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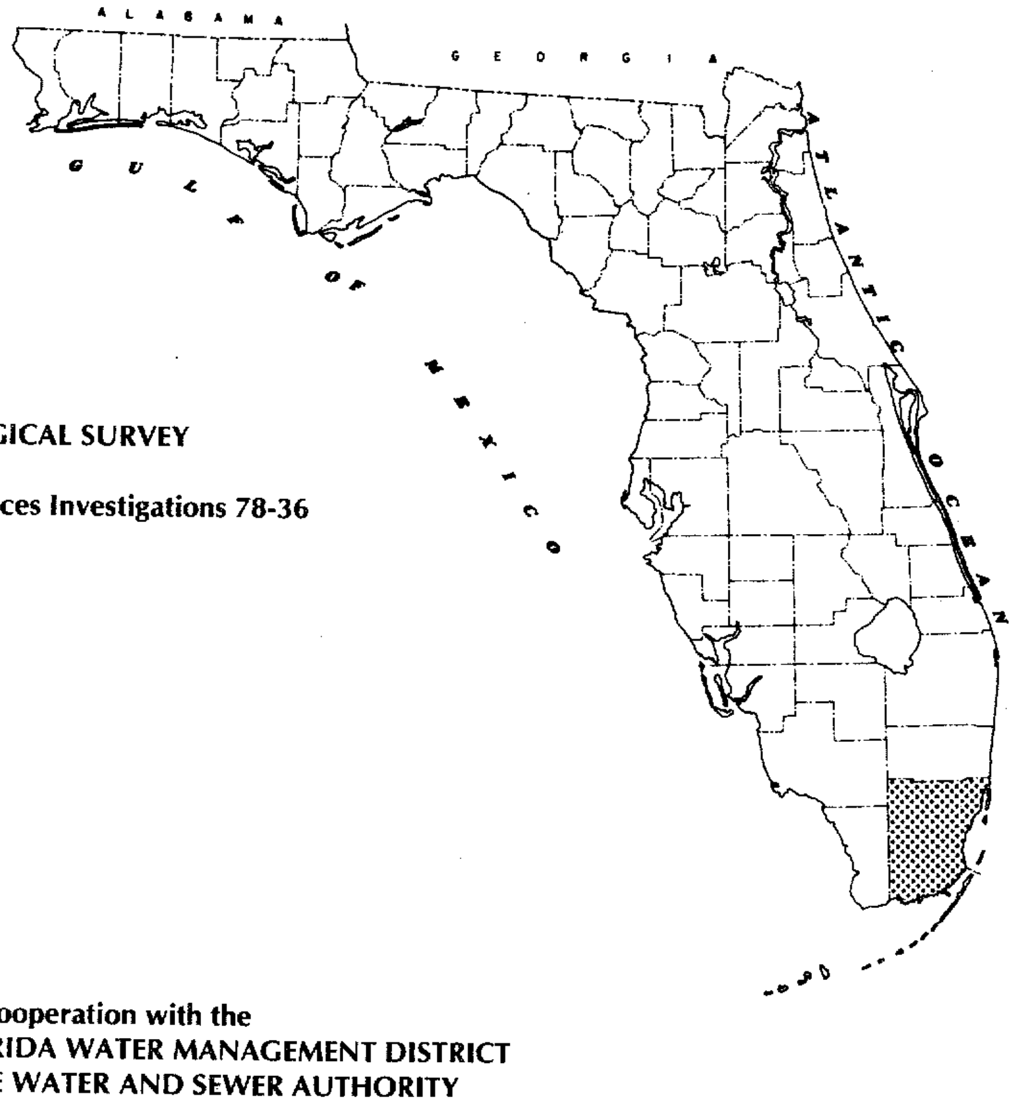
EFFECTS OF BOTTOM SEDIMENTS ON INFILTRATION FROM THE MIAMI AND TRIBUTARY CANALS TO THE BISCAYNE AQUIFER DADE COUNTY, FLORIDA



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-36

Prepared in cooperation with the
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
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16. Abstracts

Infiltration from the Miami Canal and its tributaries is an important source of recharge to the Biscayne aquifer in the vicinity of the Miami Springs-Hialeah well fields. Estimates of pumpage contributed by canal infiltration decreased from nearly 100 percent in the late 1940's to 50 percent in May 1973 while well field pumpage increased from less than 50 Mgal/d to 120 Mgal/d. As increased withdrawals enlarge the well field's cone-of-depression, the threat of saltwater intrusion during dry periods has been increased.

Data on water quality, water levels, and canal bottom sediments indicated that the sediments greatly impeded infiltration from the canals in the areas most affected by pumping. Bottom sediments reduced coliform bacteria, pesticides, PCB, metals, and other suspended materials in infiltrating canal water.

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17b. Identifiers/Open-Ended Terms

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May 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

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EFFECTS OF BOTTOM SEDIMENTS ON INFILTRATION FROM THE MIAMI AND TRIBUTARY CANALS TO THE BISCAYNE AQUIFER DADE COUNTY, FLORIDA

By

Wesley L. Miller

ABSTRACT

Infiltration from the Miami Canal and its tributaries is a major source of recharge to the Biscayne aquifer in the Miami Springs-Hialeah well-field area. In the late 1940's when average pumpage was less than 50 million gallons per day, canal infiltration contributed an estimated 80 to 100 percent of the dry season pumpage. Between 1970 and 1973, average daily pumpage increased 18 percent but the canal infiltration capacity decreased 6 percent. In May 1973, about 50 percent of the well field's peak pumpage of 120 million gallons per day was attributed to canal infiltration. Steadily increasing withdrawals have caused deepening and broadening of the well field's cone of depression thereby increasing the threat of saltwater intrusion during dry, peak demand periods.

Canal water levels were consistently higher than the water table in 1973. Canal-bottom sediments impede downward infiltration from the canals. Filtration through bottom sediments reduces concentrations of coliform bacteria, pesticides, PCB's, metals, and suspended materials. Filtration by the sandy upper part of the aquifer further reduces concentrations of these constituents as infiltrating water moves toward the pumping zone. The quantitative effects on ground-water quality resulting from the removal of the canal-bottom sediments cannot be adequately predicted from present data.

INTRODUCTION

Saltwater intrusion has been, and will continue to be, a major threat to Dade County's water supply. Therefore, protection of municipal well fields from this instrusion is of prime concern. Infiltration from the Miami Canal and its tributary canals has long been recognized as an important source of recharge to the Biscayne aquifer at the Miami-Dade Water and Sewer Authority well fields in the Miami Springs-Hialeah area (fig. 1). Recharge from the canals tends to minimize the extent and depth of the cone of depression about the well fields.

There are indications that withdrawal rates are exceeding infiltration rates due to the sealing effect of slowly accumulating sediments in the bottom of the canals. During periods of peak pumping and deficient rainfall the cone of depression has been increasing in size and depth. If it is allowed to intersect ground water containing high chloride concentrations to the south and southeast, the movement of salty water toward the well fields will accelerate. Chloride concentrations of ground water south of the well fields have been steadily increasing in response to increased pumping factors. If the rate of infiltration from canals could be increased, the inland movement of saltwater would be moderated.

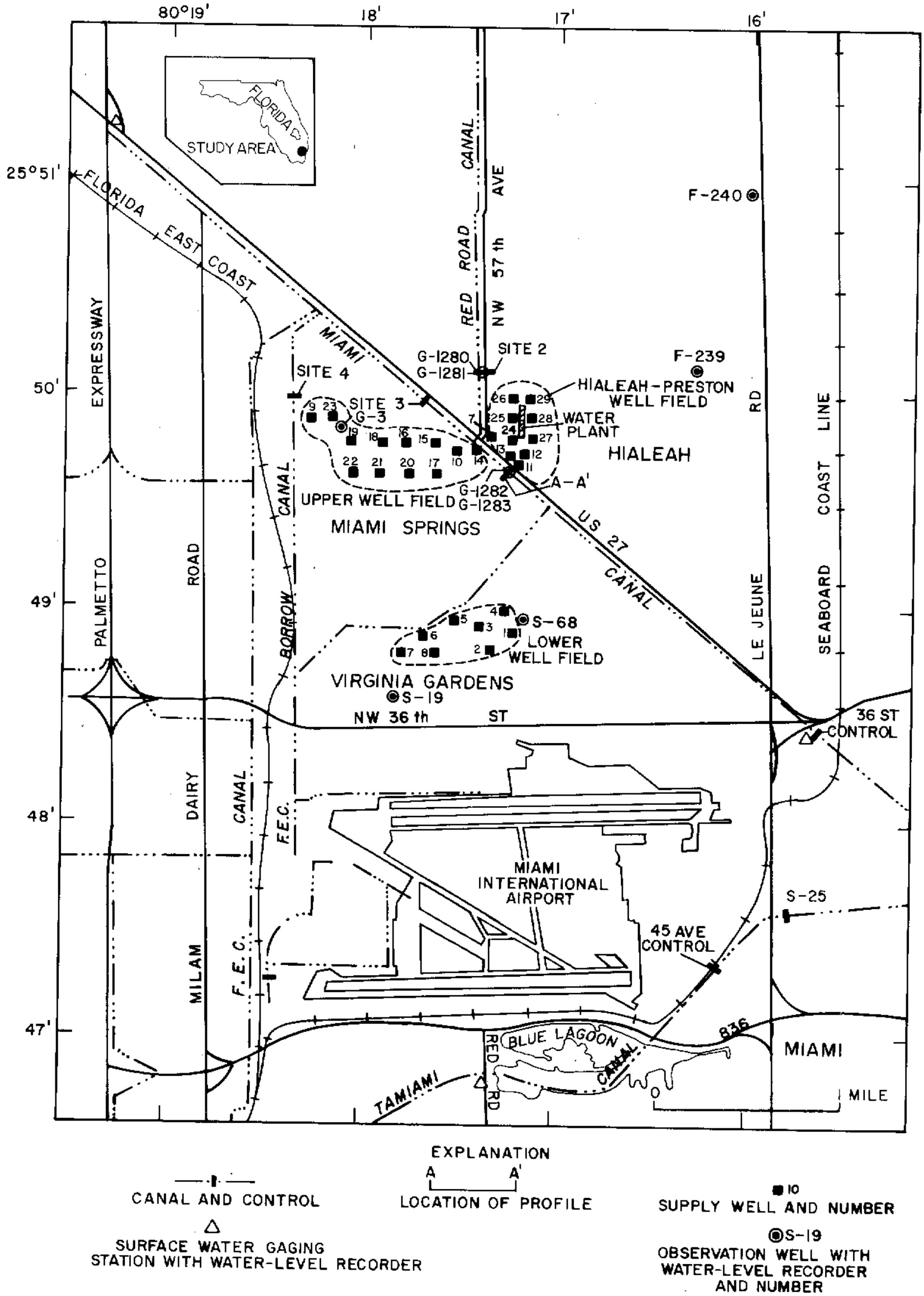


Figure 1.--Locations of well fields, principal hydrologic features, and data-collection sites.

One approach to increasing recharge by infiltration is to periodically remove the bottom sediment in the canals. However, the possible beneficial filter effects of the bottom sediments upon the quality of infiltrating canal water should be given consideration.

For use of those readers who may prefer to use metric units rather than U.S. customary units, the conversion factors for the terms used in this report are listed below:

Multiply U.S. customary unit	By	To obtain metric unit
cubic feet per second (ft^3/s)	28.32	liters per second (L/s)
million gallons per day (Mgal/d)	.04381	cubic meters per second (M^3/s)
million gallons (Mgal)	3,785	cubic meters (m^3)
feet (ft)	.3048	meters (m)
square feet (ft^2)	.0929	square meters (m^2)
miles (mi)	1.609	kilometers (km)
inches (in)	25.4	millimeters (mm)
acres	.4047	hectares (ha)

Purpose and Scope

The purpose of this investigation was to evaluate the recharge to the Biscayne aquifer from the Miami Canal and tributary canals in the vicinity of the Miami Springs-Hialeah well fields, and to examine the role that infiltration plays in the prevention of saltwater intrusion. This report, based on historical and recent data, covers: (1) the relation of the canal system and rates of infiltration to configuration of the well field's cone of depression; (2) the effects of infiltrating canal water on water quality in the Biscayne aquifer; (3) the adequacy of the canal system to supply sufficient infiltration for increasing pumpage; and (4) the effects of canal bottom sediments on rates on infiltration and ground-water quality.

Information from this investigation should be of use to local water officials in managing, planning and maintaining water supply facilities to keep pace with increasing demands.

Acknowledgments

This report was prepared by the U.S. Geological Survey as part of the cooperative water resource investigation with the South Florida Water Management District (formerly Central and Southern Florida Flood Control District) and the Miami-Dade Water and Sewer Authority.

The author wishes to thank the following people for providing valuable assistance: the late Mr. William V. Storch, Director, Resource Planning Department of the South Florida Water Management District; Mr. Garrett Sloan, Director of the Miami-Dade Water and Sewer Authority; and Mr. F. D. R. Park, Water-Control Engineer of the Water Control Division of the Dade County Department of Environmental Resources Management.

Previous Investigations

The hydrology of the Miami Springs-Hialeah well fields was described by Parker and others (1955). Water-table maps of the Miami Springs-Hialeah well fields are published annually in reports of hydrologic data in Dade County, Florida by the U.S. Geological Survey as part of the cooperative studies with the Miami-Dade Water and Sewer Authority and the Dade County Department of Public Works (Hull and Galliher, 1968, 1969; Hull, 1970, 1971, 1972; Hull and Wimberly, 1972; Hull, and others, 1973). Water-table maps of the well fields were prepared by the U.S. Geological Survey beginning in 1939. Records of pumpage and analyses of raw water from supply wells are available from the Miami-Dade Water and Sewer Authority. The results of a preliminary evaluation of infiltration from the Miami Canal system were reported by Meyer (1972) and pertinent data on canal bottom sediment and water quality were reported by Meyer and Wimberly (1972).

HYDROLOGIC SETTING

Biscayne Aquifer

The Biscayne aquifer (Parker and others, 1955, p. 160-162; Schroeder and others, 1958), a section of highly permeable limestone, ranging in age from late Pliocene 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 municipal wells of the Miami-Dade Water and Sewer Authority. Beneath the aquifer lies a relatively impermeable green shelly marl in the Tamiami Formation.

The principal formations in the aquifer in the Miami area (from oldest to youngest) are the upper part of the Tamiami Formation (Parker, 1951, p. 823), Pliocene; the Fort Thompson Formation (Cooke and Mossom, 1928, p. 211-215), Pleistocene; and the Miami Limestone (Oolite) (Hoffmeister and others, 1967), Pleistocene. Approximately 80 percent of the aquifer is composed of the highly permeable Fort Thompson Formation.

Drainage

Southeast Florida is drained chiefly by the canal system of the South Florida Water Management District (fig. 3). The facilities of the Water Management District are designed and operated to provide flood protection to urban and agricultural areas during the rainy season and to provide freshwater to recharge the aquifer during the dry season. Coastal reaches of most canals are protected from saltwater intrusion by salinity-control structures. The water management system is designed around the water-storage capabilities of Lake Okeechobee and the water-conservation areas. Seepage and controlled releases from the lake and conservation areas to the canals maintain water levels along the coast, retard saltwater intrusion, and recharge well fields. The canal system also provides facilities to discharge excess water to the sea or to backpump some excess water to storage in the lake and the conservation areas.

Drainage in the vicinity of the Miami Springs-Hialeah well fields is accomplished primarily by the Miami Canal, the Tamiami Canal, and their tributaries (fig. 1).

The Miami Canal (fig. 3) is an extension of the Miami River, which originally extended a short distance inland from Biscayne Bay. Construction of the canal began in 1909, proceeded northwestward into the Everglades, and was completed in 1932. The lower reach was dredged to an average depth of 12 feet below land surface in rock. Due to the low conveyance capacity of the middle reach, the canal was improved in 1967-69 to facilitate transfer of water from Lake Okeechobee to the lower

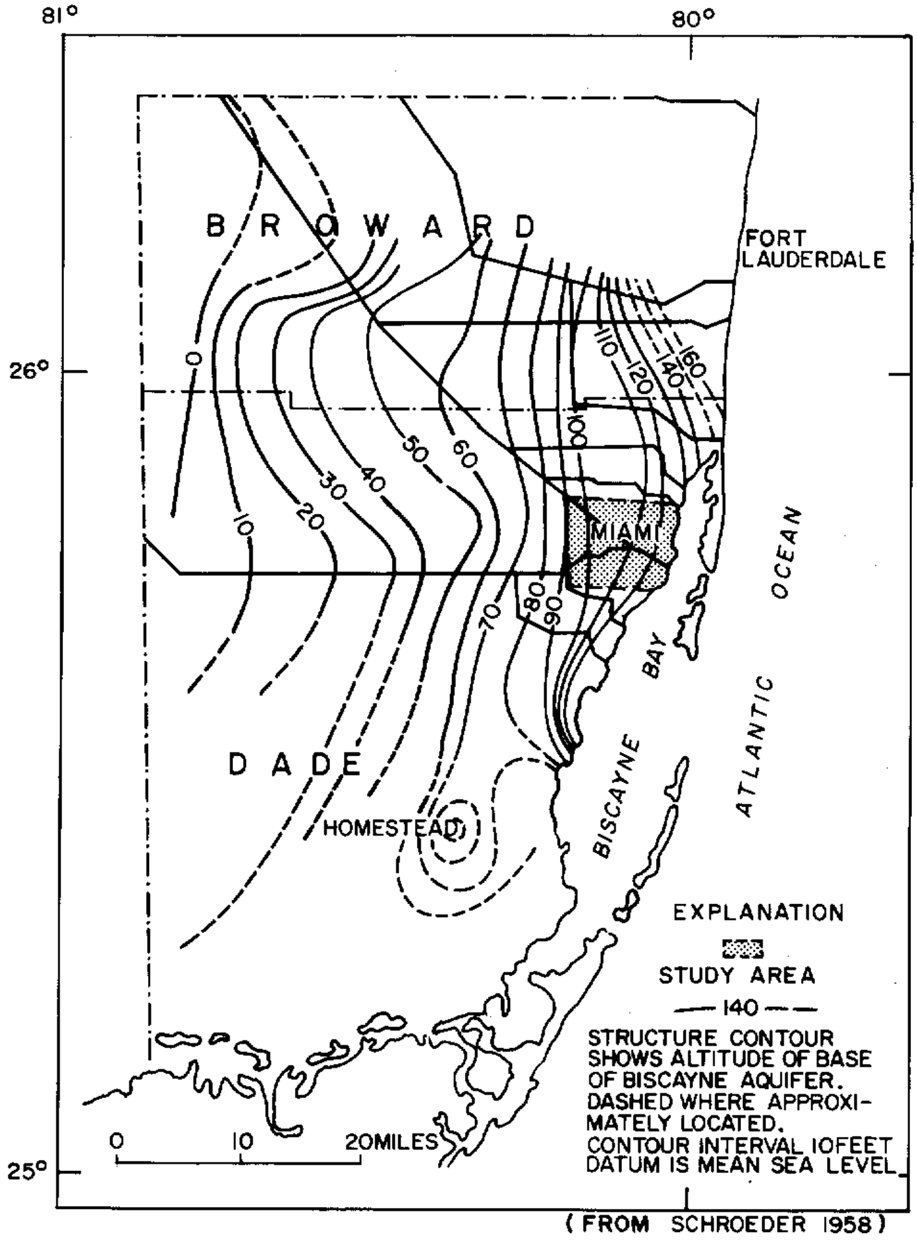


Figure 2.--Contours on the base of Biscayne aquifer.

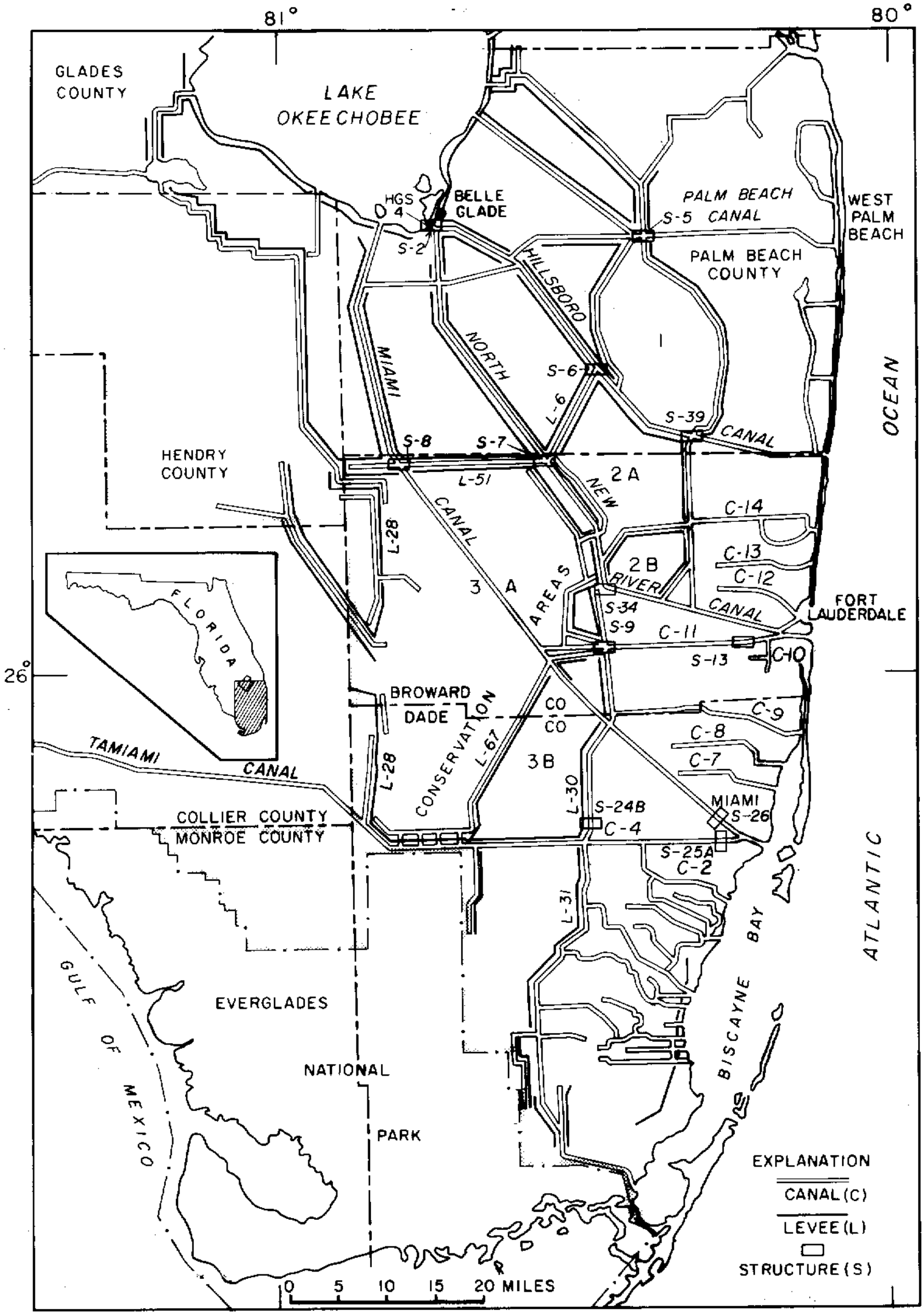


Figure 3.--South Florida Water Management District projects and hydrologic features in 1971.

east coast. The lower reach of the canal is controlled at Northwest 36th Street, Miami and at Levee 30. Details of the history of the drainage system were discussed by Parker and others (1955) and Meyer (1972).

Flow in the Miami Canal during the rainy season is composed of runoff from the conservation areas and ground water discharged into the canal. Dry season flow is mainly from controlled releases and ground water discharge along inland reaches. Much of this flow infiltrates to the aquifer in the vicinity of the well fields.

The Tamiami Canal was tidal between the Miami River and the F.E.C. Canal where a sheet-piling dam prevented westward movement of saltwater. The sheet-piling dam was removed when Structure 25 was completed in 1976. East of the dam location, secondary canals and ditches drain the south part of the Miami International Airport. A narrowing in the canal at Red Road reduces the canal's discharge capacity, but prior to the completion of Structure 25 retarded the westward movement of saltwater, and lessened tidal effects between Red Road and the sheet-piling dam. The canal widens at several deep rock pits (Blue Lagoon, fig. 1). The controlled reach of the canal west of S-25 receives some drainage from the Levee 30 borrow canal and other secondary canals to the east of Levee 30 (fig. 3). During dry periods, water is diverted northward through the F.E.C. Canal toward the Miami Canal to maintain water levels along the west side of the well-field area. Flow can be reversed depending on the operations of the 36th Street controls and the stages of the Miami and Tamiami Canals.

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

MIAMI SPRINGS-HIALEAH WELL FIELDS

History and Description

In 1925 the 10-Mgal/d-capacity Hialeah water treatment plant was constructed and eight supply wells were drilled in the lower well field (fig. 1). At that time the well field and water treatment plant were owned and operated by the city of Miami; the distribution system was owned by the Miami Water Co. In 1932, wells 11, 12, and 13 (fig. 1) were drilled at the Hialeah water plant, increasing the plant's capacity to 20 Mgal/d. The plant's capacity was again increased in 1938 when wells 14-17 were drilled, and, in 1947 when wells 18-22--all in the upper well field--were drilled. These additions increased the Hialeah water plant's capacity to 60 Mgal/d. In 1948, wells 23 and 9 were drilled in the upper well field and in 1954, well 10 was added, bringing the total to 23 wells.

Construction of the Preston plant, just north of the Hialeah plant (fig. 1), began in 1963. In 1968, this plant, with a capacity of 60-Mgal/d and served by wells 24-29, became operational. The well field surrounding the combined Hialeah-Preston water plant is treated as two fields for water management purposes. In this report, the two fields, Hialeah and Preston, are referred to as the Hialeah well field. The expression Miami Springs-Hialeah field, refers to all four fields. In 1972, after interconnection of the two treatment plants, their combined capacity was 120 Mgal/d.

The number of wells in each well field and their aggregate capacity in 1972 was as follows:

Well field	Number of wells	Yield (Mgal/d)
Preston	6	54
Hialeah	3	10
Lower Miami Springs	8	29.5
Upper Miami Springs	12	42
		135.5

When interconnection of the water plants and well fields was completed in 1972, the combined capacity of the 29 wells was 135.5 Mgal/d.

In 1973, a 9-Mgal/d well (Well S-7) was drilled near the Hialeah-Preston plant (fig. 1) to supply the Preston part of the plant. This increased the combined well-field capacity to 144.5 Mgal/d. Future needs call for the water treatment capacity of the Preston portion of the plant to be increased to 100 Mgal/d by 1980, according to the Miami-Dade Water and Sewer Authority. For a complete history and description of these well fields, see Meyer (1972).

Saltwater Intrusion

Saltwater intrusion is the major threat to the water resources of southeastern Florida (Parker and others (1955, p. 571-711). Saltwater intrusion in southeastern Florida has been attributed mainly to uncontrolled drainage by canals and lowering of the water-table. During dry periods, seawater moved several miles upstream in uncontrolled canals and contaminated freshwater supplies. This has necessitated drilling additional supply wells progressively farther inland in the Miami well fields.

Salinity controls installed in the primary canals since 1946 have retarded saltwater intrusion by maintaining high water levels upstream of the controls during dry periods. Saltwater remains a threat because pumping during dry periods may lower water levels sufficiently to allow seawater to advance inland. For example, if the water level of the

Miami Canal declines excessively, saltwater migrates short distances upstream from the NW 36th Street salinity control, even when the control is closed.

The other major source of saltwater intrusion to well fields lies southeast, where intrusion has occurred over the years adjacent to the uncontrolled reach (prior to 1976) of the Tamiami Canal. During recent prolonged dry seasons and peak well field pumping, salty ground water between the Miami and Tamiami Canals and beneath the Miami International Airport has been migrating toward the well fields at an increasing rate (Hull and others, 1973).

In September 1971, a temporary sheet-piling dam was installed in the Tamiami Canal southeast of the Miami International Airport at 45th Avenue (fig. 1) to prevent further saltwater intrusion to the well fields. This structure was removed when the permanent salinity-control structure (S-25) was completed. The salinity control will help alleviate saltwater intrusion in the vicinity of the airport, if adequate canal levels are maintained.

Pumpage and Pumping Effects

The high rate of increase in pumpage from the Miami Springs-Hialeah well fields reflects the rapid growth of Dade County. Average pumpage increased from 23 Mgal/d in 1941 to 113 Mgal/d in 1974. Pumpage usually increases during drought years, as shown by the peak-day pumpage of 1950, 1963, 1970, and 1974 on figure 4. Water-use restrictions suppressed the peaks during 1945, 1955, and 1971.

Pumpage varies seasonally and is typically greatest during the December-May dry season. Maximum daily pumpage usually occurs in April or May. In 1971, peak daily pumpage exceeded 120 Mgal and in 1974, was 134 Mgal. Meyer (1972) described the progressive expansion and deepening of the cone of depression in the well fields between 1945 and 1971 as a result of the increased pumping. His water-table contour maps show that the cone expanded largely northeast and southeast.

Between 1944 and 1961, infiltration from the Miami and tributary canals to the well fields was sufficient to minimize the depth and extent of the cone of depression as pumping rate increased from 30 to 60 Mgal/d (Meyer, 1972). Since 1961 the cone in the center of the withdrawal area has deepened and expanded markedly, particularly southward beneath the airport. As a result of this expansion salty ground water in the vicinity of the Tamiami Canal and the airport has moved northward toward the supply wells during the dry seasons.

During the 1974 drought the peak pumpage of 134 Mgal/d occurred on May 2. The water-table contour map for May 7, 1974 (fig. 5) shows that the 1,000-mg/L chloride line was near the zero water-table contour along a part of the Miami Canal. It also shows that water containing 100 mg/L of chloride at the base of the aquifer (fig. 5) was adjacent to supply

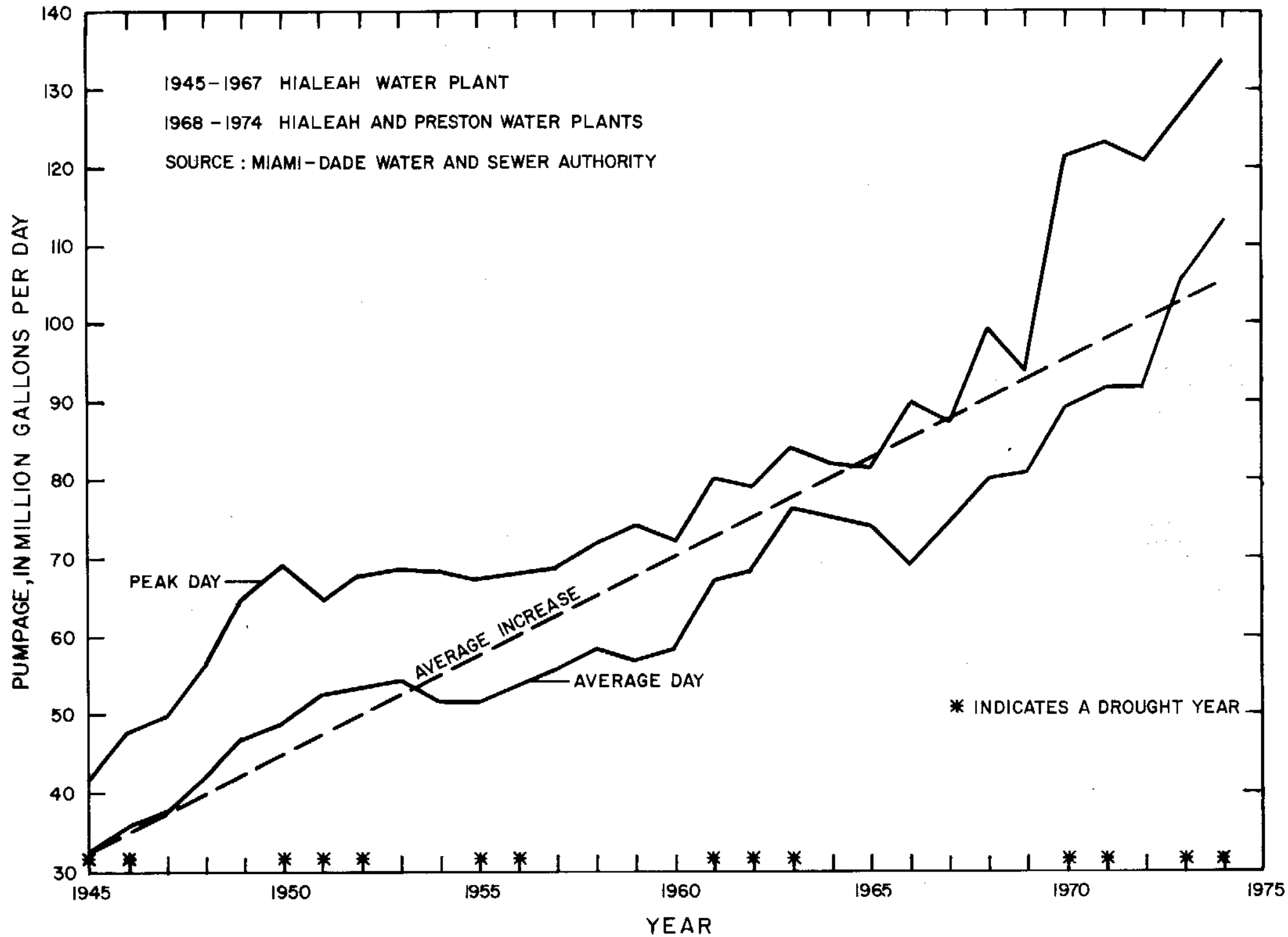
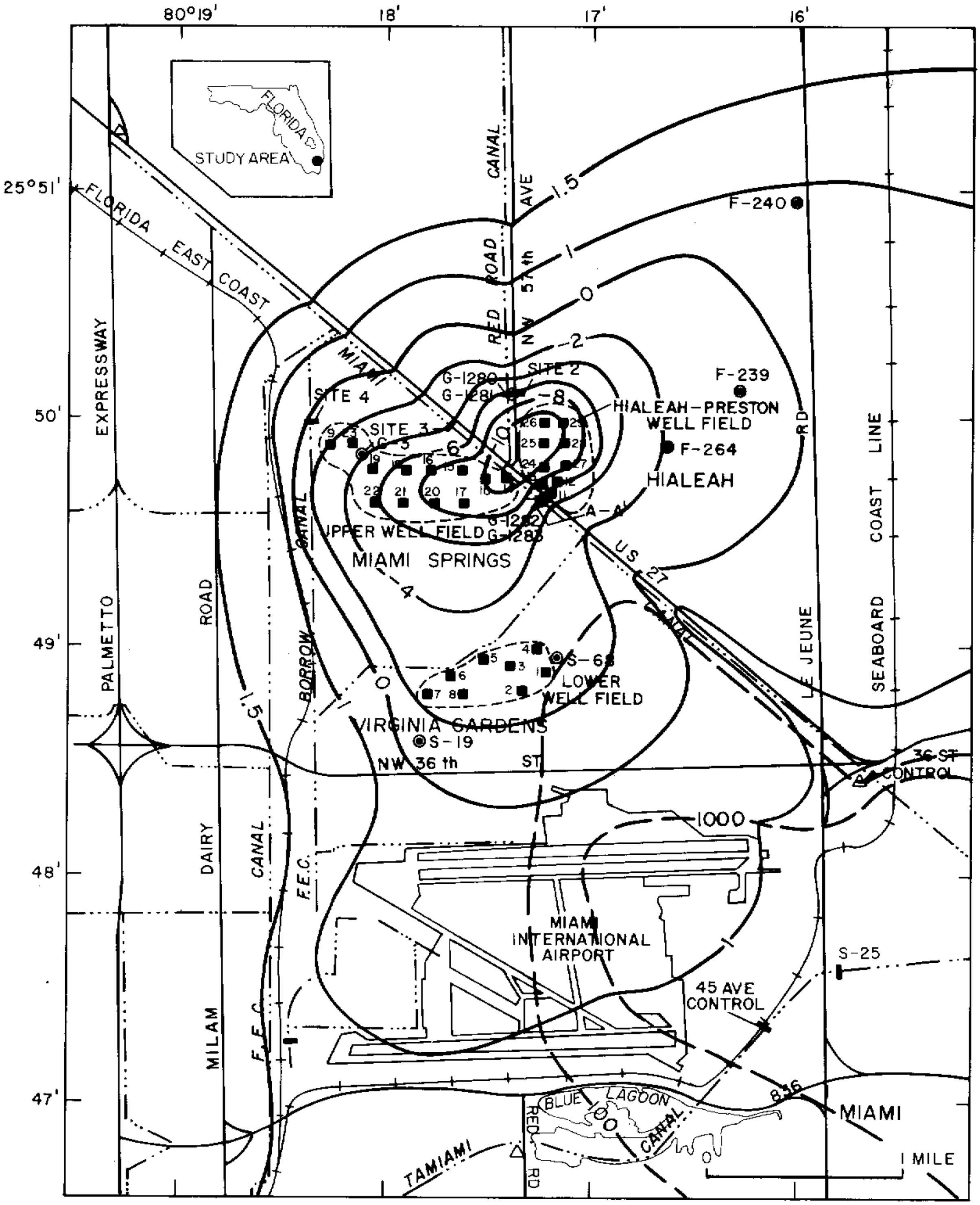


Figure 4.--Average daily and peak day pumpage from Miami Springs-Hialeah well fields, 1945-1974.



EXPLANATION

—— 2 —— WATER-TABLE CONTOUR — SHOWS ALTITUDE OF WATER TABLE. CONTOUR INTERVAL IN FEET. DATUM IS MEAN SEA LEVEL.

— —100— — LINE OF EQUAL CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER AT BASE OF BISCAYNE AQUIFER.

Figure 5.--Water-table contours and chloride concentration at base of Biscayne aquifer - Miami Springs-Hialeah well fields, May 7, 1974.

wells 1 and 2 in the lower field. The long-term effects of pumping on chloride concentrations in water from the Miami Springs-Hialeah well fields are shown on figure 6.

ESTIMATES OF INFILTRATION

Estimates of the amount of water that infiltrates from canals in the Miami Springs-Hialeah well-field area were made by determining the loss in flow between selected points in the canals. The sites selected for discharge measurement are shown in figure 7. On November 21, 1972 (fig. 7) the aggregate amount of water entering the well-field area from the northwest at sites 9 and 11 was 281 ft^3/s. Discharge from the area in the southeast at site 1 was 250 ft^3/s. Flow to the north of site 8A ceases within a short distance, recharging the aquifer rather than leaving the area. Total pumpage from the well fields on November 21, 1972 was 89 million gallons. This indicates that the decrease in flow of 31 ft^3/s or 20 Mgal, accounted for 23 percent of that day's pumpage.

Canal flows were again measured on May 3, 1973 (fig. 7). The amount of water entering the well field area at site 9 was 103 ft^3/s. An additional 8.4 ft^3/s entered the area at sites 17 and 18. The amount of water available for infiltration totalled 111.4 ft^3/s from which westward discharge at sites 12 and 16 of 6.5 ft^3/s is subtracted. Again, flow north of site 8A ceased within a short distance. The total amount of water entering the well field area was 104.9 ft^3/s. Discharge from the area at site 1 was 21 ft^3/s. Loss in flow equaled 83.9 ft^3/s or 54 Mgal/d. Thus, an estimated 46 percent of the total well-field pumpage of 118 Mgal on May 3 was contributed by infiltration from the canals.

Table 1 shows estimates of the contribution of individual segments of the canals to the total infiltrated water. When table 1 is compared to the water-table maps for May 3, 1973 (fig. 8), it is seen that the amount of water infiltrating from the canals is least near the center of the cones of depression except for the short segment of the Red Road Canal immediately north of the Miami Canal.

Insufficient infiltration from the canals near the center of the cones of depression results in a deepening and broadening the cones. As pumping rates increasingly exceed infiltration rates, the drawdown area has expanded southward and southeastward toward areas underlain by salty ground water at the base of the aquifer. Movement of that salty water toward the pumping wells (fig. 8) is thereby accelerated.

The quality of the water can often be used as an indicator of the source of the water. Three water sources are available to the aquifer in the vicinity of the well fields, each of different quality which may affect the resultant quality of the water yielded at the well fields.

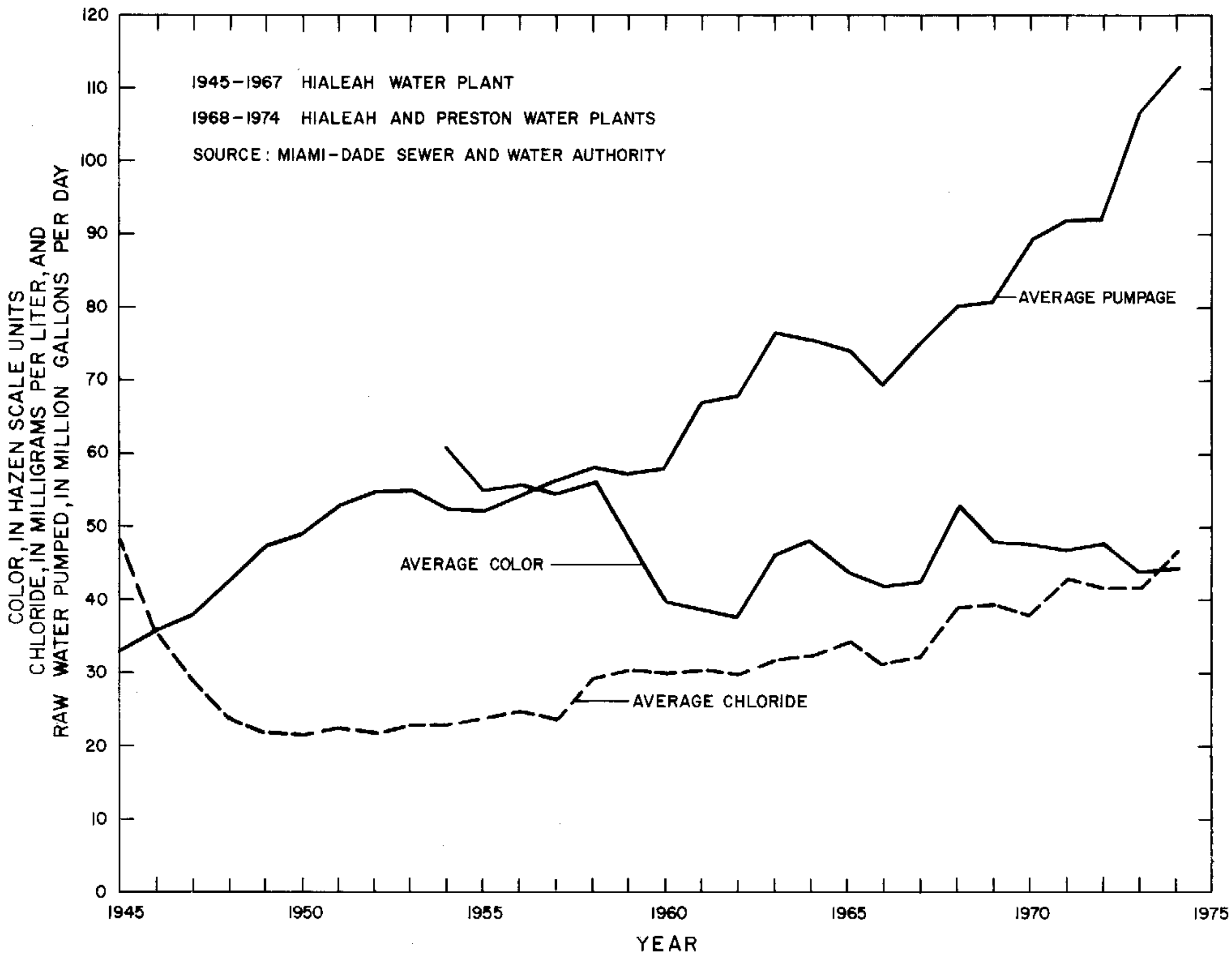
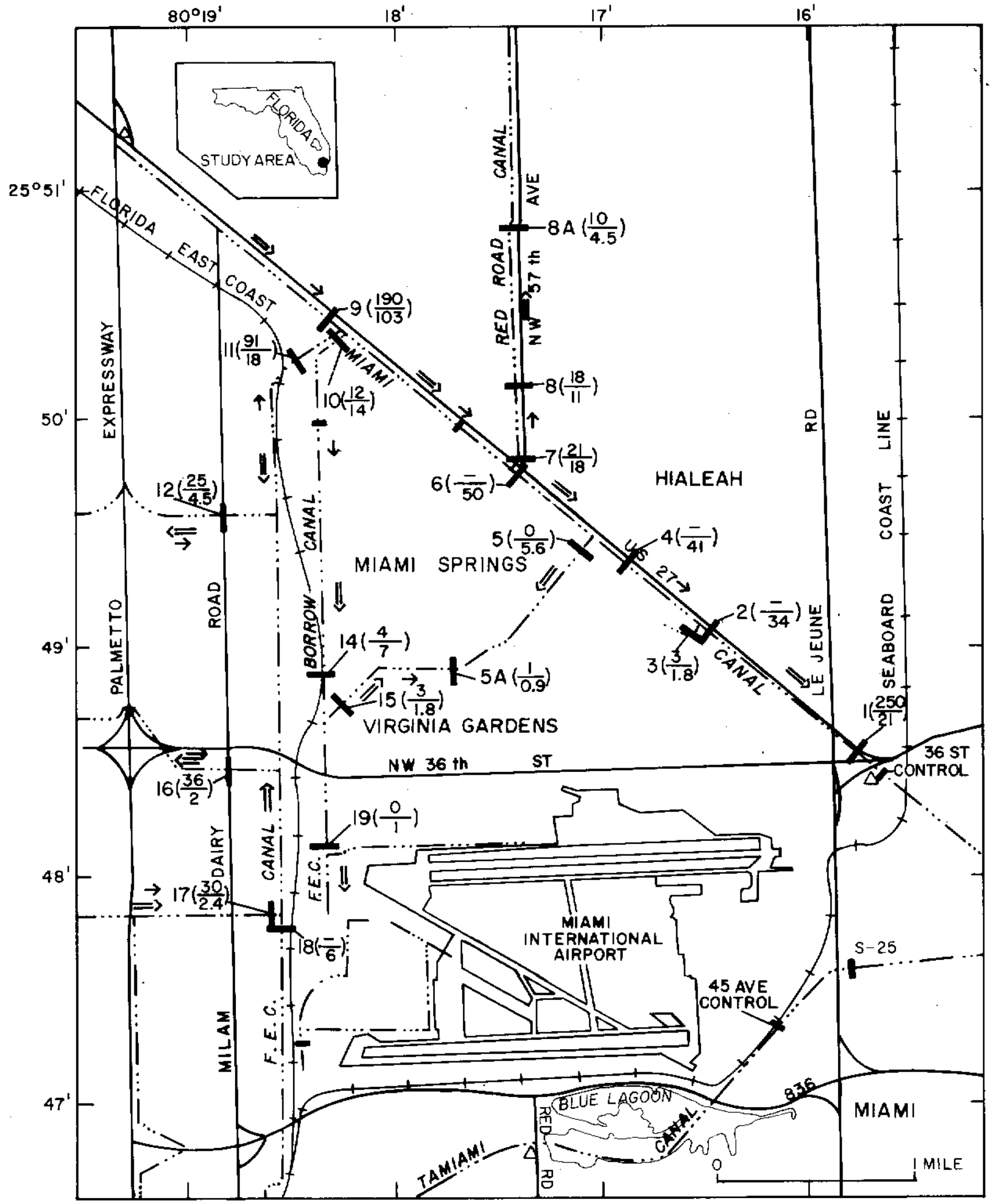


Figure 6.--Average chloride, color, and raw water pumpage from Miami Springs-Hialeah well fields, 1945-1974.



EXPLANATION

FLOW DIRECTION: → NOVEMBER 21, 1972; ⟹ MAY 3, 1973

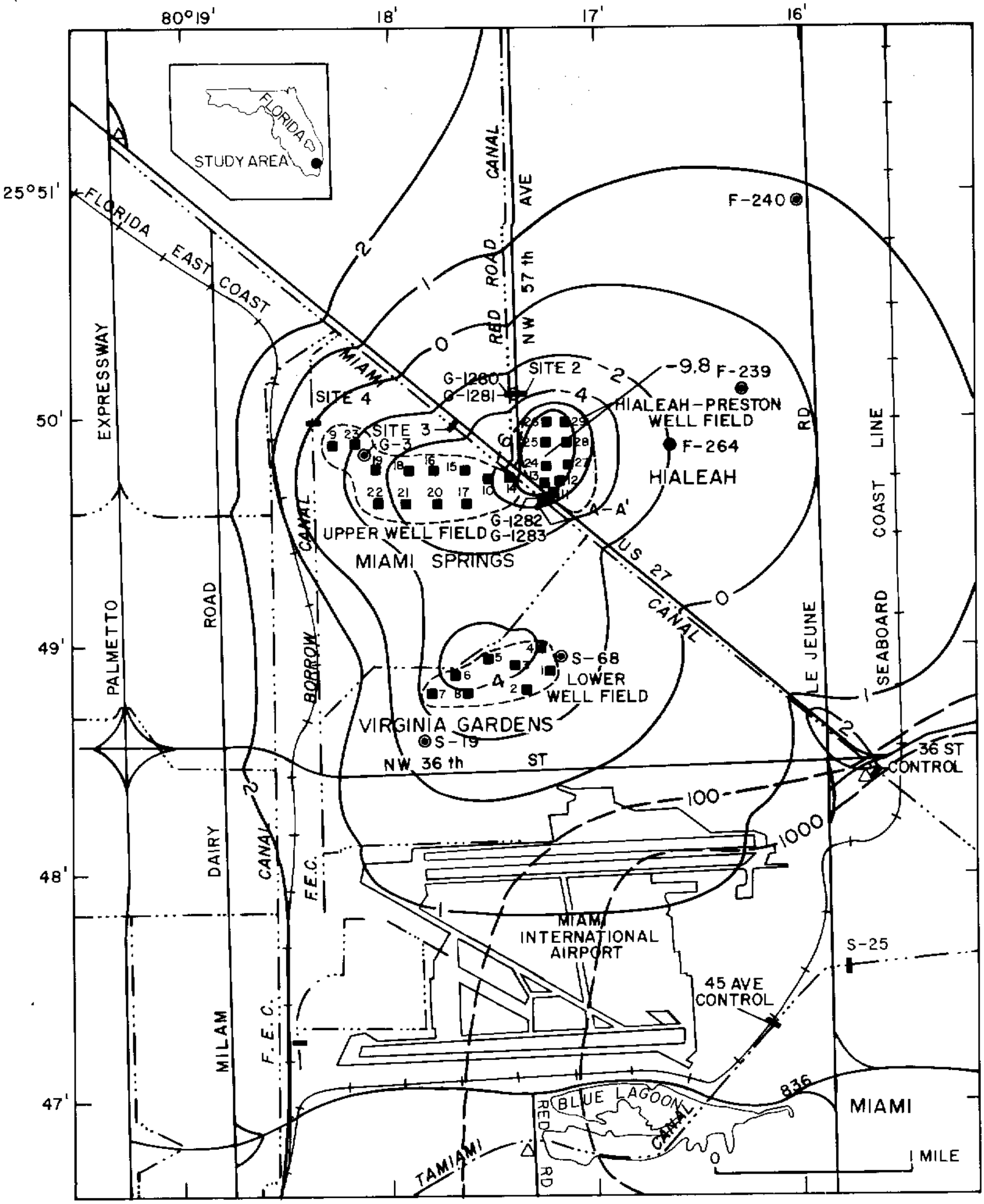
SITE NUMBER : 1–19

DISCHARGE VALUES IN CUBIC FEET PER SECOND: $\frac{1}{0.9}$ $\left(\frac{\text{NOVEMBER 21, 1972}}{\text{MAY 3, 1973}}\right)$

Figure 7.--Discharge at selected sites in canals in the vicinity of Miami Springs-Hialeah well fields, November 21, 1972 and May 3, 1973.

Table 1.--Estimates of contributions from nearby canal segments to well fields in the Miami Springs-Hialeah area, May 3, 1973.

Segment between sites	Percentage infiltration from canal	Length (miles)	Infiltration per mile (Mgal/d)
9- 6	3.9	1.32	1.9
6- 4	4.4	.71	2.2
4- 2	6.7	.64	4.3
2- 1	16.9	.85	10.9
7- 8	9.1	.36	5.9
8- 8A	8.5	.71	5.5
10-14	9.1	1.29	5.9
14-19	5.5	1.29	3.5
15-5	9.6	1.50	6.2
11-17	26.0	2.73	16.8



EXPLANATION

—— 6 —— WATER-TABLE CONTOUR-- SHOWS ALTITUDE OF WATER TABLE. CONTOUR INTERVAL IN FEET. DATUM IS MEAN SEA LEVEL.

– –100– – LINE OF EQUAL CHLORIDE CONCENTRATION, IN MILLIGRAMS PER LITER AT BASE OF BISCAYNE AQUIFER.

Figure 8.--Water-table contours of Miami Springs-Hialeah well fields, May 3, 1973.

The sources and their characteristics are: (1) fresh surface water in nearby canals whose average chloride concentration was 69 mg/L in 1973; (2) stored fresh ground water derived from local rainfall, containing about 15 mg/L chloride; and (3) ground water containing chloride concentrations from 1,000 to more than 10,000 mg/L in the lower part of the aquifer to the south and southeast of the Tamiami and Miami Canals.

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

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

where Q_1 is the infiltration from nearby canals in million gallons per day,
C_1 is the chloride concentration of water in nearby canals in milligrams per liter,
Q_2 is the contribution from rainfall in million gallons per day,
C_2 is the chloride concentration of infiltrated rainfall in milligrams per liter,
Q_3 is the contribution of salty ground water in million gallons per day,
C_3 is the chloride concentration of salty ground water in milligrams per liter,
Q_4 is the well field pumpage in million gallons per day,
and C_4 is the average chloride concentration of pumped water in milligrams per liter.

Meyer (1972, p. 61) indicated that a low ground-water divide normally was sustained beneath the Miami International Airport and it has apparently retarded northward movement of salty ground water to the pumping wells. Therefore, contribution from salty ground water (Q_3C_3) may be omitted from equation 1.

The average amount of canal water that infiltrated the Biscayne aquifer and that was removed from aquifer storage surrounding the well fields is estimated as follows:

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

and

$$Q_1C_1 + Q_2C_2 = Q_4C_4. \qquad (3)$$

Therefore

$$Q_1C_1 + (Q_4-Q_1)\ C_2 = Q_4C_4 \qquad (4)$$

where Q_1 is the canal infiltration in million gallons per day,
C_2 is the chloride concentration of Q_1 (69 mg/L),
Q_2 is the contribution from rainfall in million gallons per day,
C_2 is the chloride concentration of Q_2 (15 mg/L),
Q_4 is the average pumpage (105 Mgal/d),
and C_4 is the average chloride concentration of Q_4 (40 mg/L).

Substituting values in equation 4 and solving for Q_1,

$$15(105 - Q_1) + 69(Q_1) = (40)\ (105)$$

$$Q_1 = 48.6 \text{ Mgal/d}$$

Therefore, the estimated canal infiltration for 1973 averaged 48.6 Mgal/d or 46 percent of the pumpage, which approximates the amount determined by the canal flow method. This is 6 percent less than the amount computed by Meyer (1972, p. 72) for 1970. Average daily pumpage in 1973 showed a 15 to 17 percent increase over that of 1970 and 1971, respectively. It would be expected that the increase in pumpage would result in greater drawdowns in the well fields and increase the ground-water gradient from the canals to the well fields. A comparison of the water level contour maps of Meyer (1972, p. 27 and 40) and figure 8 shows a slight increase in gradient. An increase in the gradient should result in greater infiltration from the canals but, apparently, this has not occurred. Indications are that infiltration from the canals has reached its maximum and cannot keep pace with the increased pumping rates placed on the system.

Comparison of more recent estimates of infiltration from the canals with estimates made in the 1940's indicate the possibility of the canal bottom being plugged by sediments. In the 1940's when average pumpage was less than 50 Mgal/d the 78 to 100 percent of dry season pumpage contributed by the canals (Meyer and Wimberly, 1972 p. 7) was sufficient to prevent intrusion.

Figure 9 shows average lines of equipotential across the Miami Canal along A-A' (fig. 1) on May 3, 1973. The water level in the canal at that time was 2.32 ft above mean sea level. Depth to the water table was based on water levels in the deeper wells.

Close spacing of equipotential lines beneath the bottom of the canal indicates a large head loss across the bottom sediments and the underlying sand layer. The infiltrating canal water moves down and through fine-grained bottom sediments and the sand layer. Once the infiltrating water reaches the more permeable limestone, it moves laterally toward the well fields.

HYDRAULIC CONDUCTIVITY

Hydraulic conductivity of the bottom sediments varies across the canal as the result of differences in thickness and composition. Spacing of the equipotential lines (fig. 9) suggests that the sediments along the northeast side (right of center line) of the canal are thicker and more compact than those along the southwest side of the channel. Sediment in the center of the channel is less compact or thinner, probably due to partial removal during seasonal high flows.

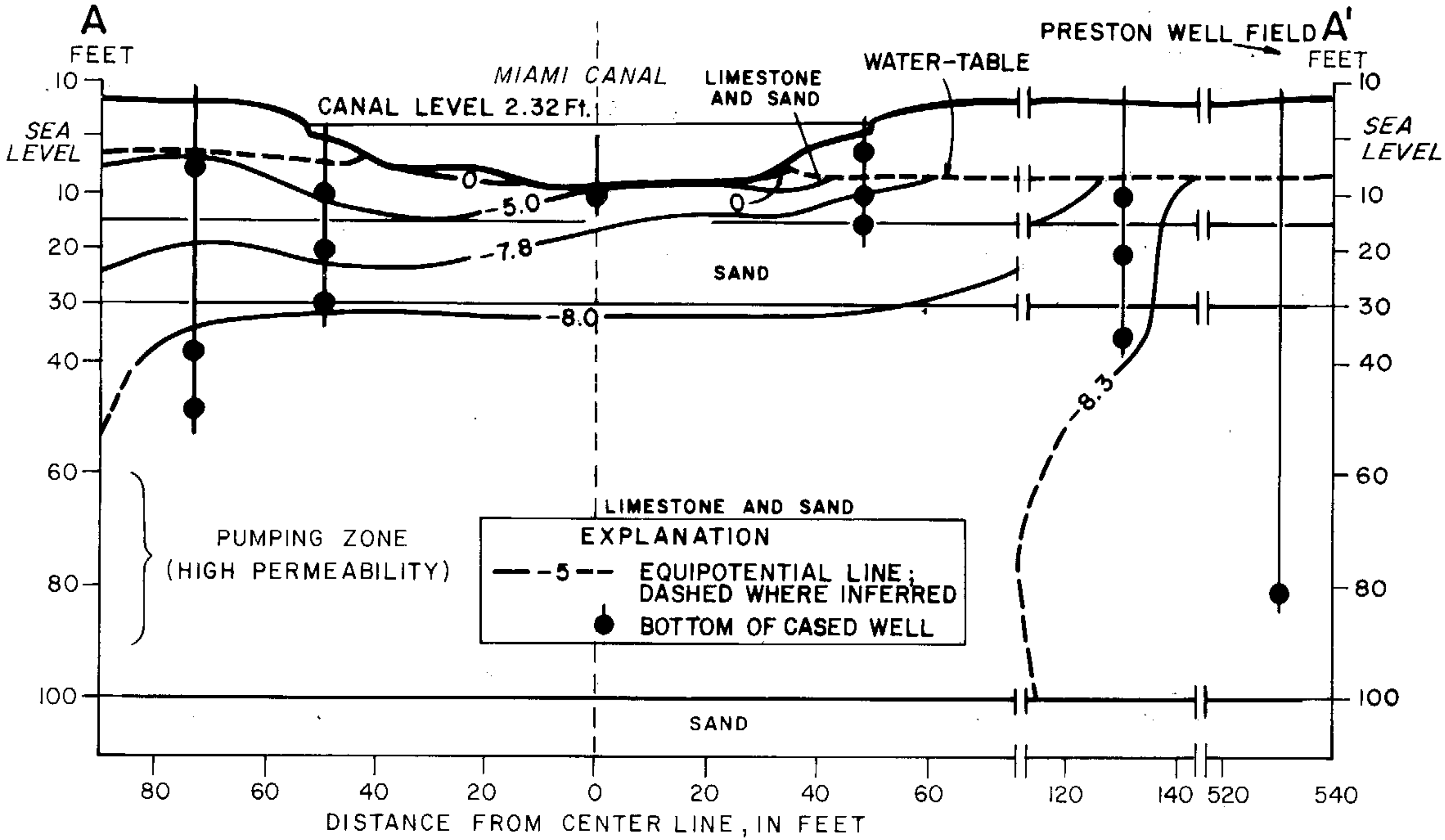


Figure 9.--Equipotential lines and water table along A-A', May 3, 1973.

An approximation of the average hydraulic conductivity of bottom sediments was made for the segment of the Miami Canal between sites 4 and 9 using discharge data for May 3, 1973 (fig. 7). This segment of the canal lies across the center of the cone of depression in the well field area as shown in figure 8. Discharge data (fig. 7) indicate infiltration from the canal of 6.4 ft^3/s within the canal segment.

Applying Darcy's Law (Johnson, 1972, p. 38):

$$K = Q/IA \qquad (5)$$

where K = hydraulic conductivity,
Q = quantity of flow per unit of time,
I = average head across sediment (h_1 h_2),
and A = length (L) times wetted perimeter (Wp) = cross-sectional area through which water moves.

Therefore

1.0 ft = estimated average sediment thickness
10.7×10^3 ft = L, distance between sites 4 and 9
105 ft = wetted perimeter of canal
4.2 ft/ft = average hydraulic gradient across sediment
$10.9 \times 10^6 ft^2$ = A
4.2×10^6 gal/d = Q in gallons per day infiltrated.

Substituting terms in equation 5:

$$K = 4.2 \times 10^6 gal/d \; / 4.2 ft/ft \; (10.7 \times 10^3 ft) \qquad 105\ ft$$
$$K = 0.89\ (gal/d)/ft^2 = 0.12 ft/d$$

It must be emphasized that this value for hydraulic conductivity is an estimate of the average for nearly a 2-mile reach of the canal. Variations in hydraulic conductivity across the canal channel, previously noted, may cause the value to be grossly in error when applied to any one point. The value should be considered as a starting point for future investigations.

Core samples of the canal bottom sediments in the vicinity of the Miami Springs-Hialeah well field were analyzed in the laboratory for hydraulic conductivity in 1971. The hydraulic conductivity of Miami Canal sediments at A-A' was 0.98 ft/d. Near the intersection of the F.E.C. Borrow Canal and the Miami Canal (fig. 1) the hydraulic conductivity was 9.80 ft/d. These data further indicate that the conductivity of the bottom sediments may have been reduced in the vicinity of maximum drawdown as a result of compaction and clogging of pore spaces in the sand directly under the bottom sediments.

WATER QUALITY

Wells in the Miami Springs-Hialeah fields yield water of good quality except for hardness (as $CaCO_3$) which is high. This is not significant, however, insofar as water use is concerned. Water treatment, which includes lime-softening, recarbonation, breakpoint chlorination, fluoridation and filtration, reduces the hardness from 230 to 70 mg/L and color from 50 to 10 units on the Hazen platinum-cobalt scale.

The quality of the canal water in the vicinity of the well fields is of concern since much of the water pumped from the wells has infiltrated from the canal system. The canals contain water whose quality depends upon numerous factors. Seasonal changes in rainfall and flow determine the amount of agricultural chemicals such as fertilizers and pesticides in the water. Ground water from wells in the north and central parts of the Everglades, which often contain residual saltwater (Parker and others, 1955, p. 686), may enter the Miami Canal during dry periods. Local urban sources of pollution such as septic tanks, industrial effluents, and storm sewers also affect water quality in the Miami Canal and its tributaries.

The hydraulic connection between the controlled canals and the Biscayne aquifer is such that a large part of the water pumped from the Miami Springs-Hialeah well fields is replaced in the aquifer by infiltration from the canals. If the infiltration capacity of the canal system is exceeded by withdrawals, the cones of depression in the well fields are enlarged and deepened. This increases the threat of saltwater intrusion to the well fields.

The lack of alternative sources of recharge enhances the impor- of the infiltrative capacity of the canals. Through the years, fine-grained sediments have accumulated on canal bottoms and have reduced infiltration. As pumping demands steadily increase, the impeding effects of the sediments may influence the ultimate withdrawal capacity and the longevity of the well fields.

Removal of the canal bottom sediments will increase the amount of infiltration which is impeded by the sediments but may, to some degree, also alter water quality in the aquifer. To determine the effects of infiltrating canal water on the quality of the ground water and aid in evaluating hydraulic conductivity and estimates of infiltration, 13 small diameter wells were drilled along section A-A' (fig. 1) near the Hialeah Water Plant in April 1972 (fig. 10). In addition to the wells, which were sampled four times in 1972-73, samples of the water and bottom sediments in the Miami Canal were analyzed. The combined adsorptive, absorptive, and filtrative characteristics, or filter effects, of the bottom sediments were evaluated from the analyses.

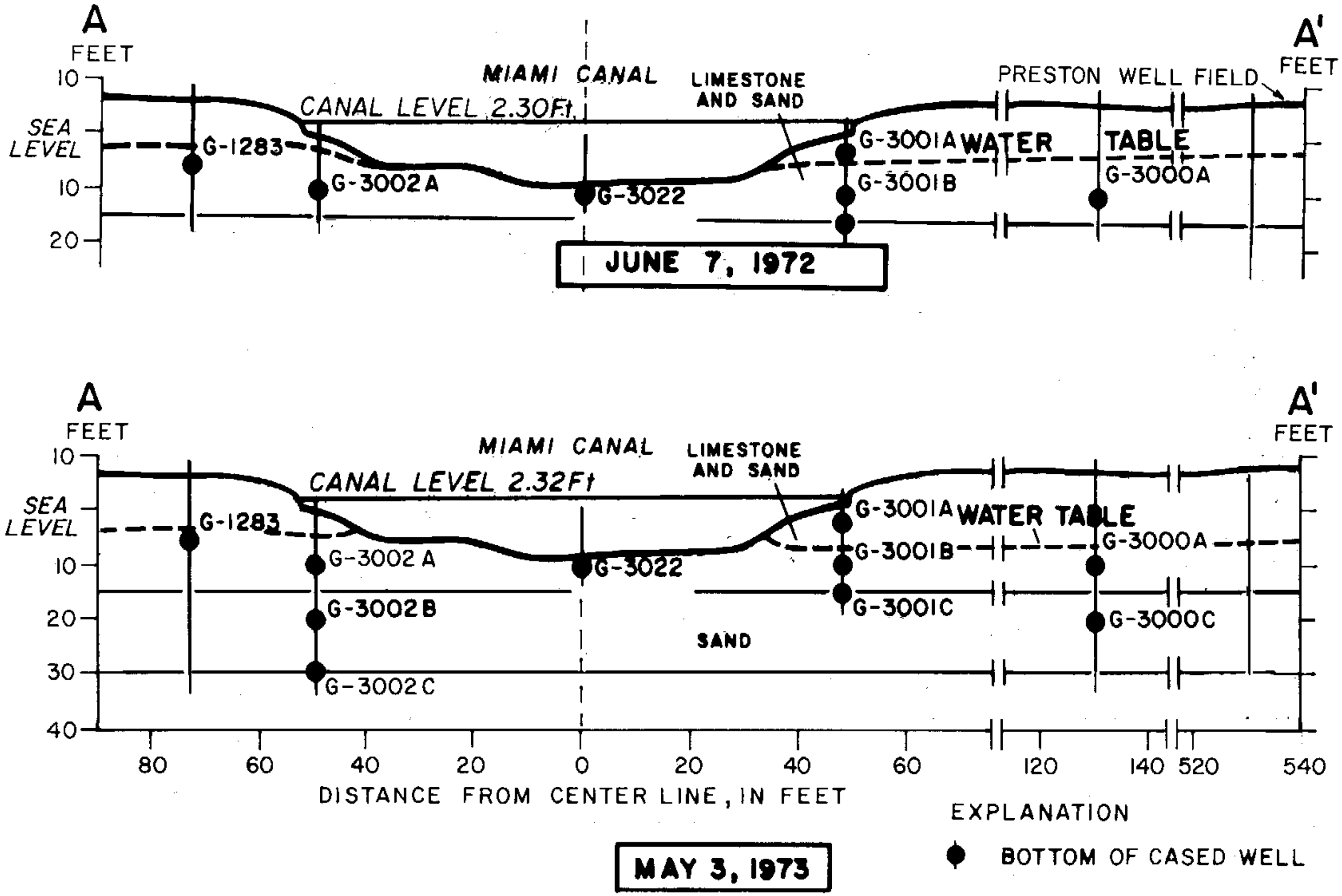


Figure 10.--Water-table and canal levels along A-A' on June 7, 1972 and May 3, 1973.

Analyses of water samples (table 2) indicate that the quality of the water varies seasonally both in the Miami Canal and in the ground water. The sampling dates represent: (1) the end of the dry season (April); (2) the beginning of the wet season (May); and (3) the beginning of the dry season (November). During these periods, the quantity of water infiltrating the aquifer from the canal varies greatly because of changes in the level of the water table (fig. 10) and in pumping rate.

In early June 1972 the water levels were measured and samples taken in the wells and the Miami Canal along A-A'. During the preceding 2 months, rainfall in the Miami Canal basin was high. Average rainfall in the basin for May was 8.02 in and for April, 4.18 in. The water table was high (fig. 10) for that time of year and the level of the Miami Canal in the vicinity of the well fields was 2.30 ft above msl. The prevailing conditions at the beginning of the wet season were such that comparatively little water was infiltrating from the canal.

The data collected in late November 1972 represent water conditions at the beginning of the dry season. Rainfall in October averaged 2.13 in and the November average was 2.52 in in the area. The water table in the vicinity of the well fields was near the June 1972 level and the level of the Miami Canal was maintained at 2.30 ft above msl. Pumping demands in the well fields were increasing and the resulting drawdown was inducing infiltration from the canal. Even so, at that time most of the water pumped was from aquifer storage rather than from infiltration from the canals.

Water-level data obtained on May 3, 1973, near the end of the dry season, showed that the water table along A-A' was lowered by pumping to a point where the Miami Canal was perched in places particularly along the edges (fig. 10). The extent of the cones of depression is shown in figure 8. The center of the larger cone was 9.8 ft below msl which is at or below the bottom of the Miami Canal. At that time the well fields were heavily dependent on infiltration from the canal system for replenishment and the rate of withdrawal was exceeding the rate of canal water infiltration as evidenced by the deepening of the cones of depression. The consequences of steady increases in pumping and a limit to the rate of canal water infiltration are indicated by a comparison for May 3, 1973 with the contour map for May 1974. The map for May 1974 shows a single cone of depression expanded eastward and southward into areas of salty ground water.

Data Interpretation

As previously stated, the main objection to removal of the canal bottom sediments as a means of increasing infiltration is the loss of the filter effect of the sediments. Consequently, the data were viewed with respect to changes in concentration of constituents or charac-

Table 2.--Analyses of water samples from Miami Canal and wells along A-A'.

(Values in milligrams per liter except where indicated).

Sampling station	Date of col- lection	Depth (ft)	Temperature (°C)	Specific con- ductance (umho/cm at 25°C)	pH	Color	Turbidity (JTU)	Dissolved oxygen	BOD	Total coliform (col/100 mL)	Fecal coliform (col/100 mL)	Fecal streptococcus (col/100 mL)	Ammonia nitro- gen (NH_3-N)	Nitrite-nitro- gen (NO_2-N)	Nitrate-nitro- gen (NO_3-N)	Organic nitro- gen	Ortho- phosphate (P)	Total phosphate (P)	MBAS 1/	Total carbon	Organic carbon	Inorganic carbon	Dissolved solids: Residue at 180°C	Dissolved solids: Calcu- lated
G-3000A	5-11-72	17.0	26.5	570	7.4	20	80	-	-	2900	0		0.22	0.01	0.00	1.3	0.01	0.02		91	15	76		
	6- 6-72		26.0	580	7.3	60	7	0.6	0.2	-	0	-	.45	.00	.00	.79	.02	.04	0.05	76	8	68	366	335
	11-29-72		27.0	670	8.0	60	9	-	.3	120	14	1	.31	.00	.00	.84	.02	.02	.00	74	21	53	399	320
	5- 1-73		-	930	7.3	30	65	-	.3	0	0	2	.05	.00	.00	.85	.00	.00	.09	90	6	84	631	590
G-3000C	5-11-72	27.0	26.5	580	7.4	10	110	-	-	1900	0	0	.61	.00	.00	.93	.00	.03	-	340	25	310	-	-
	6- 7-72		25.0	540	7.4	70	200	.5	.2	-	0	-	.60	.01	.00	1.5	.02	.07	.06	160	40	120	374	326
	11-29-72		26.5	560	8.3	140	20	-	.5	0	0	2	.60	.00	.00	.65	.01	.01	.01	71	16	55	350	310
	5- 1-73		24.0	550	7.4	100	60	-	.6	2	0	0	.59	.01	.00	.88	.01	.13	.13	72	9	63	345	310
G-3000D	5-11-72	42.0	25.5	580	7.3	70	9	-	-	360	0	0	.48	.00	.00	1.2	.03	.04	-	72	9	63	-	-
	6- 7-72		25.0	530	7.2	60	7	.4	.6	-	0	-	.33	.00	.00	1.8	.04	.06	.07	47	2	45	365	300
	11-29-72		26.5	535	8.2	120	45	-	1.7	0	0	22	.18	.01	.00	.57	.03	.04	.00	57	12	45	267	250
	5- 1-73		24.5	580	7.4	70	10	-	.3	6	0	0	.56	.00	.00	1.4	.03	.04	.08	71	8	63	364	330
G-3001A	5-11-72	7.0	-	-	-	25	20	-	-	-	0	0	-	-	-	-	-	-	-	58	0	58	-	-
	6- 7-72		26.5	510	7.4	80	7	.7	1.2	-	120	-	1.0	.05	.22	1.8	.02	.03	.07	76	9	67	362	306
G-3001B	5-11-72	20.0	27.5	570	7.4	20	35	-	-	0	0	79	.33	.01	.00	1.3	.04	.05	-	80	10	70	-	-
	6- 7-72		25.0	540	7.4	90	20	.4	.2	-	0	-	.33	.01	.00	1.2	.02	.03	-	78	14	64	372	309
	12- 1-72		25.0	540	7.3	100	15	-	.8	20	0	0	.98	.01	.00	.97	.07	.07	.00	26	3	23	348	310
	5- 1-73		-	710	7.6	80	30	-	.0	240	0	4	.17	.01	.00	.90	.02	.02	.08	87	21	66	454	400
G-3001C	5-11-72	15.0	28.0	540	7.3	10	260	-	-	900	0	0	.22	.00	.00	1.1	.01	.03	-	118	20	98	-	-
	6- 7-72		25.5	550	7.5	10	20	.5	.2	-	2	-	.26	.00	.00	.98	.03	.05	.05	77	12	65	354	311
	12- 1-72		Dry	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1/ Methylene active blue substance

Table 2.--Analyses of water samples from Miami Canal and wells along A-A'. (continued)

(Values in milligrams per liter except where indicated).

Sampling station	Date of col-lection	Depth (ft)	Temperature (°C)	Specific con-ductance (umho/cm at 25°C)	pH	Color	Turbidity (JTU)	Dissolved oxygen	BOD	Total coliform (col/100 mL)	Fecal coliform (col/100 mL)	Fecal streptococcus (col/100 mL)	Ammonia nitro-gen (NH_3-N)	Nitrite-nitro-gen (NO_2-N)	Nitrate-nitro-gen (NO_3-N)	Organic nitro-gen	Ortho-phosphate (P)	Total phosphate (P)	MBAS 1/	Total carbon	Organic carbon	Inorganic carbon	Dissolved solids: Residue at 180°C	Dissolved solids: Calcu-lated
G-3001C	5- 1-73		26.0	690	7.5	80	60	-	.3	8	0	0	.02	.01	.00	1.1	.02	.02	.09	81	17	64	429	390
G-3002A	5-12-72	12.0	26.0	550	7.6	50	7	-		-	240	-	.46	.16	.27	1.3	.01	.03	-	77	20	57	-	-
	6- 5-72		27.0	540	-	75	4	.4	.6	-	-	100	1.3	.04	.25	1.2	.02	.05	-	75	13	62	354	300
G-3002B	5-12-72	23.0	26.0	550	7.6	60	3	-	-	0	0	-	.07	.00	.00	.98	.01	.03	-	73	14	59	-	-
	6- 6-72		27.0	530	7.6	100	95	.4	.2	-	0	0	.11	.03	.00	1.0	.07	.18	.04	74	13	61	357	300
	11-30-72		24.0	540	7.4	340	40	-	.6	0	0	6	.87	.01	.00	.78	.01	.01	.00	65	16	49	-	300
	4-30-73		-	780	8.5	45	7	-	.8	140	14	20	.02	.01	.10	1.1	.00	.00	.10	53	9	44	421	300
G-3002C	5-12-72	33.0	26.0	600	7.3	80	7	-	-	4	0	-	.30	.01	.00	.85	.06	.08	-	64	12	52	-	-
	6- 6-72		26.5	580	7.3	100	15	.4	.2	-	0		.25	.00	.00	.69	.05	.05	.00	67	3	64	384	330
	11-30-72		24.0	450	7.2	50	10	-	.5	0	0	0	.25	.00	.00	.61	.04	.04	.00	55	8	47	320	300
	4-30-73		-	780	8.2	120	60	-	.0	12	0	0	.05	2.1	.00	1.0	.00	.00	.09	60	2	58	414	370
G-3021	11-30-72	38.0	24.5	492	7.2	90	25	-	2.0	0	0	0	.26	.00	.00	.54	.03	.04	.00	65	17	48	344	310
	4-30-73		25.0	670	7.4	120	15	-	.6	90	0	0	.15	.01	.00	.82	.02	.02	.11	59	0	59	374	350
G-3022	11-30-72	13.0	24.5	550	7.4	100	10	-	.7		4800	0	1.1	.01	.00	.85	.06	.07	.00	69	21	48	358	300
G-1282	5-12-72	57.0	25.0	350	7.9	0	1	-	-	0	0	-	.05	.00	.00	.00	.00	-	-	36	7	29	-	-
	6- 5-72		25.0	530	-	50	15	-	.2	0	0	15	.49	.00	.00	.45	.11	.12	-	31	3	28	200	185
	11-30-72		24.0	330	7.6	20	15	-	.5	4	0	54	.42	.00	.00	.37	.00	.01	.00	29	11	18	190	180
	4-30-73		-	550	8.3	30	30	-	1.0	360	14	30	.27	.00	.00	.66	.00	.00	.12	45	0	45	268	260
G-1283	5-12-72	14.0	26.0	540	7.5	55	3	-		-	83	-	.31	.04	.17	1.1	.01	.03	-	76	19	57	-	-

1/ Methylene blue active substance

Table 2.--Analyses of water samples from Miami Canal and wells along A-A'. (continued)

(Values in milligrams per liter except where indicated).

Sampling station	Date of col- lection	Depth (ft)	Temperature (°C)	Specific con- ductance (umho/cm at 25°C)	pH	Color	Turbidity (JTU)	Dissolved oxygen	BOD	Total coliform (col/100 mL)	Fecal coliform (col/100 mL)	Fecal streptococcus (col/100 mL)	Ammonia nitro- gen (NH_3-N)	Nitrite-nitro- gen (NO_2-N)	Nitrate-nitro- gen (NO_3-N)	Organic nitro- gen	Ortho- phosphate (P)	Total phosphate (P)	MBAS 1/	Total carbon	Organic carbon	Inorganic carbon	Dissolved solids: Residue at 180°C	Dissolved solids: Calcu- lated
G-1283	6- 5-72			540	-	70	3	-	.3	-	2	15	1.5	.01	.01	1.4	.03	.04	.05	75	12	63	370	304
	11-30-72		24.5	550	7.4	60	1	-	.9	23	0	12	.86	.00	.00	.89	.02	.02	.02	70	17	53	246	300
	4-30-73		24.0	740	8.1	60	4	-	.7	2	0	0	.00	.00	.10	1.3	.00	.00	.08	58	0	58	419	380
S-1476	5-12-72	79.0	27.5	540	7.4	50	1	-	-	0	0	-	.72	.00	.00	.93	.01	.03	-	73	8	65	-	-
	6- 5-72		-	590	-	50	2	-	1.1	-	20	0	.73	.01	.00	.51	.02	.20	-	72	8	64	332	290
	11-30-72		26.0	565	7.2	50	2	-	.6	0	0	0	.69	.01	.00	.56	.01	.02	.00	72	17	55	359	330
	5- 1-73		25.5	660	7.5	45	4	-	.0	0	0	0	.83	.60	.00	.64	.01	.02	.15	81	18	63	343	360
Miami Canal Hialeah Water Plant	5-12-72		28.0	570	7.4	50	4	-	-	1000	590	-	.53	.09	.17	1.1	.00	.03	-	73	10	63	-	-
	6- 5-72		26.0	530	7.6	50	3	2.7	1.1	-	80	100	.67	.05	.24	1.6	.02	.03	.00	75	12	63	341	310
	12- 1-72		24.5	540	7.2	60	3	3.0	1.1	1800	140	260	.91	.01	.03	1.1	.02	.03	.01	68	21	47	298	300
	5- 2-73		23.0	660	7.8	50	6	5.6	2.8	1000	30	120	.13	.02	.10	1.1	.00	.00	.06	81	19	62	407	360

1/ Methylene blue active substance

Table 2.-- Analyses of water samples from Miami Canal and wells along A-A'. (Continued)

(Values in milligrams per liter except where indicated)

Sampling station	Date of collection	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non-carbonate	Alkalinity as $CaCO_3$	Bicarbonate (HCO_3)	Chloride (Cl)	Fluoride (F)	Sulfate (SO_4)	Silica (SiO_2)	Total Aluminum (Al) 1/	Total Arsenic (As) 1/	Calcium (Ca)	Total Chromium (Cr) 1/	Total Copper (Cu) 1/	Total Iron (Fe) 1/	Total Lead (Pb) 1/	Magnesium (Mg)	Carbon dioxide (CO_2)	Potassium (K)	Sodium (Na)	Total Strontium (Sr) 1/
G-3000A	5-11-72	-	-	350	-	-	-	-	4.9	-	-	-	-	-	-	-	-	-	-	-	-
	6- 6-72	250	7	210	250	50	0.3	7.0	6.3	0	10	85	0	0	1,200	3.0	8.4	31	1.7	31	700
	11-29-72	230	0	230	280	48	1.0	1.6	5.6	30	10	80	0	10	1,300	9.0	7.4	-	1.6	30	900
	5- 6-73	450	140	320	380	55	.3	130	4.2	0	10	160	0	10	12,000	24	12	-	1.9	37	1,300
G-3000C	5-11-72	-	-	-	-	-	-	-	7.2	-	-	-	-	-	-	-	-	-	-	-	-
	6- 7-72	240	4	280	350	48	.3	7.3	6.7	3,100	10	82	0	30	6,900	17	8.4	-	1.8	33	2,700
	11-29-72	220	0	230	280	38	.3	7.2	6.5	20	10	76	0	0	3,100	16	7.3	-	1.6	32	900
	5- 1-73	230	0	260	320	43	.3	.8	6.2	130	2	80	0	10	4,500	7.0	7.6	23	1.8	31	800
G-3000D	5-11-72	-	-	210	250	-	-	-	5.7	-	-	-	-	-	-	-	-	-	-	-	-
	6- 7-72	230	42	240	300	44	.3	16.	5.4	0	10	83	0	0	2,800	-	5.7	-	1.9	30	670
	11-29-72	180	0	180	220	37	.2	10	4.5	10	10	62	0	20	13,000	35	5.2	-	2.0	23	720
	5- 1-73	240	7	240	290	49	.4	8.0	6.2	40	5	84	0	0	2,700	4.0	6.8	21	1.6	33	800
G-3001A	5-11-72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6- 7-72	230	0	240	290	39	.3	3.5	5.5	0	10	80	0	0	990	10	7.0	-	2.6	26	670
G-3001B	5-11-72	-	-	200	240	-	-	-	5.7	-	-	-	-	-	-	-	-	-	-	-	-
	6- 7-72	220	0	250	300	45	.3	.6	5.2	100	10	74	0	10	3,600	9.0	8.2	-	1.5	32	640
	12- 6-72	220	0	240	250	46	.1	.8	5.8	760	10	77	0	0	3,400	8.0	7.6	-	1.7	28	800
	5- 1-73	270	24	260	310	76	.3	21.	5.5	10	46	92	0	10	4,400	6.0	10	13	1.6	46	900
G-3001C	5-11-72	-	-	540	660	-	-	-	3.8	-	-	-	-	-	-	-	-	-	-	-	-
	6- 7-72	220	0	250	300	45	.3	.8	5.2	20	0	75	0	20	3,400	15	8.4	-	1.4	30	680
	12- 1-72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1/ Micrograms per liter

Table 2.--Analyses of water samples from Miami Canal and wells along A-A'. (Continued)

(Values in milligrams per liter except where inciated)

Sampling station	Date of collection	Hardness as $CaCO_3$		Alkalinity as CaCO3	Bicarbonate (HCO3)	Chloride (Cl)	Fluoride (F)	Sulfate (SO)	Silica (SiO)	Total Aluminum (Al) 1/	Total Arsenic (As) 1/	Calcium (Ca)	Total Chromium (Cr) 1/	Total Copper (Cu) 1/	Total Iron (Fe) 1/	Total Lead (Pb) 1/	Magnesium (Mg)	Carbon dioxide (CO_2)	Potassium (K)	Sodium (Na)	Strontium (Sr) 1/
		Calcium magne-sium	Non-carbonate																		
G-3001C	5- 1-73	260	20	270	230	78	.4	14	4.5	490	5	88	0	20	6,000	16	9.2	17	1.5	50	880
G-3002A	5-12-72	-	-	220	260	-	-	-	5.0	-	-	-	-	-	-	-	-	-	-	-	-
	6- 5-72	230	1	-	-	40	.3	4.0	5.6	0	0	79	0	20	1,000	1	7.4	-	2.7	26	820
G-3002B	5-12-72	-	-	240	290	-	-	-	4.0	-	-	-	-	-	-	-	-	-	-	-	-
	6- 6-72	230	8	210	260	43	.3	3.2	5.3	2,000	10	79	0	10	4,400	26	8.6		1.4	27	800
	11-30-72	210	0	220	260	52	.2	.8	5.1	20	10	72	0	0	11,000	9	7.2		1.7	31	800
	4-30-73	250	7	240	290	78	.4	.8	10	200	4	80	0	10	2,000	11	12		1.7	50	800
G-3002C	5-12-72	-	-	210	250	-	-	-	5.7	-	-	-	-	-	-	-	-	-	-	-	-
	6- 6-72	240	18	200	250	44	.4	1.8	5.2	0	10	87	0	0	3,000	6	5.5	-	2.0	30	860
	11-30-72	210	0	210	250	46	.4	15	4.5	10	10	74	0	0	1,600	4	5.3	-	1.8	31	800
	4-30-73	240	4	260	310	76	.4	.8	6.2	30	5	76	0	10	14,000	16	12	4.6	1.4	50	800
G-3021	11-30-72	210	0	220	260	46	.3	14	4.8	10	10	76	0	0	3,700	4	5.8	-	1.8	50	800
	4-30-73	250	10	240	290	56	.4	9.6	5.5	20	2	88	0	0	3,600	4	7.1	-	1.6	38	400
G-3022	11-30-72	220	0	230	280	46	.4	.8	6.0	500	0	73	0	0	2,200	12	8.0	-	1.6	32	800
G-1282	5-12-72	-	-	98	120	-	-	-	.7	-	-	-	-	-	-	-	-	-	-	-	-
	6- 5-72	100	0	-		50	.2	.2	.7	100	10	33	0	0	2,700	7	4.2	-	2.0	28	670
	11-30-72	98	0	98	120	50	.2	.8	.8	10	0	32	0	0	2,000	6	4.4	-	1.9	29	400
	4-30-73	180	0	170	230	44	.3	.8	1.9	0	2	64	-	0	2,600	9	4.8	-	1.9	30	680
G-1283	5-12-73	-	-	200	240	-	-	-	5.0	-	-	-	-	-	-	-	-	-	-	-	-

1/ Micrograms per litre

Table 2.--Analyses of water samples from Miami Canal and wells along A-A'.--Continued

(Values in milligrams per liter except where indicated)

Sampling station	Date of collection	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Non-carbonate	Alkalinity as $CaCO_3$	Bicarbonate (HCO_3)	Chloride (Cl)	Fluoride (F)	Sulfate (SO_4)	Silica (SiO_2)	Total Aluminum (Al) 1/	Total Arsenic (As) 1/	Calcium (Ca)	Total Chromium (Cr) 1/	Total Copper (Cu) 1/	Total Iron (Fe) 1/	Total Lead (Pb) 1/	Magnesium (Mg)	Carbon dioxide (CO)	Potassium (k)	Sodium (Na)	Total Strontium (Sr) 1/
G-1283	6- 5-72	230	0	-	-	40	.3	1.4	5.8	0	20	79	0	0	1,400	0	7.1	-	2.6	27	880
	11-30-72	210	0	220	260	52	.3	.8	5.4	20	0	73	0	0	760	7	7.8	-	1.6	32	800
	4-30-73	270	17	240	300	78	.4	.8	7.1	00	7	84	0	0	12,000	9	12	-	1.7	50	1,000
S-1476	5-12-72	-	-	210	250	-	-	-	6.9	-	-	-	-	-	-	-	-	-	-	-	-
	6- 5-72	230	38	-	-	42	.3	16	6.6	200	10	82	0	0	880	0	6.6	-	2.1	15	1,000
	11-30-72	230	0	240	290	46	.3	15	6.3	10	10	82	0	0	810	11	6.2	-	2.2	30	880
	5- 1-73	260	7	250	310	47	.4	14	6.4	20	4	94	0	0	790	9	7.0	-	2.9	32	720
Miami Canal at Hialeah Water Plant	5-12-72	-	-	210	230	-	-	-	4.8	-	-	-	-	-	-	-	-	-	-	-	-
	6- 5-72	230	3	-	-	42	.4	2.8	5.2	100	10	81	0	10	180	20	7.2	-	2.5	26	800
	12- 1-72	220	0	220	270	47	.3	.8	5.5	40	10	74	0	0	440	8	7.6	-	1.7	33	720
	5- 2-73	270	22	250	300	66	.3	1.2	5.0	50	3	88	0	0	190	4	11	-	1.4	42	840

1/ Micrograms per liter

teristics with changes in depth below and distance from the Miami Canal. If it is assumed that the canal water was infiltrating through the sediments and the aquifer materials, then changes in ground-water quality should reflect the filter effects.

A semi-logarithmic nomograph comparing the average values for inorganic chemical constituents in the ground water along A-A' with those in the canal water (fig. 11) shows the similarity of canal water and ground water. This further indicates a connection between the canal and the aquifer.

Profiles along A-A' were constructed and the concentrations of the constituents were plotted at the points from which the samples were collected for all the samples analyzed during 1972-1973. Selected profiles are shown in figures 12-28.

Long-term water-quality data are necessary to establish definite trends in water quality modifications with increasing depth and distance from the canals. While such data are not presently available, the data gathered in 1972-73 indicate changes in a number of physical characteristics and constituent concentrations as canal water infiltrates.

Recognition of trends in modification of water quality is hampered by large variations in hydraulic conductivity within the Biscayne aquifer. Vertical and horizontal movement rates of water in the aquifer vary greatly over short distances. Resultant time lags of water movement from the canal to the wells cause difficulty in correlating water qualities. Constant monitoring of canal water quality for long periods would be required for precise correlation.

Mixing of infiltrated canal water, rainfall, and stored ground water within the aquifer tends to mask water quality modifications that are caused by the filter effects of canal bottom sediments and aquifer materials.

Available data indicate the following trends of change in water quality during infiltration from the canal to the wells along A-A' (fig. 10):

Physical Characteristics

Ground-water temperatures (fig. 12) generally increase with depth. Canal water temperatures ranged between 28° and 23°C (Celsius) when samples were collected, but a more accurate measure of the average canal water temperature is the Miami area mean air temperature of 24°C (National Oceanic and Atmospheric Administration, p. 20) because low flow and perched water conditions during the dry season limit interaction with ground water. Assuming the water temperature of the canal reflects mean air temperature, the average ground-water temperature of 25.5°C is 1.4°C higher than that of the canal water. Ground-water

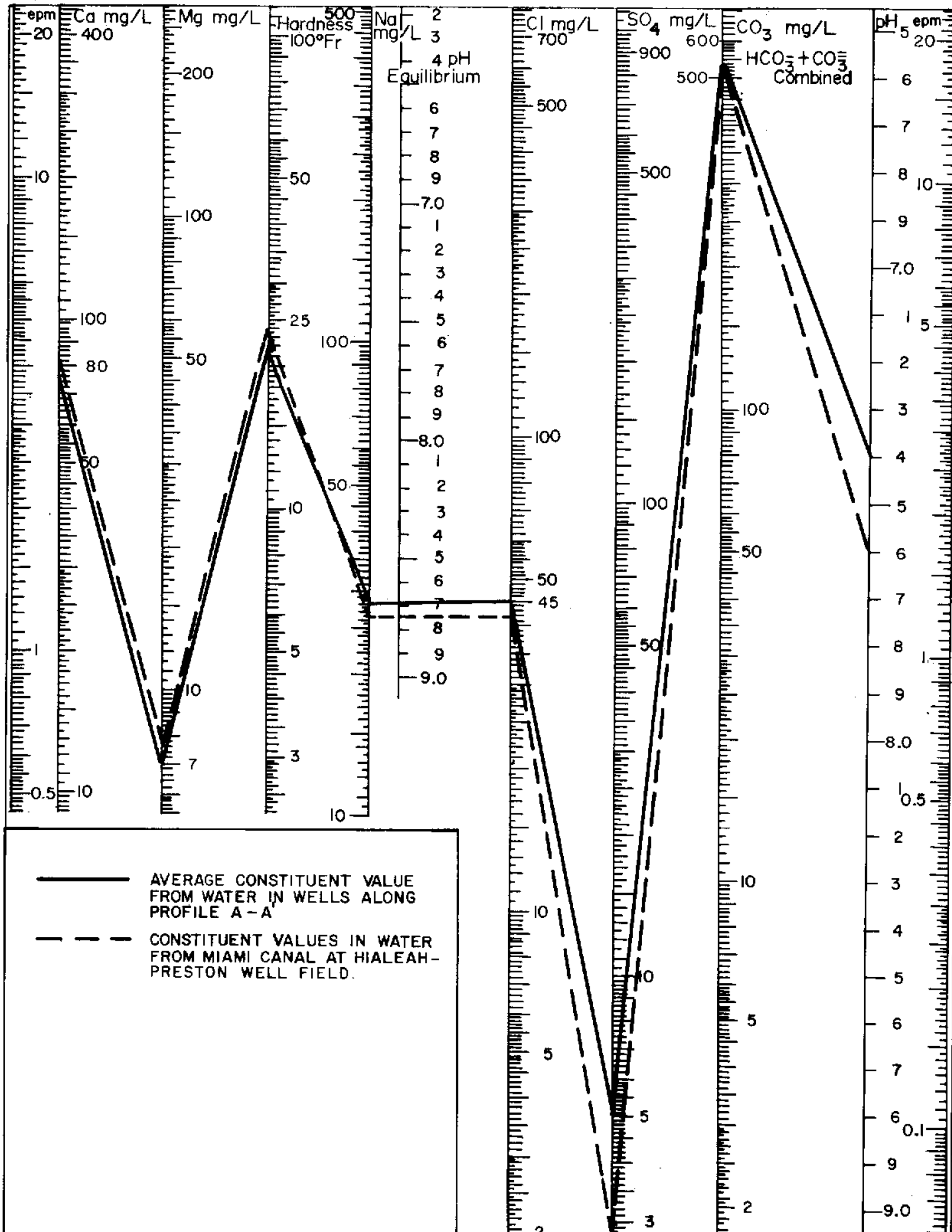


Figure 11.--Nomographs of analyses of well and canal water along A-A', June 7, 1972.

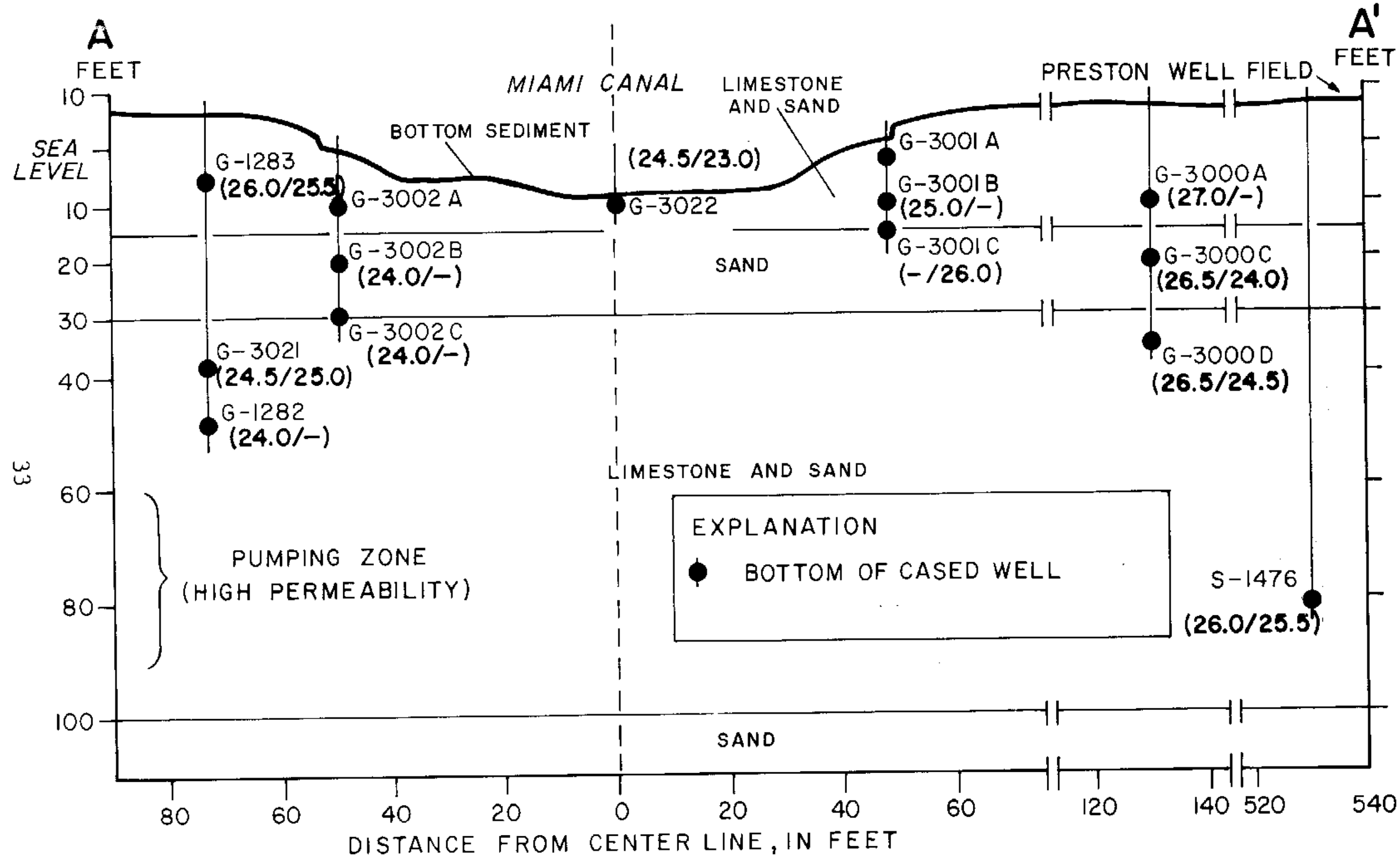


Figure 12.--Water temperatures in degrees Celsius (upper value measured between 11-29-72 and 12-1-72/ lower value measured between 4-30-73 and 5-1-73) in Miami Canal and wells along A-A'.

temperature at 30 to 60 feet below land surface is normally 1.1°-1.6°C higher than the mean annual air temperature in the United States (Todd, 1959, p. 195). Extremes of air temperatures are reflected in the temperature of the ground water in the upper 20 to 30 feet of the aquifer when pumping from wells at a high rate cause increased infiltration of canal water as illustrated by water temperature observed between November 29 and December 1, 1972 (fig. 12).

Data from wells along A-A' indicate highly colored ground water in the upper 50 ft of the aquifer, particularly in the sand zone, and less color in water in the pumping zone (fig. 13). Canal bottom sediments have little effect on the observed color in the ground water. The naturally occurring ground water in the upper part of the aquifer contains more color-causing materials than does the canal water. Reduced color in the pumping zone is due to dilution by water from surrounding areas. Data for well G-1282 indicates a possible reduction in color that is attributed to induced infiltration from the canal. Color in water from the canal ranged between 50 and 60 units in 1972 and 1973 (table 2). Early data obtained by Parker and others (1955, table 94, 95) show that color in canal water at the water plant was as high as 120 units in 1941-42, and ranged from 50-110 units during 1943-48.

Turbidity in the canal water and ground water tends to correspond to data for color. Turbidity is lower in the canal as is color. Color-causing materials in the water may have interfered with the turbidity determinations.

No correlation between pH values (table 2) in the Miami Canal and the ground water in adjacent wells can be made using the available data. A pH greater than 8.0 in water from several of the wells may be the result of increased water movement in the aquifer because of pumping in nearby supply wells. Both the quantity of carbon dioxide present and the formation of bicarbonates are influenced by rates of water-movement and according to Johnson (1972, p. 70) changes in the carbon dioxide-bicarbonate relation alter the pH. Recharge of the pumping zone from several sources of differing pH value mask the effect of pH changes caused by the individual recharge sources.

Seasonal variations in specific conductance (fig. 14) are evident. Measurements made during the wet season (June 1972) are consistently lower than dry season measurements (May 1973). During the dry season, evapotranspiration removed water from the canal and aquifer, thereby concentrating dissolved solids. Infiltration from the canal is greatest at this time. Specific conductance decreases with depth, but mixing of water from several sources masks the trend in the pumping zone.

Bacteriological Characteristics

Coliform bacteria are largely removed from infiltrating canal water by the bottom sediments. Data indicate that coliform beneath the

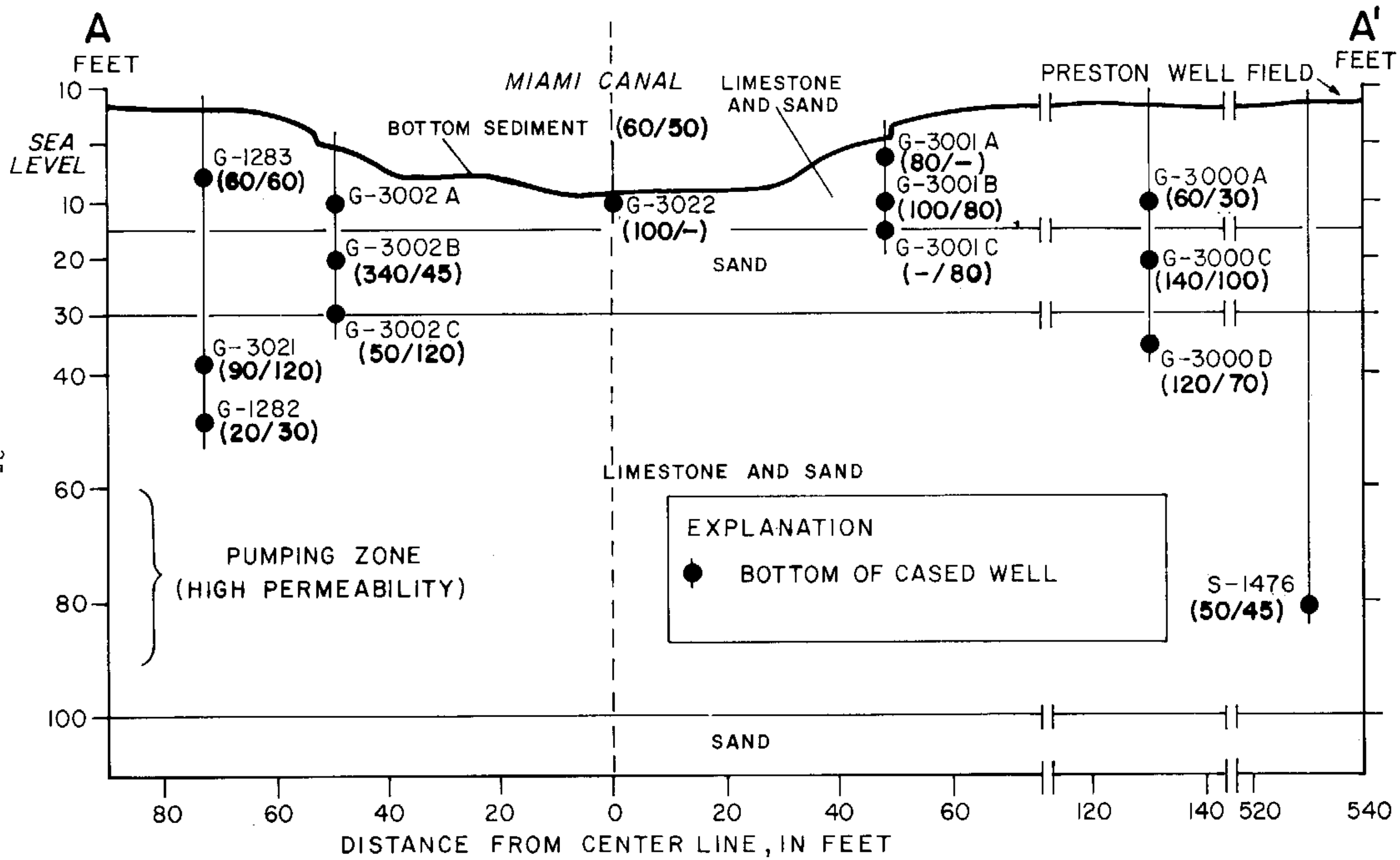


Figure 13.--Water color in Hazen Scale Units (upper value measured between 11-29-72 and 12-1-72/ lower value measured between 4-30-73 and 5-1-73) in Miami Canal and wells along A-A'.

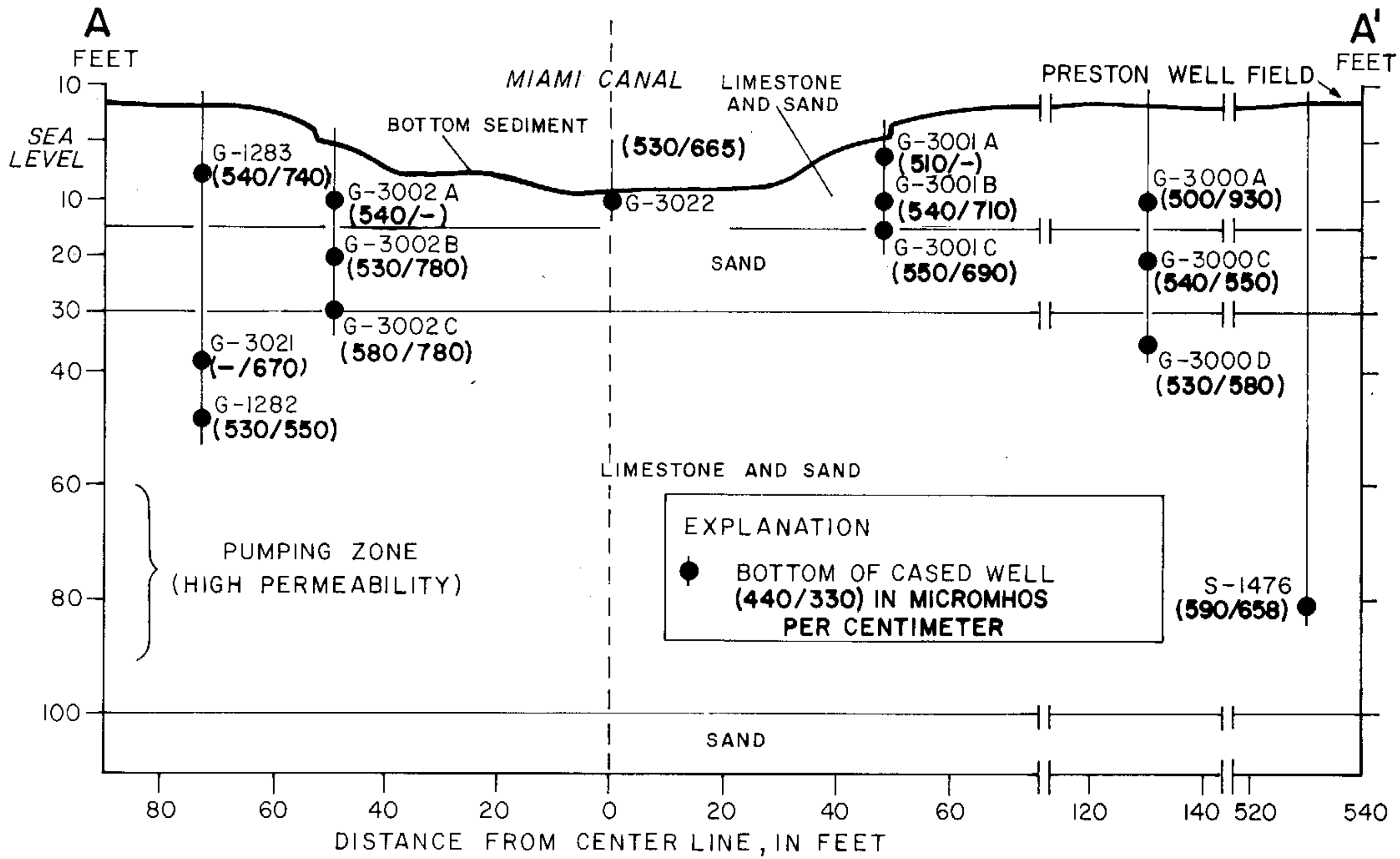


Figure 14.--Specific conductance of water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 4-30-73 and 5-1-73) in Miami Canal and wells along A-A'.

sediments decrease rapidly with depth. Fecal coliform were present in only one sample from the pumping zone (S-1476), the count was low (table 2), and it is unlikely that the bacteria originated from the canal. Total coliform and fecal streptococcus data indicate a similar decrease with depth. None of the samples taken from the pumping zone were found to contain these bacteria.

Biochemical oxygen demand (BOD) decreases away from the Miami Canal (fig. 15). This is an indication that oxygen demanding agents may be removed by bottom sediments and aquifer materials as well as being degraded. Variations in the trend of reduction are probably the result of the time lag of water movement from the canal to the wells, as infiltrating canal water moves within the aquifer. Water in the pumping zone generally has a lower BOD than water in the canal because of the combined effect of dilution by ground water, degradition of oxygen demanding material as water flows through the aquifer, and the filter effects of the sediments in the canal.

Nutrients

Total carbon decreases with vertical and horizontal distance from the canal (fig. 16). Organic carbon (fig. 17) is both removed by bottom sediments and degraded within the aquifer during infiltration. Particulate organic carbon is especially susceptible to filtration by sediments (Stumm and Morgan, 1970, pp. 347-49). Inorganic carbon moves relatively unaffected throughout the canal-ground-water system. Total carbon in the pumping zone remains relatively high, indicating sources other than the Miami Canal.

Organic nitrogen (fig. 18) decreases with depth and distance from the canal because of partial removal by the filter effects of the bottom sediments and aquifer materials.

Small amounts of ammonia-nitrogen are present in both the canal and ground water (fig. 19). Samples taken from the pumping zone (S-1476) generally contained higher concentrations than those from the upper units of the aquifer.

Nitrate-nitrogen was present in very small quantities in the ground water and canal water when samples were collected. The reducing environment in the aquifer retards oxidation of NH_3 and NO_2 which could increase nitrate-nitrogen (Hem, 1971, p. 180).

Total phosphorus, including orthophosphates, is high throughout the sampling section and no trends of reduction are evident during infiltration of canal water. A seasonal trend is indicated (fig. 21) by the lower phosphate concentrations during the dry season (5-1-73). Low rainfall runoff and plant growth probably reduce the quantity of phosphate bearing fertilizers entering the canal system.

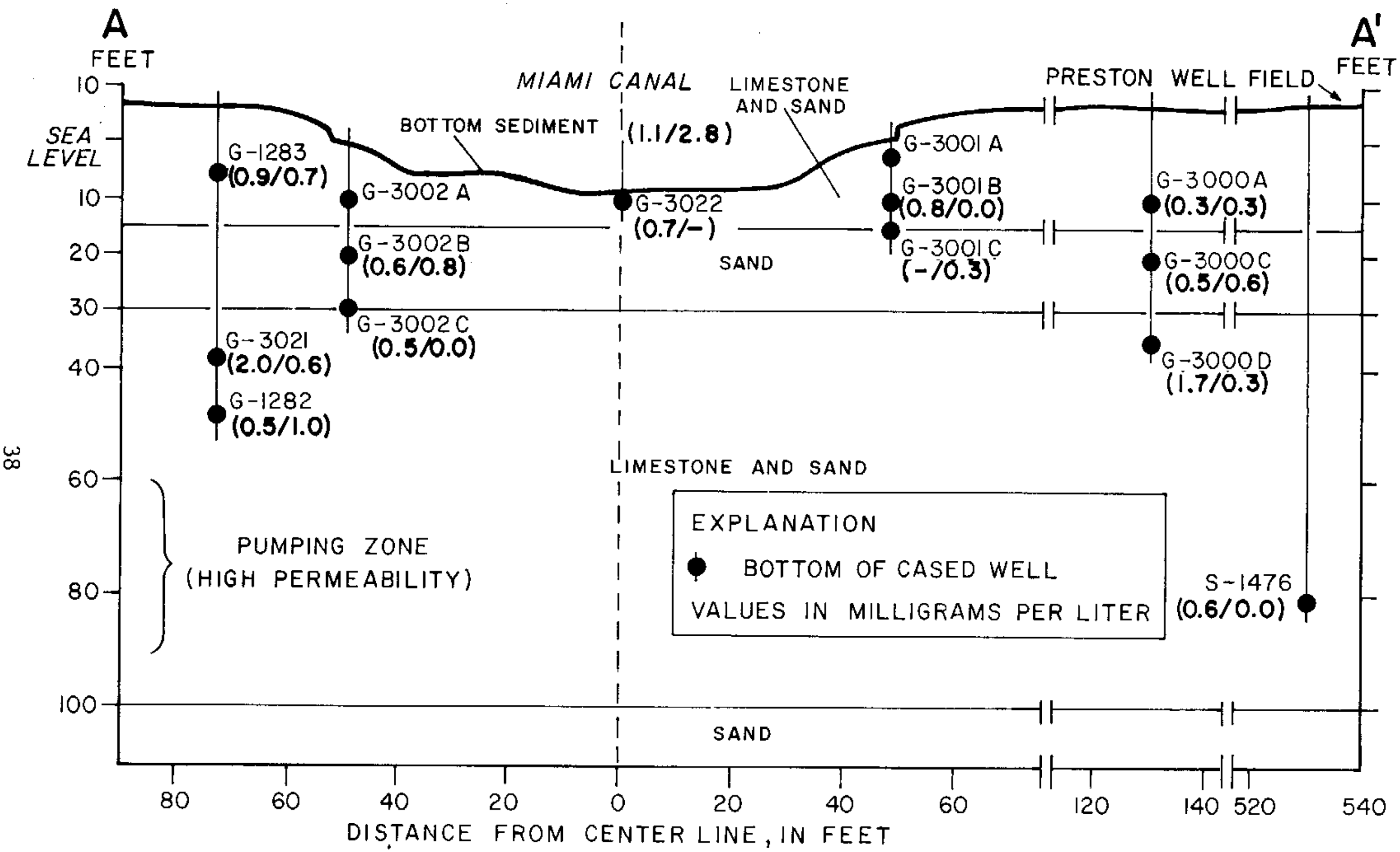


Figure 15.--Biochemical oxygen demand in water (upper value measured between 11-29-72 and 12-1-72/ lower value measured between 4-30-73 and 5-1-73) in Miami Canal and wells along A-A'.

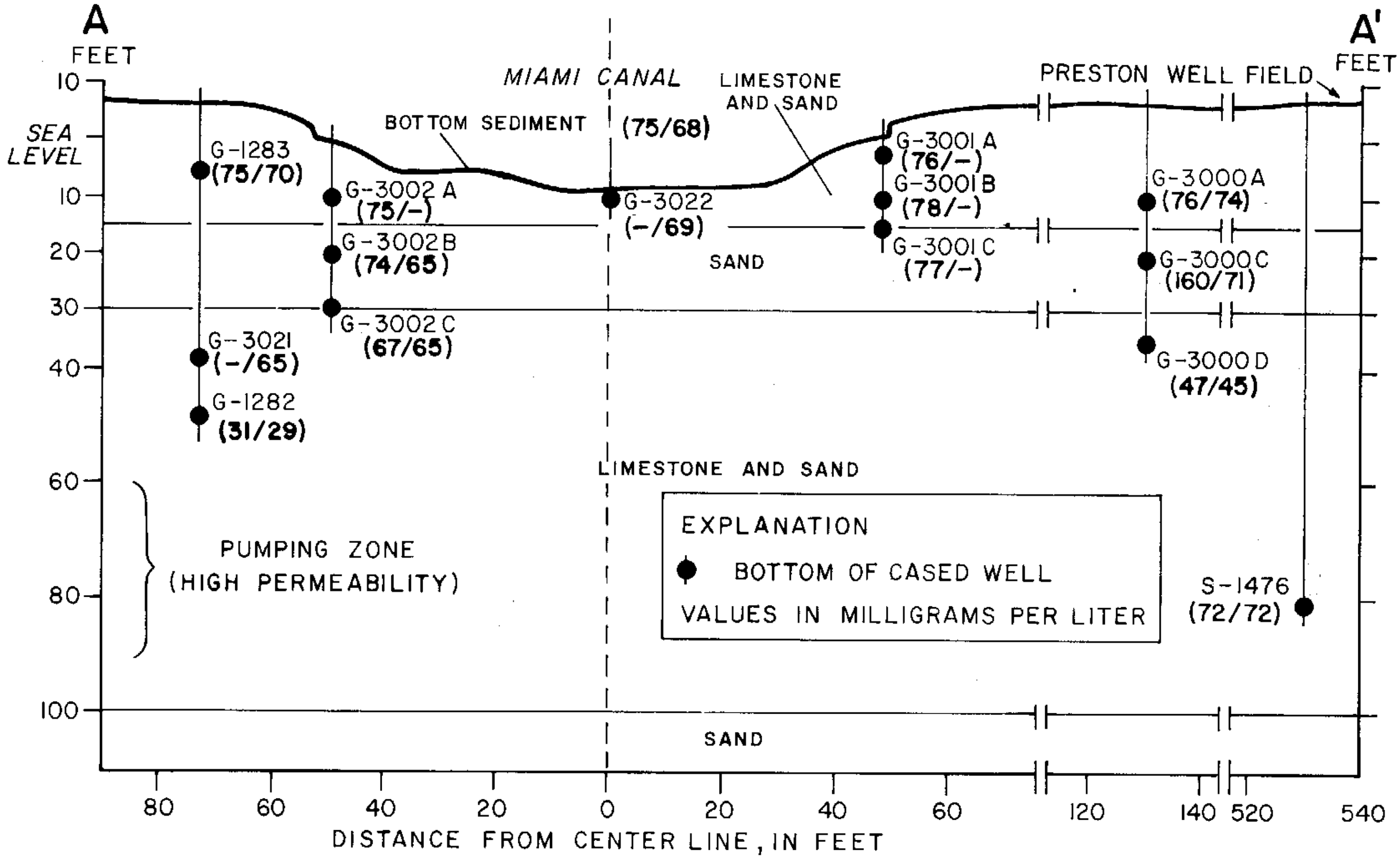


Figure 16.--Total carbon in water (upper value measured on 6-5-72/lower value measured on 11-29-72) in Miami Canal and wells along A-A'.

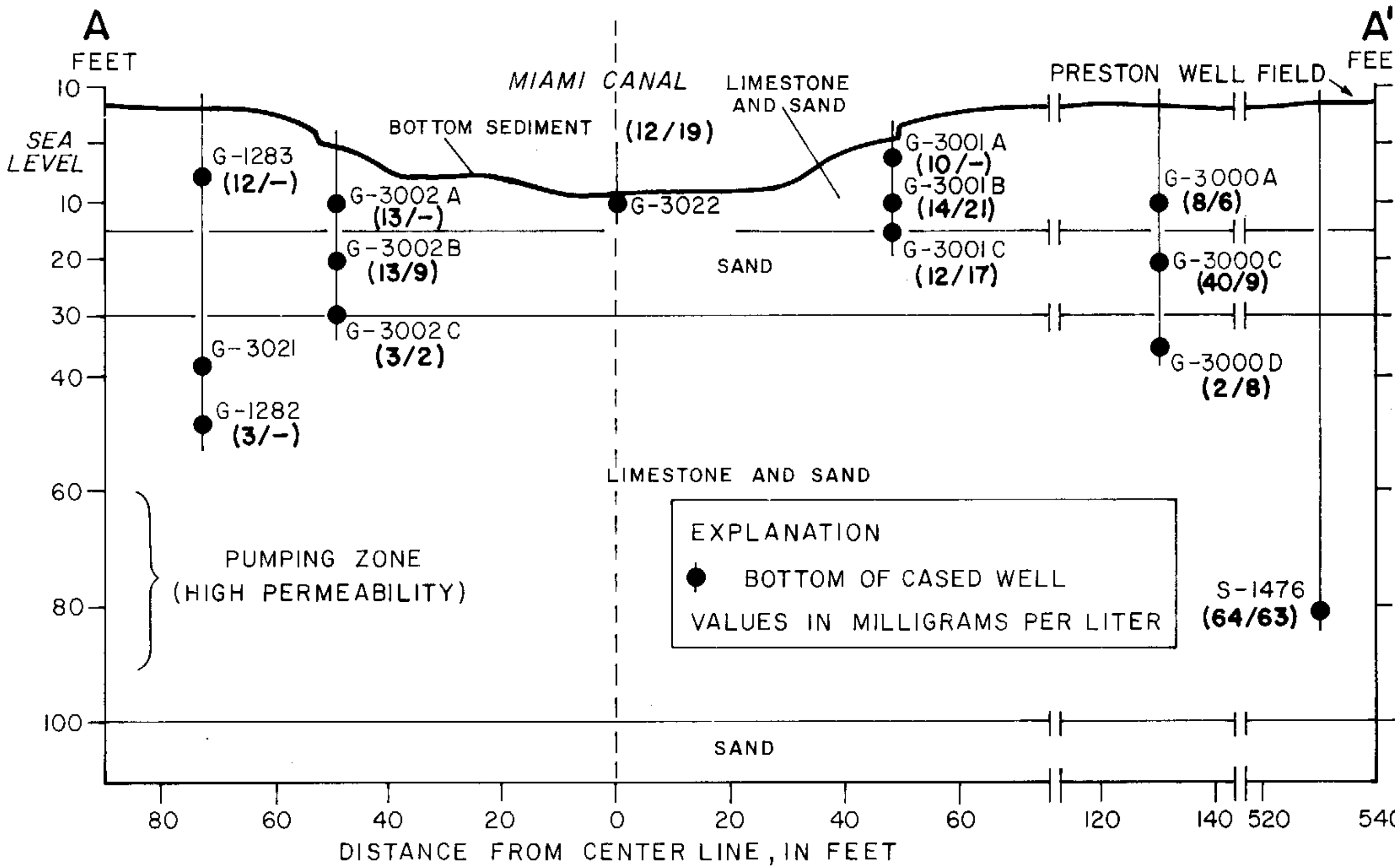


Figure 17.--Organic carbon in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 11-29-72 and 12-1-72) in Miami Canal and wells along A-A'.

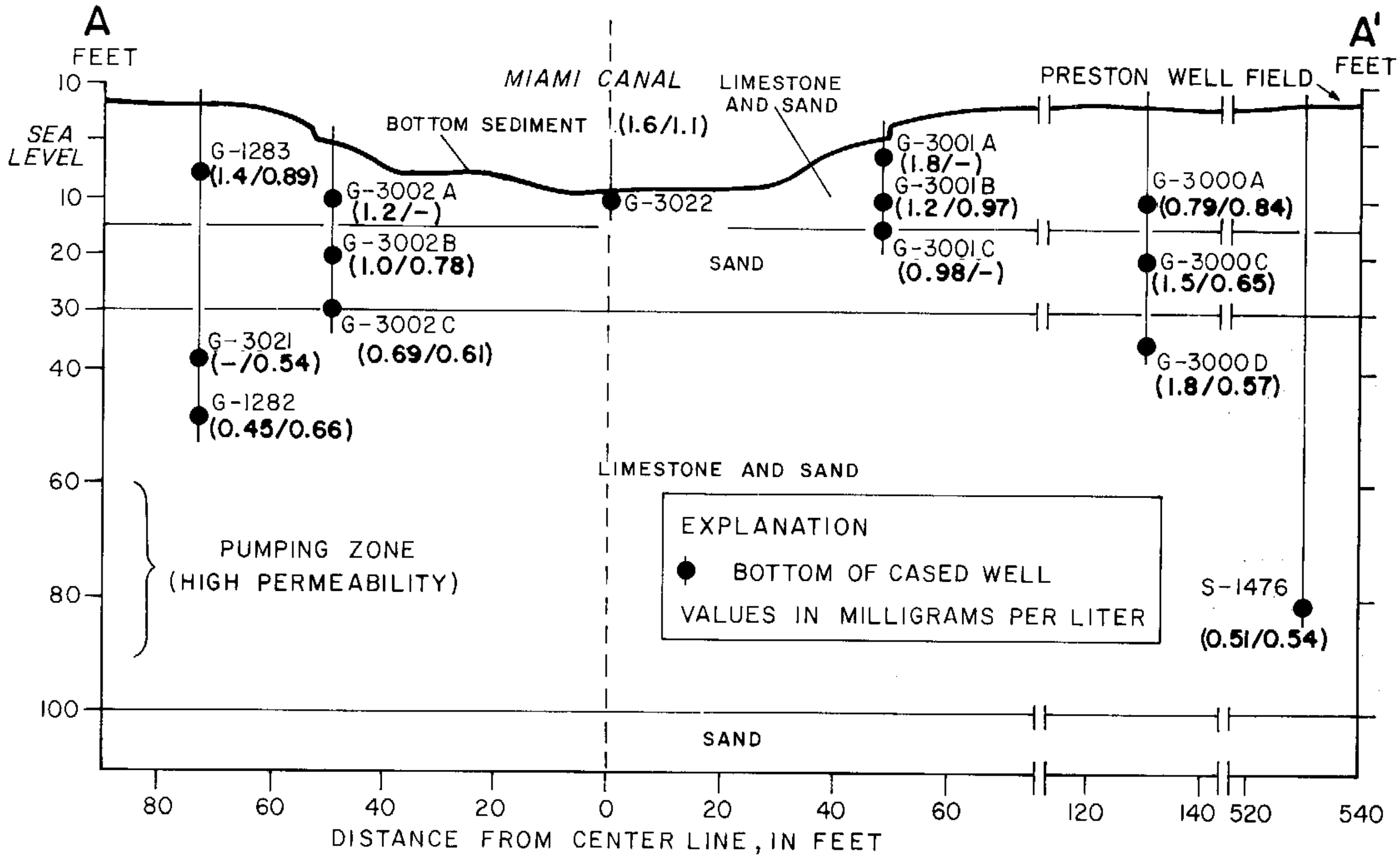


Figure 18.--Organic nitrogen in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 11-29-72 and 12-1-72) in Miami Canal and wells along A-A'.

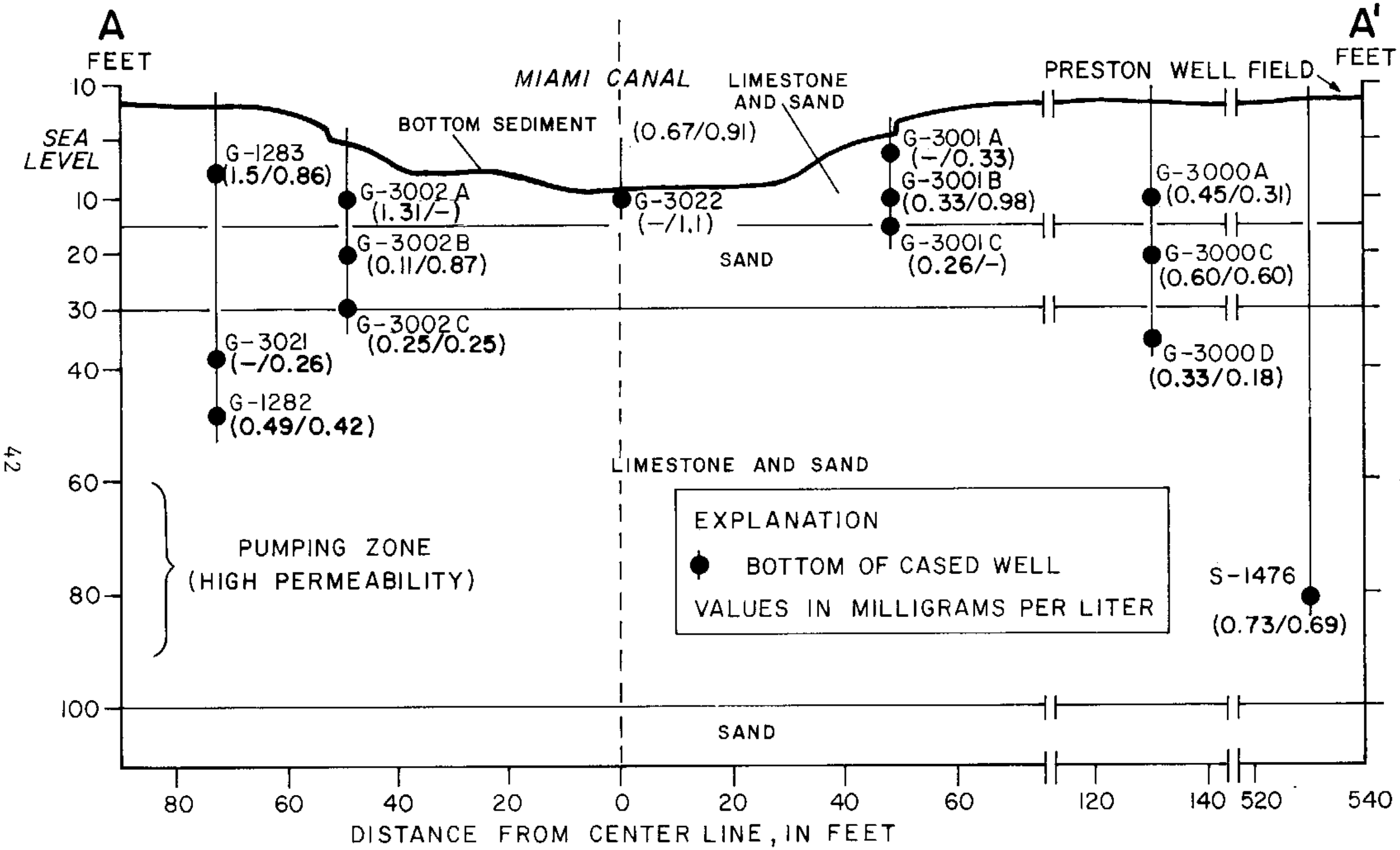


Figure 19.--Ammonia nitrogen in water (upper value measured between 6-5-72/ lower value measured between 11-29-72 and 12-1-72) in Miami Canal and wells along A-A'.

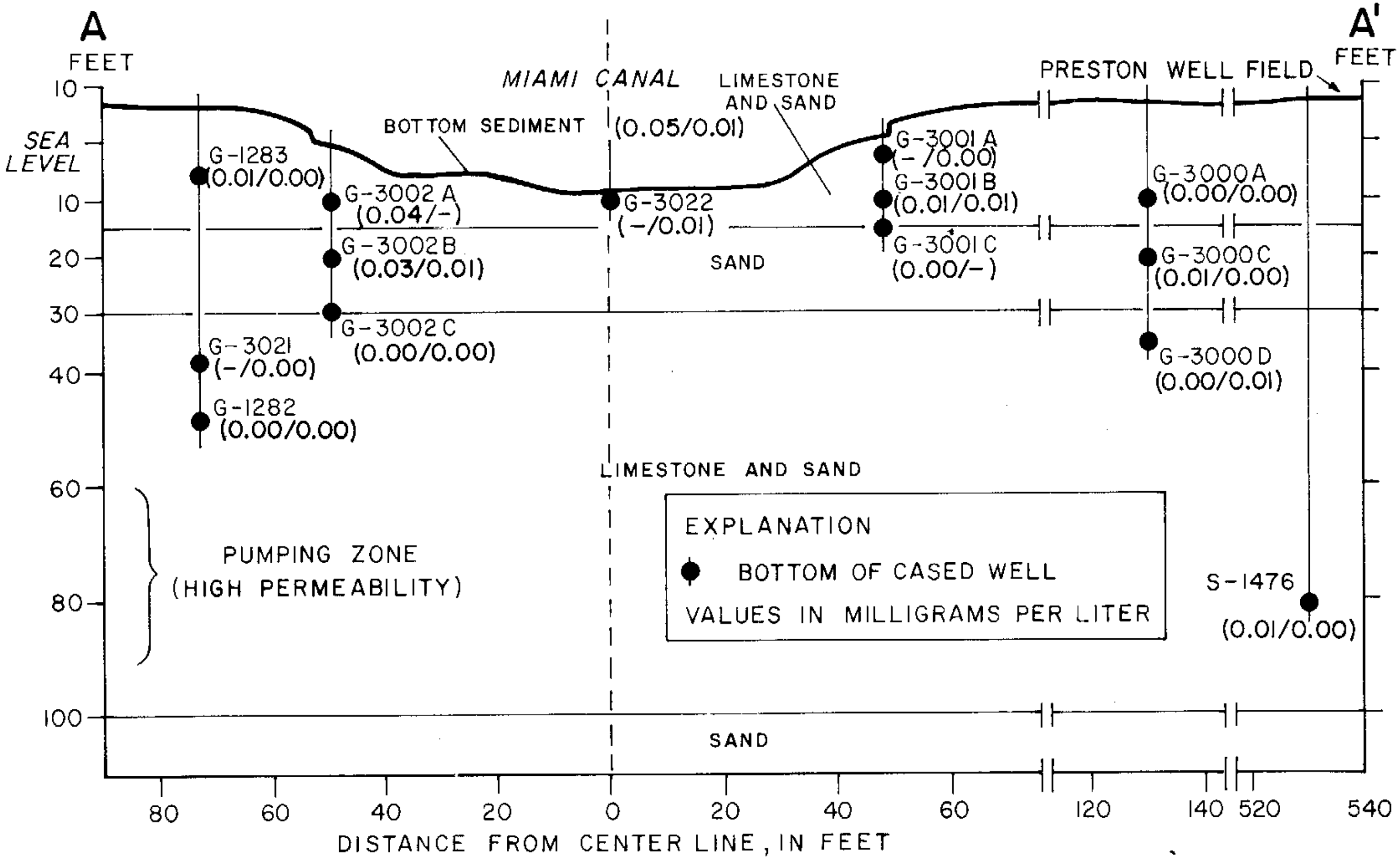


Figure 20.--Nitrite-nitrogen in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 11-29-72 and 12-1-72) in Miami Canal and wells along A-A'.

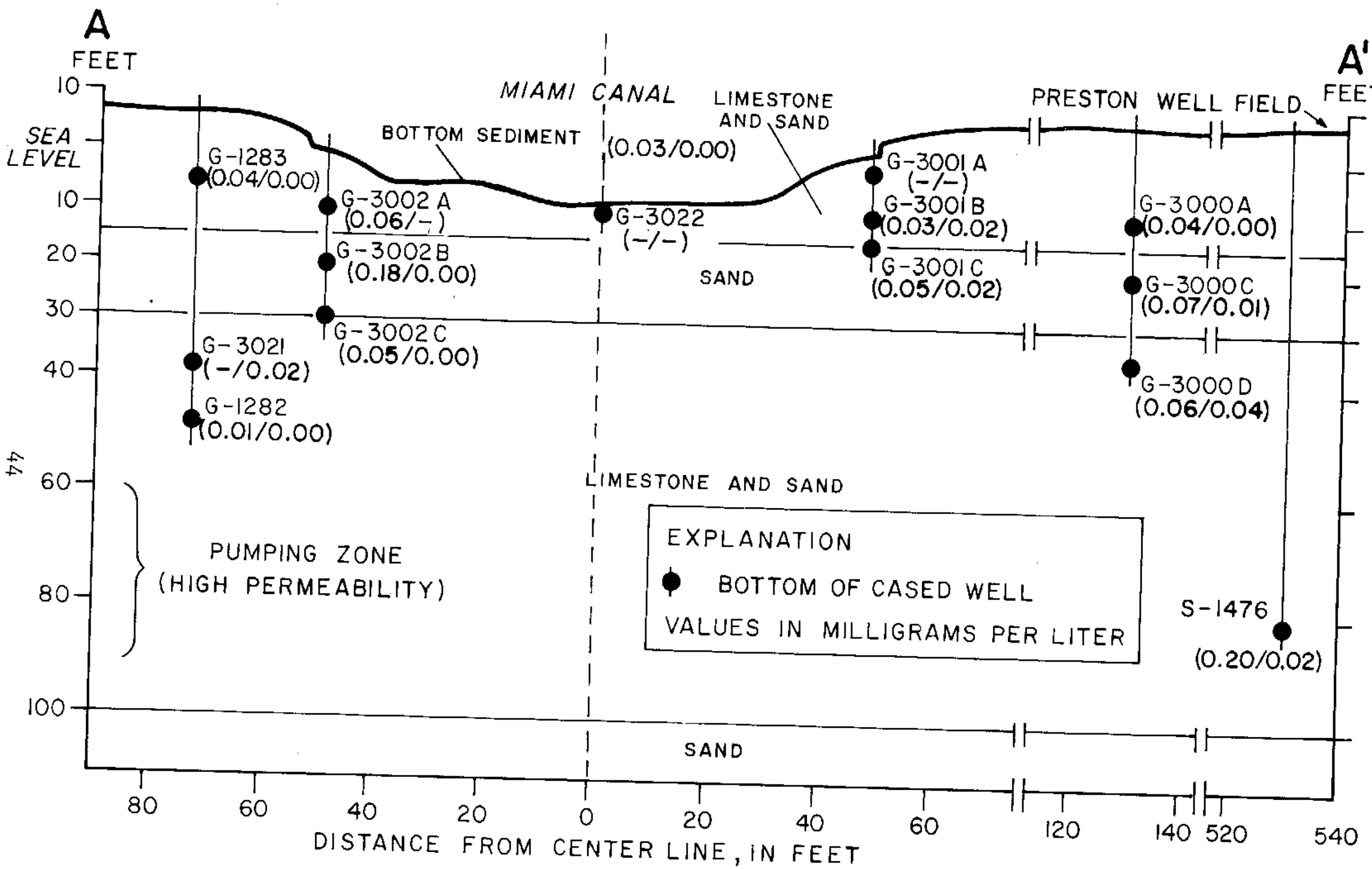


Figure 21.--Total phosphate in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 4-29-73 and 5-1-73) in Miami Canal and wells along A-A'.

Both the water of the Miami Canal and the adjacent wells along section A-A' contain moderate concentrations of orthophosphate (fig. 22). In general, concentrations are higher in the ground water than in the canal water. Runoff from agricultural areas through which the Miami Canal flows (fig. 1) contributes to orthophosphate concentrations in the canal while aquatic plant growth removes it. Available data are insufficient to determine any filter effects which may be present in either the bottom sediments or aquifer materials.

Major Cations and Anions

The filter effects of bottom sediments and aquifer materials do not alter sodium concentrations in infiltrating canal water. Variations in the observed values are due to mixing of water from several sources and the time lag as water moves from the canal to the wells along A-A'.

Magnesium concentrations decrease with depth from the canal (fig. 23). Ion exchange with calcium carbonates and dilution are probably the dominant causes for the decrease.

Concentrations of calcium exhibit no discernible trends of increase or decrease during infiltration from the canal. Induced water movement in the vicinity of supply wells may cause calcium precipitation and some localized decreases in calcium concentrations. This may also remove excess calcium released by ion exchange with magnesium.

The only changes in chloride concentrations as canal water infiltrates are due to mixing with ground water of varying chloride con-concentrations. Seasonal variations in canal flow and chloride concentrations are reflected in the ground water (fig. 24). During dry periods, high pumping rates in the well fields increase infiltration from the canal at a time when canal chloride concentrations are usually the highest.

The concentrations of potassium observed in both canal and ground water range from 1.4 to 2.9 mg/L (fig. 25). Agricultural fertilizers contribute potassium to the canal water and concentrations are increased in the canal during periods of high runoff. The filter effect within the aquifer materials and dilution may cause a slight reduction of potassium concentrations which occur with depth.

Fluoride concentrations in the Miami Canal and adjacent wells are not affected during infiltration (table 1).

Strontium concentrations along section A-A' are consistently above the median of 0.11 mg/L for water supplies of the larger cities in the United States (Hem, 1971, p. 197). Although there is an indication of seasonal variation, further data are required to demonstrate this.

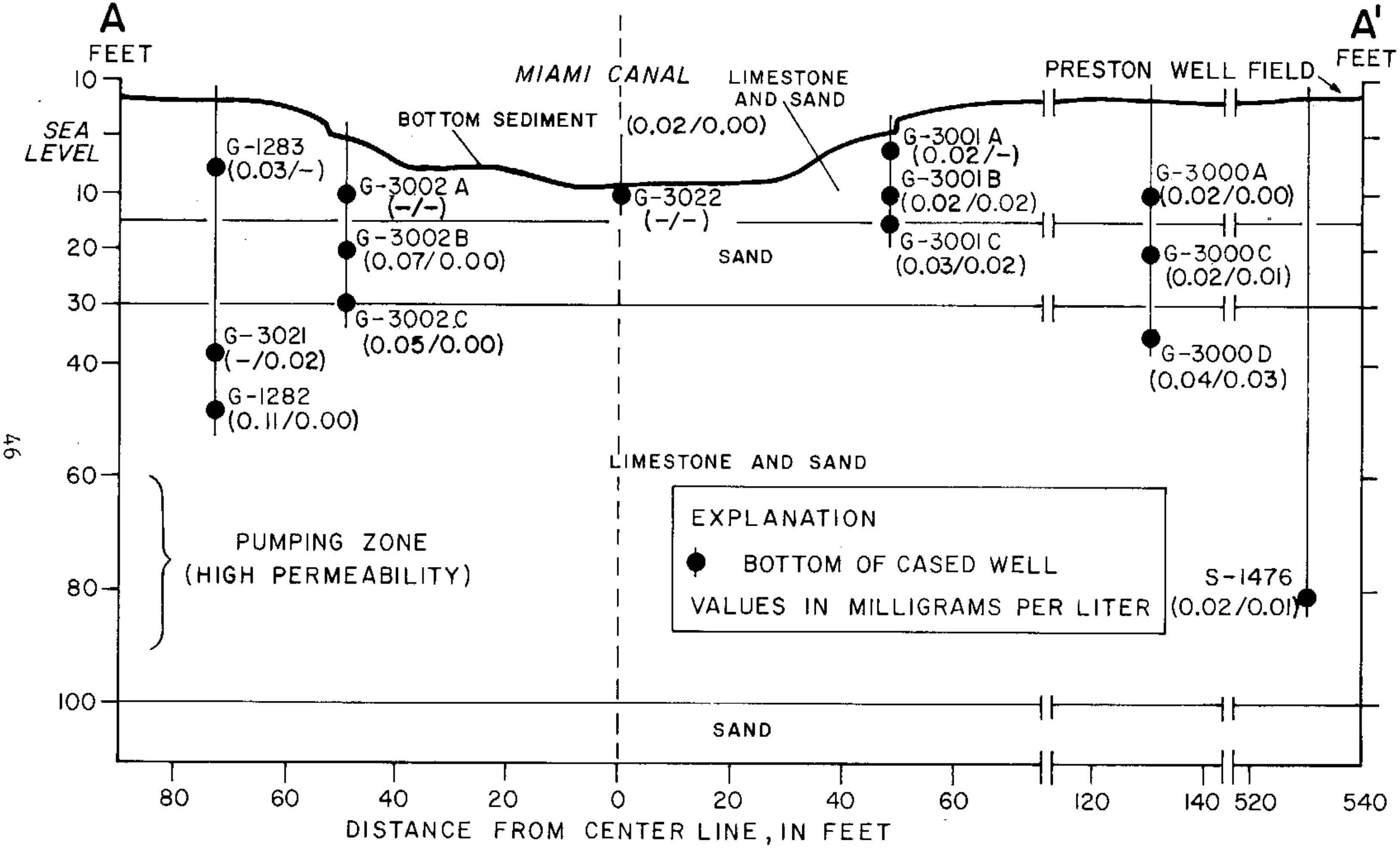


Figure 22.--Orthophosphate in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 4-29-73 and 5-1-73) in Miami Canal and wells along A-A'.

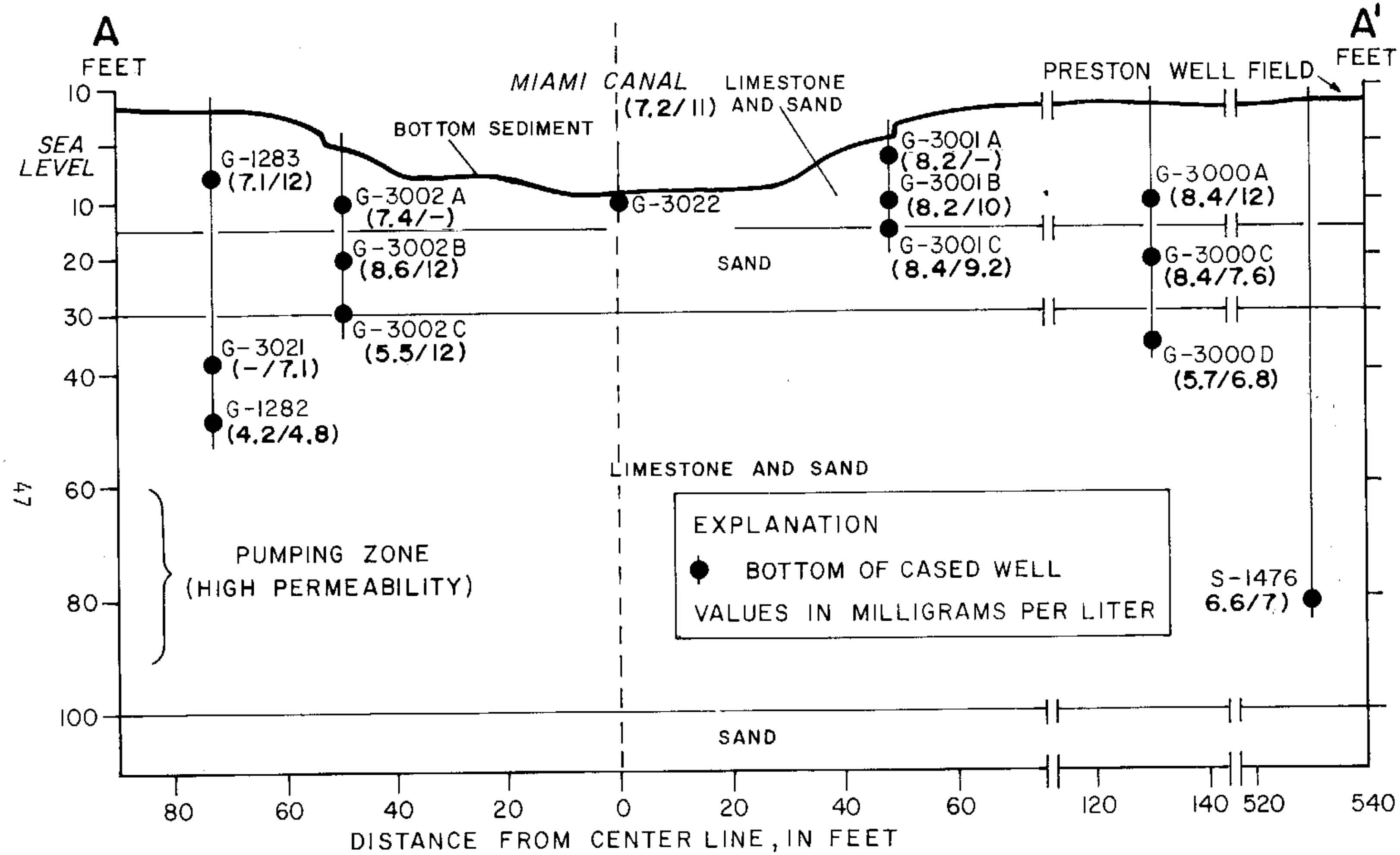


Figure 23--Magnesium in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 4-29-73 and 5-1-73) in Miami Canal and wells along A-A'.

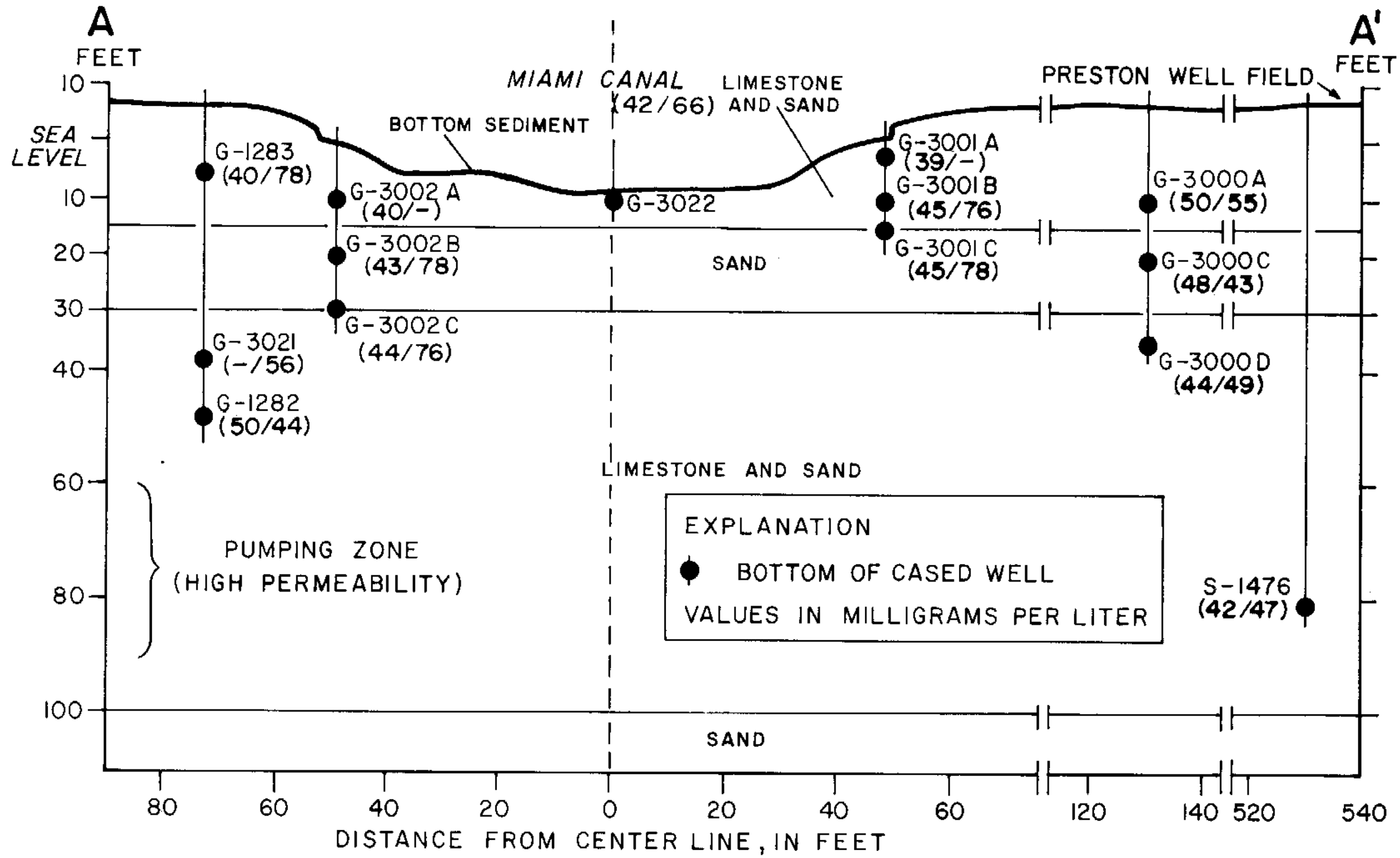


Figure 24.--Chloride in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 4-29-73 and 5-1-73) in Miami Canal and wells along A-A'.

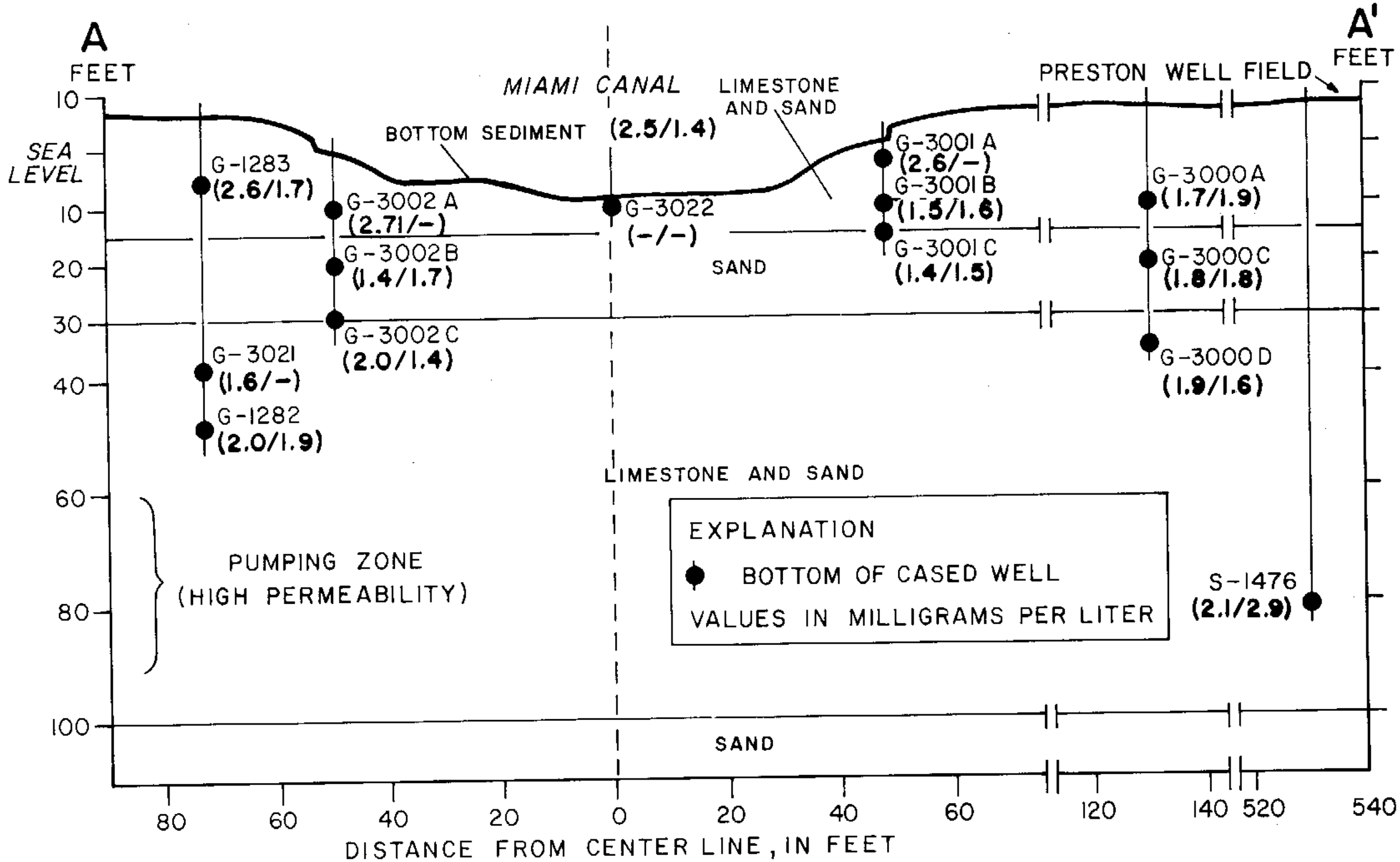


Figure 25.--Potassium in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 4-29-73 and 5-1-73) in Miami Canal and wells along A-A'.

Trace Metals

Aluminum in the infiltrating canal water is being decreased by the filter effects and chemical exchange with both canal bottom sediments and aquifer materials (fig. 26). Induced water movement in the aquifer as the result of dry-season pumping demands appears to increase removal of aluminum from the infiltrating water.

As distance from the canal increases, lead concentrations decrease (fig. 27). Removal of lead by bottom sediments and aquifer materials may cause an accumulation of lead in the upper part of the aquifer, but additional investigation would be needed to demonstrate this.

Most well casings are iron, putting observed iron concentrations of ground water in doubt. Consequently, there is no further discussion of iron concentrations at this time.

The concentration of arsenic in infiltrating canal water decreases with depth. The reduction is more evident in the dry season sampling (April-May 1973) when infiltration is greatest (fig. 28).

Three additional sampling sites were chosen in the vicinity of the Miami Springs-Hialeah well fields, anticipating continued investigation. The three sites shown in figures 1 and 29 are: Site 2 on the Red Road Canal, site 3 on the Miami Canal, and site 4 on the F.E.C. Borrow Canal. A total of 36 wells, in addition to 2 existing wells, were drilled in September and October 1972 at the sites and samples collected from the wells and adjacent canals on May 2-4, 1973. All analytical data for these sites are shown in table 3. The lack of sufficient data precludes further discussion of sites 2, 3, and 4 at this time.

Canal Bottom Sediment

Canal bottom sediments were sampled along A-A' in the Miami Canal three times in 1972-73 and once at each of the three other canal sampling sites (fig. 29) on May 2-8, 1973. The samples were collected as point samples, not composite samples. The results of the analyses are shown in table 4.

The samples of May 2-8, 1973 are of particular interest because they were collected after several months of low or zero flow in the canals. High rates of continuous well-field pumping had created maximum canal water infiltration.

Bottom sediments contained metals, organic and inorganic carbon, nitrogen species, strontium, and arsenic, suggesting that some absorption and adsorption of these constituents in canal water takes place as it moves downward through the sediments. Concentrations of many of these constituents in the ground water immediately underlying and

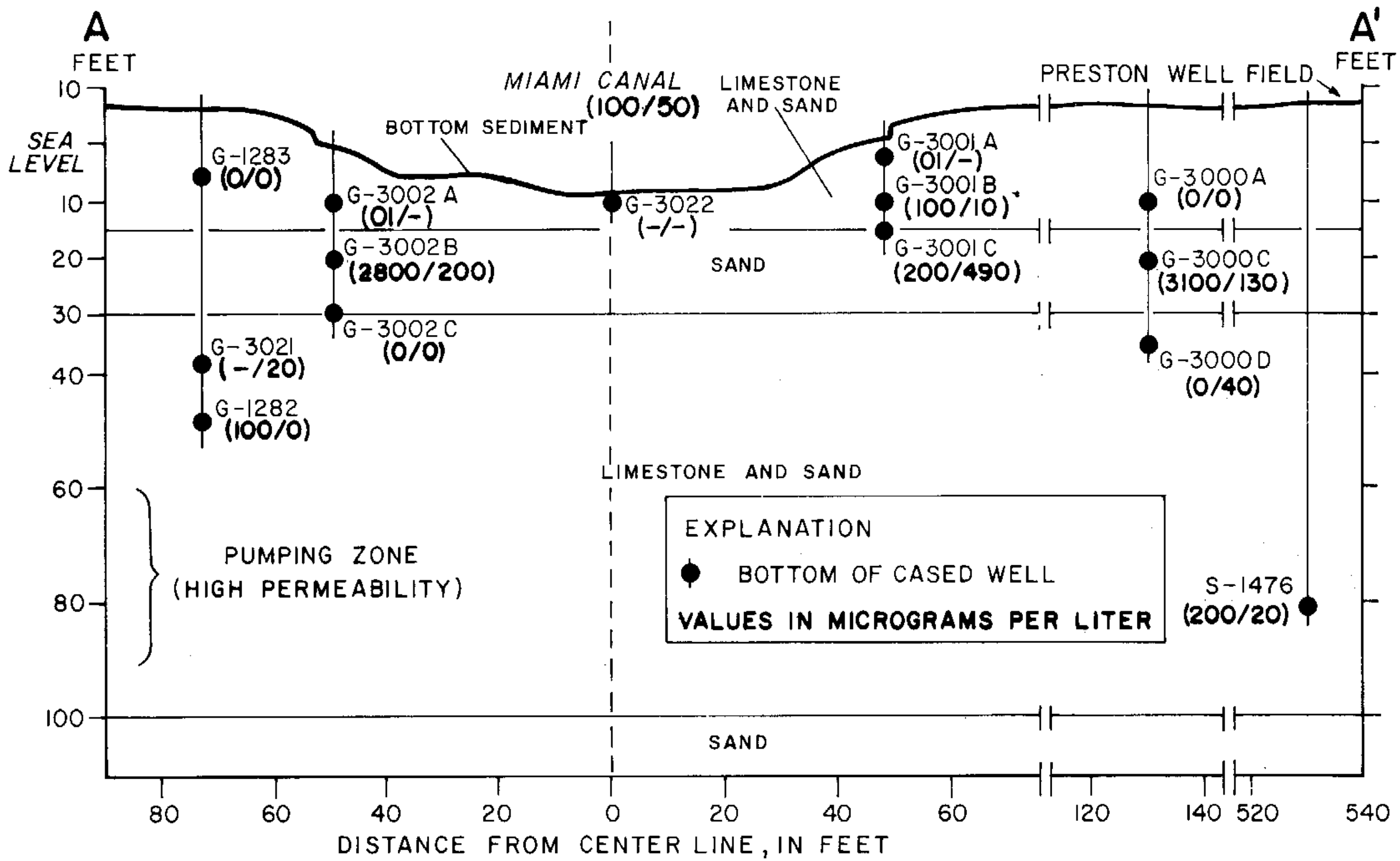


Figure 26.--Aluminum in water (upper value measured betwen 6-5-72 and 6-7-72/ lower value measured between 4-29-73 and 5-1-73) in Miami Canal and wells along A-A'.

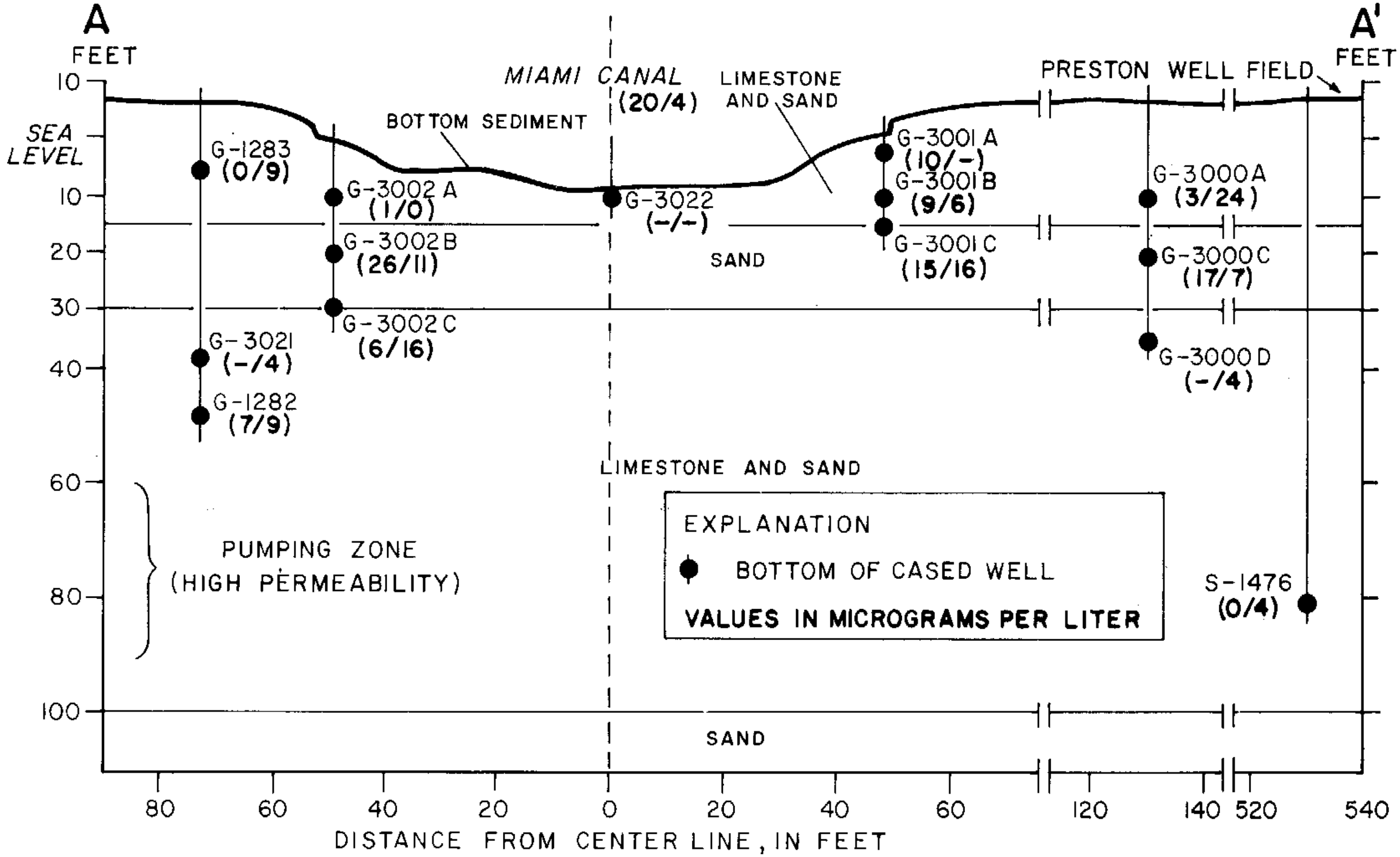


Figure 27.--Lead in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 4-29-73 and 5-1-73) in Miami Canal and wells along A-A'.

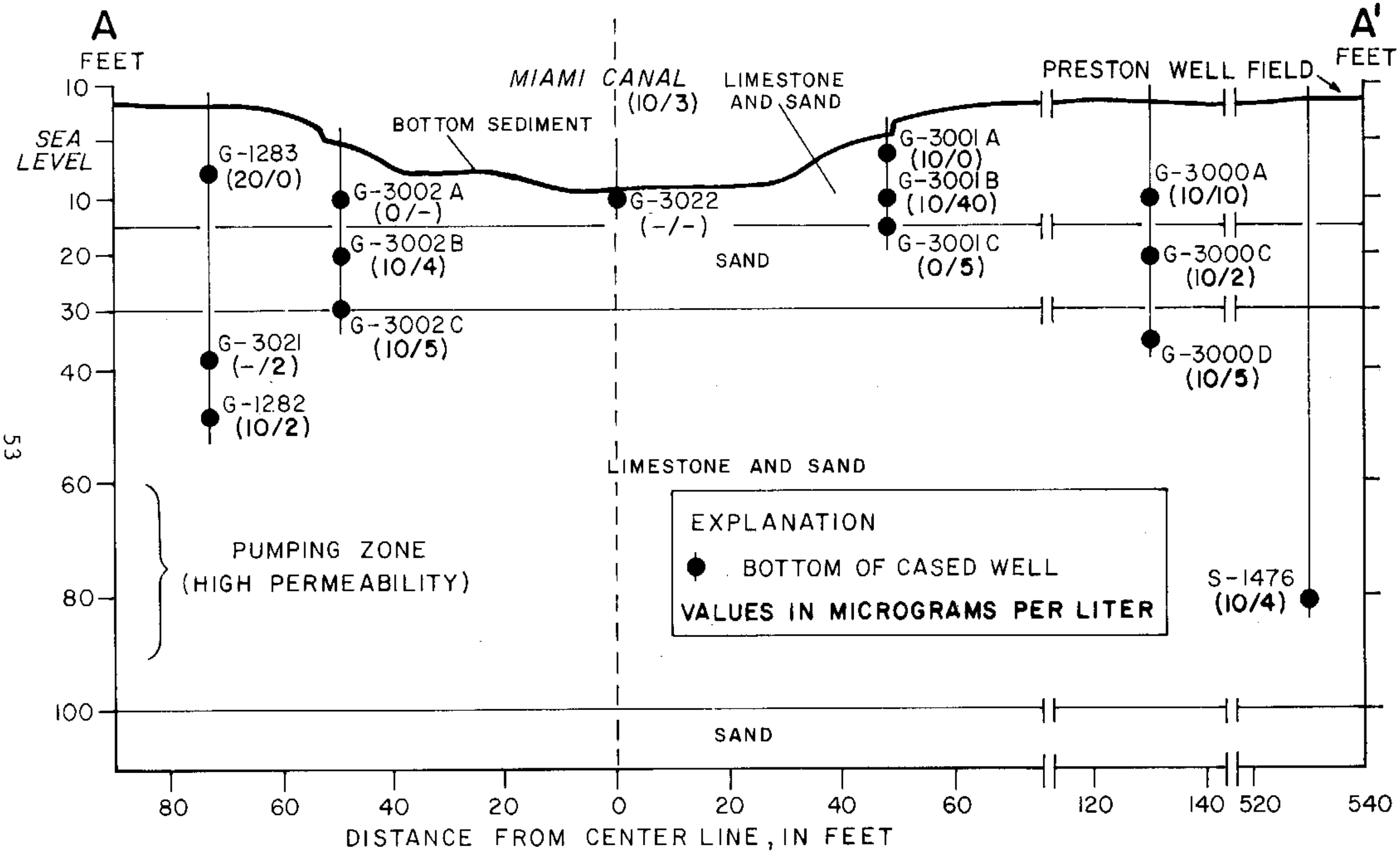


Figure 28.--Arsenic in water (upper value measured between 6-5-72 and 6-7-72/ lower value measured between 4-29-73 and 5-1-73) in Miami Canal and wells along A-A'.

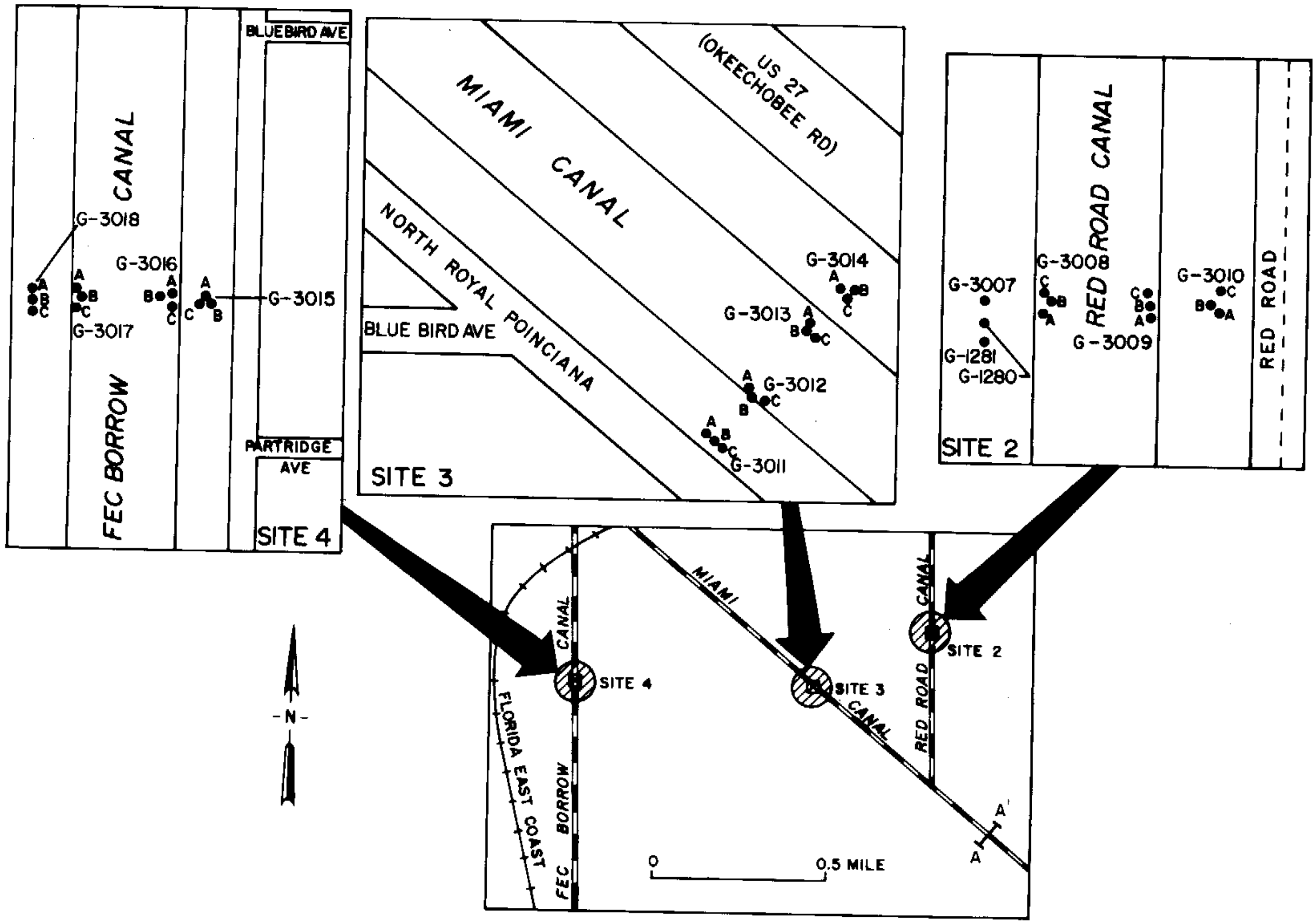


Figure 29.--Locations of sampling site 2, 3, 4, and section A-A'.

Table 3.--Analyses of water samples from wells and canals at sites 2, 3, and 4.

(Values in milligrams per liter except where indicated)

Well or station number	Depth of well (ft)	Date of collection	Color	Turbidity (JTU)	Total coliform (col /100 mL)	Fecal coliform (col /100 mL)	Fecal streptococcus (col /100 mL)	Ammonia nitrogen (NH_3-N)	Nitrite-nitrogen (NO_2-N)	Nitrate-nitrogen (NO_3-N)	Organic nitrogen	Ortho-phosphate (P)	Total phosphate (P)	Specific conductance (umho/cm at 25°C)	Chloride (Cl)	BOD
Site 2																
G-1280	48.57	5- 2-73	25	25				0.35	0.00	0.00	0.64	0.00	0.00	520	48	1.8
G-1281	13.64	5- 2-73	50	7				.01	.00	.20	.96	.00	.00	690	70	1.1
G-3007	27.4	5- 2-73	30	20				.09	.00	.00	.90	.01	.02	690	74	1.4
G-3008A	10.4	5- 2-73	25	55				.06	.01	.20	.90	.00	.00	620	68	1.7
G-3008B	25.9	5- 2-73	50	35				.02	.00	.00	1.2	.00	.00	690	76	.3
G-3008C	16.0	5- 2-73	35	70				.06	.01	.00	1.0	.00	.00	680	73	1.5
G-3009A	10.0	5- 3-73	70	70				.04	.00	.20	1.1	.00	.00	670	67	2.4
G-3009B	24.5	5- 3-73	70	20				.09	.00	.00	1.0	.02	.03	680	79	2.5
G-3009C	14.3	5- 3-73	70	25				.04	.01	.00	1.2	.00	.00	680	72	1.4
G-3010A	45.0	5- 3-73	50	40				.82	.00	.00	1.1	.00	.00	540	55	2.5
G-3010B	15.2	5- 3-73	45	150				.04	.00	.00	.93	.00	.00	680	76	1.4
G-3010C	28.2	5- 3-73	45	30				.04	.00	.00	1.1	.00	.01	700	79	.8
Red Road Canal at Hialeah Water Plant		5- 2-73	50		1900	0	110							690	67	2.3
Site 3																
G-3011A	29.6	5-3-73	80	25				0.35	0.00	0.00	1.1	0.00	0.01	580	44	1.5
G-3011B	46.2	5-3-73	55	25				.69	.01	.00	1.0	.00	.01	580	44	1.0
G-3011C	18.9	5-3-73	55	55				.17	.00	.00	1.1	.01	.01	670	71	1.5
G-3012A	10.6	5-3-73	50	20				.12	.00	.00	1.1	.01	.01	670	71	1.3
G-3012B	24.9	5-3-73	100	10				1.2	.00	.00	1.0	.07	.07	590	52	1.4

Table 3.-Analyses of water samples from wells and canals at sites 2, 3, and 4.--Continued

Well or station number	Depth of well (ft)	Date of collection	Color	Turbidity (JTU)	Total coliform (col /100 mL)	Fecal coliform (col /100 mL)	Fecal strep-tococcus (col /100 mL)	Ammonia nitro-gen (NH3-N)	Nitrite-nitro-gen (NO2-N)	Nitrate-nitro-gen (NO3-N)	Organic nitrogen	Ortho-phosphate (P)	Total phosphate (P)	Speicific Con-ductance (umho/cm at 25°C)	Chloride (Cl)	BOD
							Site 3.--Continued									
G-3012C	14.3	5-3-73	45	340				.22	.00	.00	1.4	.00	.00	670	70	1.7
G-3013A	26.0	5-3-73	60	45				.35	.01	.00	1.1	.04	4.2	620	61	1.6
G-3013B	15.2	5-3-73	50	100				.19	.01	.00	1.1	.02	.03	650	69	1.6
G-3014A	11.2	5-3-73	60	45				.15	.00	.00	1.1	.04	.04	690	68	1.0
G-3014A	44.0	5-3-75	70	40				1.4	.00	.00	.39	.01	.02	600	54	1.2
G-3014B	29.8	5-3-73	50	45				.97	.00	.00	.92	.02	.03	600	57	1.7
G-3014C	16.0	5-3-73	50	15				.19	.00	.00	1.3	.04	.04	690	74	1.2
Miami Canal at Blue Bird Miami Springs	- -	5-3-73	40		1200	40	60							680	67	0.6
							Site 4									
G-3015A	27.7	5-4-73	50	40				0.97	0.00	0.00	1.4	0.00	0.00	540	39	1.1
G-3015B	11.9	5-4-73	50	55				.33	.00	.00	1.1	.01	.01	640	66	1.6
G-3015C	47.2	5-4-73	50	15				.75	.00	.00	1.1	.01	.01	540	41	1.0
G-3016A	24.2	5-4-73	60	15				.67	.00	.00	1.0	.01	.01	540	44	1.2
G-3016B	10.2	5-4-73	50	530				.91	.00	.00	1.1	.01	.01	560	47	1.7
G-3016C	46.2	5-4-73	50	20				.70	.00	.00	1.1	.01	.01	510	39	1.6
G-3017A	25.0	5-4-73	80	50				.20	.00	.00	1.2	.01	.01	690	78	0.9
G-3017B	12.8	5-4-73	100	40				.15	.00	.00	1.2	.01	.01	670	72	2.1
G-3017C	45.1	5-4-73	70	20				.66	.00	.00	1.0	.01	.01	520	34	1.4
G-3018A	26.2	5-4-73	100	40				.12	.00	.00	1.0	.01	.01	580	55	1.8
G-3018B	48.3	5-4-73	60	20				.69	.00	.00	.8	.00	.00	510	33	1.4
G-3018C	10.7	5-4-73	70	75				.07	.00	.00	1.1	.00	.00	670	72	1.4
G-3019	46.6	5-4-73	100	20				.85	.00	.00	.94	.00	.00	510	31	1.6
G-3020	43.9	5-4-73	80	10				.82	.00	.00	.97	.00	.00	560	28	2.9
F.E.C. Borrow Canal at Partridge in Miami Springs		5-2-73	40		2300	0	68							640	73	2.2

Table 4.--Analyses of canal bottom sediment in vicinity of Miami Springs-Hialeah well fields.

(values in micrograms per gram except where noted)

Sampling Location	Red Road Canal (site 2)	Miami Canal (site 3)	F.F.C. Borrow Canal (site 4)	Miami Canal (Section A-A')
Date sampled	5-2-73	5-2-73	5-8-73	5-2-73
Arsenic	6	1	5	3
Inorganic carbon (mg/g)	45	31	51	39
Organic carbon (mg/g)	60	24	61	52
Copper	36	12	45	26
Iron	4,500	1,800	8,000	4,300
Lead	750	65	95	210
Organic nitrogen (mg/g)	-	-	-	-
Nitrogen (NO_3+NO_2) (mg/g)	0.001	0.003	0.001	0.001
Ammonia nitrogen (NH_4) (mg/g)	0.230	0.099	0.068	0.150
Total phosphorus (mg/g)	0.014	0.092	0.007	0.004
Strontium	770	330	1,600	950

adjacent to the canal suggest that their removal by the sediments is incomplete, and that further reduction in their concentrations is due to removal by the aquifer materials or dilution by water from other sources.

Analyses for pesticides in the canal sediment (table 5) show an accumulation of DDD, DDE, DDT, dieldrin, silvex, chlordane, and PCB in one or more samples. When compared with analyses of water from the Miami Canal and adjacent wells along A-A' (table 6), it is evident that most pesticides and PCB are effectively removed by the bottom sediments. The only pesticides detected in the ground water were 2, 4-D, silvex, and methyl parathion, which are more soluble in water than other pesticides analyzed.

Although the removal of the canal bottom sediments would allow pesticides and PCB's to enter the aquifer, zones of low hydraulic conductivity, primarily the sand in the upper part of the aquifer, may delay or completely prevent their reaching the pumping zone. Pesticides and PCB's are poorly water soluble and are usually transported on suspended materials. Consequently, removal of the canal bottom sediments may not cause these compounds to enter the aquifer in large amounts if the suspended material continues to be filtered out and deposited on the bottom of the canal. No pesticides were detected in water from the pumping zone (well S-1476) even though several were present in the upper part of the aquifer.

None of the following pesticides were detected in water or sediment samples: toxaphene, aldrin, heptachlor, lindane, malathion, parathion, diazinon, ethion, trithion, methyl trithion.

SUMMARY AND CONCLUSIONS

Municipal wells in the Miami Springs-Hialeah area penetrate the Biscayne aquifer and depend heavily upon induced infiltration from the Miami Canal and other nearby canals for recharge. In 1970 the canals contributed an estimated 52 percent of the total pumpage, while in 1973, canals contributed 46 percent. During that period, average pumpage increased from 89 to 105 Mgal/d. This indicates that while pumping demands increased 18 percent the canal infiltration capability decreased 6 percent. The result is a deepening and expanding of the cone of depression in the well fields especially during periods of peak demand and drought, thereby increasing the threat of saltwater intrusion.

Fine-grained sediments which have accumulated on canal bottoms have greatly retarded infiltration. The canal is partially perched above the water-table much of the time. Nearly all infiltration from the Miami Canal occurs in the center of the canal where sediments are thinnest. The filter effects of the bottom sediments remove or lessen the concentrations of some constituents in the infiltrating water. Materials in that part of the aquifer lying between the canal bottom sediments and

Table 5.--Analyses of pesticides and PCB in canal bottom sediment from Miami Springs-Hialeah well field area.

(Values in micrograms per kilogram)

Sampling location	Red Road Canal (Site 2)	Miami Canal (Site 3)	F.E.C. Borrow Canal (Site 4)	Miami Canal (Section A-A')		
Date sampled	5-2-73	5-2-73	5-8-73	6-5-72	11-6-72	5-2-73
DDD	4	9	22	14	0.0	13
DDE	31	12	49	20	1.5	13
DDT	4	0.0	110	11	0.0	3
Dieldrin	2.4	0.5	3.2	0.8	0.0	0.5
Endrin	0.0	0.0	0.0	0.0	0.0	0.0
2,4 -D	0.0	0.0	0.0	0.0	0.0	0.0
2,4,5 -T	0.0	0.0	0.0	0.0	0.0	0.0
Silvex	0.0	0.0	0.0	0.8	0.0	0.0
Chlordane	120	23	70	80	0.0	32
PCB	100	70	100	90	100	130

Table 6.--Analyses of pesticides and PCB in Miami Canal and wells along A-A' June 5-7, 1972.

(Concentrations in micrograms per liter)

Sampling location	G-3000A	G-3000C	G-3000D	G-3001A	G-3001B	G-3001C	G-3002A	G-3002B	G-3002C	G-1282	G-1283	G-1476	Miami Canal (Section A-A')
DDD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DDE	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
DDT	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Dieldrin	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Endrin	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2,4-D	.00	.00	.00	.05	.00	.00	.02	.00	.00	.03	.01	.00	.00
2,4,5-T	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
Silvex	.00	.00	.00	.01	.03	.02	.02	.02	.00	.05	.01	.00	.02
Methyl parathion	.00	.00	.00	.01	.00	.00	.05	.01	.00	.00	.00	.00	-
Chlordane	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
PCB	0	0	0	0	0	0	0	0	0	0	0	0	0

the pumping zone also provide a filtering effect on the water. The data do not indicate how effectively these materials will remove constituents subject to filtration if the canal-bottom sediments are removed. Available data indicate that removal of the canal bottom sediments will increase infiltration from the canal to the Biscayne aquifer but may affect water quality in the aquifer.

The increase in demand upon the Miami Springs-Hialeah well fields will steadily increase the threat of saltwater intrusion in the well fields. Additional water-quality data are needed to determine the ability of aquifer materials to remove objectionable constituents from the water infiltrating the canal bottom if the canal-bottom sediments were removed. The optimum course of action to safeguard both the quantity and quality of water in the Miami Springs-Hialeah well fields cannot be determined with existing data.

SELECTED REFERENCES

Cooke, C. W., and Mossom, Stuart, 1928, Geology of Florida, Florida Geol. Survey 20th Ann. Rept. p. 29-227.

Hem, J. D., 1971, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 363 p.

Hoffmeister, J. E., Stockman, K. W., and Malter, H. G., 1967, Miami Limestone of Florida and its recent Bahamian counterpart: Geol. Soc. America Bull. v. 78, p. 175-190.

Hull, J. E., 1970, Hydrologic conditions during 1968 in Dade County, Florida: U.S. Geol. Survey open-file rept, 80 p.

______ 1971, Hydrologic conditions during 1969 in Dade County, Florida: U.S. Geol. Survey open-file rept 50 p.

______ 1972, Hydrologic conditions during 1970 in Dade County, Florida: U.S. Geol. Survey open-file rept., 80 p.

Hull, J. E. and Galliher, C. F., 1968, Hydrologic conditions during 1966 in Dade County, Florida: U.S. Geol. Survey open-file rept., 41 p.

______ 1969, Hydrologic conditions during 1967 in Dade County, Florida: U.S. Geol. Survey open-file rept., 74 p.

Hull, J. E. and Wimberly, E. T., 1972, Hydrologic conditions during 1971 in Dade County, Florida: U.S. Geol. Survey open-file rept., 109 p.

Hull, J. E., McKenzie, D. J., and Meyer, F. W., 1973, Summary of Hydrologic data collected during 1972 in Dade County, Florida: U.S. Geol. Survey open-file rept., 109 p.

Johnson Division, Universal Oil Products Co., 1972, Ground water and wells, 440 p.

Meyer, F. W., 1972, Preliminary evaluation of infiltration from the Miami Canal to well fields in the Miami Springs-Hialeah area, Dade County, Florida: U.S. Geol. Survey open-file rept., 85 p.

Meyer, F. W., and Wimberly, E. T., 1972, Summary of data collected for the Miami River restoration project during March and September, 1971: U.S. Geol. Survey open-file rept., 8 p.

National Academy of Science, National Academy of Engineering, 1973, Water quality criteria 1972: U.S. Environmental Protection Agency rept. EPA-R3-73-033, 594 p.

National Oceanic and Atmospheric Administration, 1972, Climates of the states, climate of Florida: Climatography of the United States no. 60-8, 112 p.

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., 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. D., Klein, Howard, and Hoy, N. D., 1958, Biscayne aquifer of Dade and Broward Counties, Florida: Florida Geol. Survey Rept. Inv. 17, 73 p.

Stumm, W. and Morgan, J. J., 1970, Aquatic chemicstry, an introduction emphasizing chemical equilibrium in natural waters: New York, John Wiley and Sons, Inc., 583 p.

Todd, D. K., 1959, Ground water hydrology: New York, John Wiley and Sons, Inc., 336 p.

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