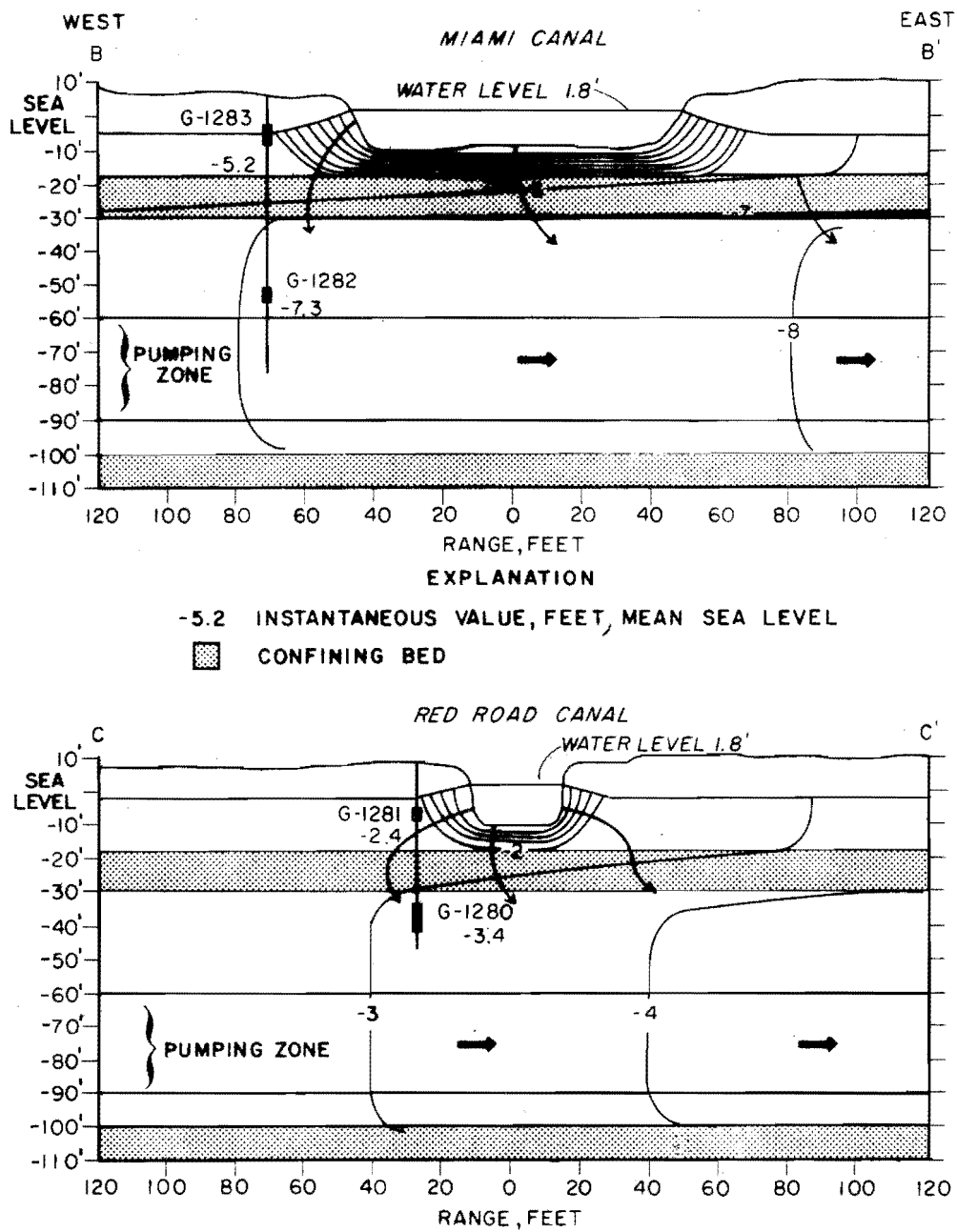


Figure 22.--Hypothetical hydraulic profiles along B-B' and C-C',
May 14, 1970.

Adequacy of the Canal System
to Meet Future Pumping Demands

Can the present canal-aquifer system safely supply the future demands on the Miami Springs-Hialeah well fields? The effects of the 1971 drought indicate that the 1971 peak pumpage was approaching the limit of the aquifer recharge capability, and that future increases in pumpage and similar drought conditions will cause sea-water intrusion unless appropriate steps are taken. The first major step was taken in September 1971 when the temporary control was constructed in the Tamiami Canal at NW 45th Avenue. This control will lessen the potential threat of sea-water intrusion from the vicinity of the airport and will increase fresh-water infiltration to the lower Miami Springs well field. Also, the Corps of Engineers is currently preparing plans for a permanent control at NW 36th Street which should reduce leakage losses there.

The maximum development of the Biscayne aquifer in the vicinity of the well fields will depend chiefly on adjustments in the location of canals (recharge boundaries), ability to maintain high heads in the canals, and possibly increased canal infiltration by deepening canals or by removal of some bottom-sediment. However, deepening canals or removing of bottom sediment may be undesirable because of the adsorptive, absorptive, and filter effects of the sediment on the water that recharges the aquifer.

FUTURE STUDY

Studies pertaining to the sediment permeability; head distribution beneath canals; and the adsorptive, absorptive, and filter-effects of the bottom sediment are planned. Several small-diameter wells will be drilled to various depths in a line across a part of the canal to sample the sediment and to measure hydraulic gradients. Samples of the sediment will be analyzed for mineral content and hydraulic characteristics. Water samples will be obtained periodically from the wells and the canal, and the samples will be analyzed to determine variations in water quality. The data thus obtained should indicate the ability of the sediment to remove certain dissolved and suspended material from the infiltrating canal water, the beneficial characteristics of the bottom sediment.

Additional necessary studies follow:

1. Analysis of effects of future pumpage in the Hialeah-Miami Springs area according to the present canal configuration and planned locations of salinity controls. Construction of a digital or analog model, which would utilize the data compiled during the study. It could be used to forecast the maximum safe pumpage of the present well fields and the effects that changes in the canal system would have on the amount of ground water available for use.

2. Redetermination of areas and rates of infiltration by periodic discharge measurements at selected points in the canal system. Measurements could be compared with hydraulic profiles to detect changes in rates of infiltration.

3. Drilling of deep and shallow observation wells at several locations in or adjacent to the well fields to determine head distribution in the aquifer and hydraulic gradients near the canals and to prepare flow nets to evaluate infiltration rates previously obtained by discharge measurements.

4. Testing in selected parts of canals to evaluate the effects that bottom-sediment removal or canal deepening would have on the rates of infiltration and on the resultant quality of the canal and ground waters. The tests would require the cooperation and assistance of several agencies.

5. Continuous monitoring of chloride concentrations of water in the Miami Canal at locations, such as S-8, S-151, L-30 and the Hialeah Water Plant, to relate long-term changes in the quality of canal water to changes in the quality of well-field water.

SUMMARY

Part of the water pumped from the Biscayne aquifer by the city of Miami's Spring-Hialeah well fields is obtained by induced infiltration from the Miami Canal and other nearby canals. In 1971 the canals contributed about 55 percent of the total pumpage, and the contribution may be increasing in response to increased pumpage. However, during peak demands and during drought the canal-infiltration capability may be exceeded; therefore, the percentage of water pumped contributed by infiltration from nearby canals is decreasing at least during such times. Studies during 1940's indicated that the canals contributed 78 to 100 percent of the peak demands during dry periods. However, in 1971 the peak demand apparently exceeded the canal's recharge capability, and pumping had to be reduced in the lower well field in Miami Springs in order to prevent sea-water intrusion. The installation of a temporary salinity control in the Tamiami Canal at NW 45th Avenue in September 1971 will provide additional infiltration to the well fields and will reduce the threat of sea-water intrusion. Accumulations of fine-grained bottom sediment in the canals have, no doubt, impeded infiltration to the well fields; but the filter, adsorptive, and absorptive effects of the sediment might be beneficial.

The maximum development of the well fields will require detailed knowledge of the hydrology of the canal-aquifer system. Plans to increase withdrawals from the well fields require evaluation before implementation. Additional studies will be required to evaluate the effects that bottom sediment has on the quality of infiltrating canal water, the effects that the bottom sediment or deepening the canals will have on well-field yield, and the effects that changes in the configuration of the canal system will have on the amount of ground water available for use.

REFERENCES

- Cooke, C.W., and Mossom, Stuart, 1928, Geology of Florida; Florida Geol. Survey 20th Ann. Rept. p. 29-227.
- Dinn, Walter, 1970, Water and Miami -- a story of challenge: City of Miami Department of Water and Sewers, Miami, Florida.
- Hoffmeister, J.E., Stockman, K.W. and Multer, H.G., 1967, Miami Limestone of Florida and its recent Bahamian counterpart: Geol. Soc. America Bull. v. 78, p. 175-190.
- Kohout, F.A. and Hartwell, J.H., 1967, Hydrologic effects of Area B flood-control plan on urbanization of Dade County, Florida: Florida Geol. Survey Rept. Inv. 47.
- Leach, S.D., and Grantham, R.G., 1966, Salt water study of the Miami River and its tributaries, Dade County, Florida: Florida Geol. Survey Rept. Inv. 45, 36 p.
- Leach, S.D., Klein, Howard, and Hampton, E.R., 1972, Hydrologic effects of water control and management of southeastern Florida: Florida Dept. Nat. Res. Rept. Inv. 60.
- Meyer, F.W., 1971, Preliminary evaluation of the hydrologic effects of implementing water and sewerage plans, Dade County, Florida: U.S. Geol. Survey open-file rept. 71003.
- City of Miami, 1958, Report on future growth of water system: Miami Department of Water and Sewers, Miami, Florida, mimeo. rpt.
- City of Miami, 1970, Annual Statistical Operating Reports Water and Sewerage: City of Miami Department of Water and Sewers, Miami, Florida.

REFERENCES (Continued)

- Olsson, A.A., and Petit, R.E., 1964, Some Neogene Mollusca from Florida and the Carolinas: *Bulls. Am. Paleontology* v. 47, no. 217, p. 509-574.
- Parker, G.G., 1951, Geologic and hydrologic factors in the perennial yield of the Biscayne aquifer: *Am. Water Works Assoc. Jour.* v. 45, p. 817-834.
- Parker G.G., and Cooke, C.W., 1944, Late Cenozoic geology of southern Florida, with a discussion of ground water: *Florida Geol. Survey Bull.* 27, 119 p.
- Parker, G.G., Ferguson, G.E., Love, S.K., and others, 1955, Water resources of southeastern Florida with special reference to the geology and ground water of the Miami area: *U.S. Geol. Survey Water-Supply Paper* 1255, 903 p.
- Schroeder, M.C., Klein, Howard, and Hoy, N.D., 1958, Biscayne aquifer of Dade and Broward Counties, Florida: *Florida Geol. Survey Rept. Inv.* 17.
- Sherwood, C.B., and Klein, Howard, 1963, Surface and ground-water relation in a highly permeable environment: *Internat. Assoc. Sci. Hydrology*, v. 63, p. 454-468.

