UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

RESPONSE OF GROUND-WATER LEVELS TO FLOOD CONTROL OPERATIONS IN THREE BASINS, SOUTHEASTERN FLORIDA

By

William A. J. Pitt, Jr.

U. S. Geological Survey

Open-File Report 74-86

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
CENTRAL AND SOUTHERN FLORIDA FLOOD CONTROL DISTRICT

Tallahassee, Florida

1974

CONTENTS

	Page
Abstract	7
Introduction	8
Purpose and scope	10
Acknowledgments	12
Previous investigations	12
Hydrologic setting	13
Rainfall	13
Topography and drainage	19
Method of investigation	21
The Snapper Creek Canal basin	23
Collection of data	23
Data analysis	26
The Snake Creek Canal basin	40
Collection of data	40
Data analysis	42
The Pompano-Cypress Creek Canal basin	54
Collection of data	56
Data analysis	58
Conclusions	67
References	70

ILLUSTRATIONS

		Page
Figure 1.	Map of southeast Florida showing the drainage basins investigated	9
2.	Map of southeast Florida showing the configuration of the coastal ridge, the natural drainageways cutting through it, and the location of rainfall stations . . .	14
3.	Lithologic section parallel to Snapper Creek Canal . .	24
4.	Map of part of the western segment of the Snapper Creek Canal basin showing the location of the wells and the surface-water measuring sites	25
5.	Map of part of the eastern segment of the Snapper Creek basin showing contours on the water table on October 27, 1970	27
6.	Map of part of the eastern segment of the Snapper Creek basin showing contours on the water table on October 28, 1970	28
7.	Map of part of the eastern segment of the Snapper Creek basin showing contours on the water table on October 29, 1970	30
8.	Map of part of the eastern segment of the Snapper Creek basin showing the change in the water table between October 27 and 28, 1970	31
9.	Hydrographs of selected wells and selected parts of the canal in the Snapper Creek Canal basin . . .	32

ILLUSTRATIONS (Continued)

		Page
Figure 10.	Lithologic section parallel to Snake Creek Canal	41
11.	Map of part of the western segment of the Snake Creek Canal basin showing the location of the surface-water measuring sites and the wells . . .	43
12.	Map of part of the eastern segment of the Snake Creek Canal basin showing contours of the water table on September 15, 1971	45
13.	Map of part of the eastern segment of the Snake Creek Canal basin showing contours on the water table on September 16, 1971	46
14.	Map of part of the eastern segment of the Snake Creek Canal basin showing contours on the water table on September 17, 1971	47
15.	Hydrographs of selected wells and selected parts of the canals in the Snake Creek Canal basin	48
16.	Graph showing the change of water level in Snake Creek Canal as a function of distance from the control	50

ILLUSTRATIONS (Continued)

		Page
Figure 17.	Lithologic section parallel to Pompano-Cypress Creek Canal	55
18.	Map of part of the western segment of the Pompano-Cypress Creek Canal basin showing the location of the surface-water measuring sites and the wells	57
19.	Map of part of the Pompano-Cypress Creek basin showing contours on the water table on July 24, 1972, before the control had been opened	59
20.	Map of part of the Pompano-Cypress Creek basin showing contours on the water table on July 24, 1972, after the control had been opened	60
21.	Map of part of the Pompano-Cypress Creek basin showing contours on the water table on July 25, 1972	61
22.	Hydrographs of selected wells and selected parts of the canal in the Pompano-Cypress Creek Canal basin	63
23.	Graph showing the change of water level in Pompano-Cypress Creek Canal as a function of distance from the control	66

CONVERSION FACTORS

rameters	English unit	Multiplied by	Metric unit
ea	Square miles (sq mi)	2.5898	Square kilometres
ngth	Inches (in)	2.54	Millimetres
		25.4	Centimetres
	Miles (mi)	1.6093	Kilometres
	Feet (ft)	0.3048	Metres
lume	Cubic feet (cu ft)	0.2832	Cubic metres
		28.317	Litres
	Gallons (gal)	3.7854	Litres
te of flow ischarge)	Cubic feet per second (cfs)	28.317	Litres per second
		0.2832	Cubic metres per second
	Million gallons per day (mgd)	3.785×10^6	Litres per day
ans- issivity	Million gallons per day per foot (mgd per ft)	1.24×10^4	Square metres per day

TABLES

		Page
Table	1. Maximum recorded rainfalls	15
	2. Maximum expected rainfalls	17
	3. Maximum expected rise of the water table from rainfall in the three drainage basins	18
	4-6. Summary of discharge measurements at the:	
	4. Snapper Creek Canal basin	35
	5. Snake Creek Canal basin	52
	6. Pompano-Cypress Creek Canal basin	64

RESPONSE OF GROUND-WATER LEVELS TO FLOOD CONTROL OPERATIONS IN THREE BASINS, SOUTHEASTERN FLORIDA

By

William A. J. Pitt, Jr.

ABSTRACT

Three basins in southeastern Florida were investigated to determine, in each, the changes in ground-water levels and canal flows that occurred in response to operation of coastal water-control structures in each canal. All three basins are underlain by the Biscayne aquifer. They are, Snapper Creek Canal basin, where the Biscayne aquifer is of high permeability; the Snake Creek Canal basin, where the aquifer is of moderate permeability; and the Pompano-Cypress Creek Canal basin, where the aquifer is of low permeability. In each basin, drainage is a function of permeability; thus, where the permeability of the aquifer is high, drainage is excellent.

The coastal water-control structures are intended in part to afford flood protection in the three basins. In general, the control operation criteria for flood control in newly developing areas in southeastern Florida do not everywhere provide effective protection from flooding because of the time required for the aquifer to respond to changes in the controls.

If the criteria were such that 2 days were available to lower the water table, the Snapper Creek Canal system appears to be adequate to protect areas as far as 1.5 miles west of it from Kendall Drive to Tamiami Trail. If additional drainage is required, secondary canals draining into Snapper Creek would be more effective than those draining into Bird Drive Canal.

Except for a narrow strip along Snake Creek Canal and Cypress Creek Canal it is not now possible to provide protection from a 1-in 10-year storm in less than 2 days. To provide adequate protection would require increasing the density of secondary drainage canals in both basins but this could be achieved only by reducing the quantity of water available for recharging those segments of the Biscayne aquifer adjacent to the canals.

INTRODUCTION

Continued urban growth in southeast Florida during the last 5 years is spreading inland into sparsely developed areas which are subject to occasional inundation. Protecting these areas from flood damage is a responsibility of the Central and Southern Florida Flood Control District. That agency also has the responsibility of managing the water resources in such a way that water supplies will be available for the growing population, but with minimal environmental degradation. Some alternative methods of developing these marginally developable lands are:

(1) Digging canal networks to drain flood water to the ocean.

(2) Backpumping flood water into the water conservation areas.

(3) Raising land above flood levels by using fill from borrow pits and canals.

(4) Combinations of the above alternatives.

The impact of method (1) would be the removal of large quantities of fresh water that could otherwise be used and needed for water supplies. Such removal could degrade aquatic environments earmarked for protection of wildlife and aquifer recharge. Method (2) would conserve water resources but would degrade the environment of the conservation areas if backpumped water is contaminated. Method (3) would conserve water resources and cause little effect to the environment.

As part of the cooperative program between the Central and Southern Florida Flood Control District and the U. S. Geological Survey an investigation was undertaken by the Geological Survey in three drainage systems or basins to determine the effectiveness of the drainage systems in providing flood protection. The drainage basins are Snapper Creek Canal basin, Snake Creek Canal basin, and the Pompano-Cypress Creek Canal basin. The locations of all three are shown on figure 1.

Figure 1.--Southeast Florida showing the drainage basins investigated.

Purpose and Scope

The investigation was made to determine the changes in ground-water levels and canal flows in the three basins that occurred in response to operation of the coastal water-control structures in the canals.

Specifically, the investigation was undertaken to obtain information on:

1. The areal extent, rate, and magnitude of the water-level changes in the aquifer.
2. The time interval between control operations and responses in the system.
3. The discharge rates at selected reaches of both primary and secondary canals.

Each of the three basins investigated is characterized by differences in the degree of hydraulic connection between the drainage canals and the aquifer. The Snapper Creek Canal basin is an area of high permeability and excellent drainage, the Snake Creek Canal basin is an area of moderate permeability and moderate drainage, and the Pompano-Cypress Creek Canal basin is an area of low permeability and poor drainage. The three basins selected, in Dade and Broward Counties, are in areas of typical urban expansion.

The Snapper Creek Canal basin, the southernmost of the three, and the area of excellent drainage, is 58.9 square miles in extent of which the newly developing areas west of Range 40 East comprise 34.8 square miles. The Snake Creek Canal basin, where drainage is moderate, includes parts of south Broward and north Dade counties. The drainage basin has an area of 79.4 square miles of which 43.6 square miles undergoing rapid development are west of Range 41 East. In the Pompano-Cypress Creek Canal basin -- the northernmost basin investigated -- the aquifer is of low permeability and the connection between the canals and the aquifer is poor. This basin covers an area of 62.3 square miles of which more than half is composed of rapidly developing communities west of Range 42 East.

Acknowledgments

Personnel of the Central and Southern Florida Flood Control District operated the control structures during the field tests, and the Dade County and the Broward County Public Works Department provided aerial photography of the individual drainage basins, thus facilitating selection of field measurement sites. The Dade County Port Authority permitted access to the Opa-Locka West airfield to install gaging stations.

Previous Investigations

Parker and others (1955) summarized the hydrology and the geology of the Biscayne aquifer. Stallman (1956) described the results of an electric analog model study of the hydrology of intercanal areas of Dade County. Klein and Sherwood (1961) described the hydrologic conditions in the vicinity of Levee 30. Sherwood and Leach (1962) gave a detailed description of the hydrologic environment in the Snapper Creek Canal area, and Leach and Sherwood (1963) described the results of a similar investigation in the eastern part of the Snake Creek Canal basin.

HYDROLOGIC SETTING

Rainfall

Rainfall is the most important hydrologic factor affecting the groundwater levels in southeast Florida; thus, it is of major importance in developing flood criteria for the area. Rainfall averages 60 inches per year, about 75 percent of which occurs during May through October, the normal rainy season and the hurricane season.

Rainfall data from selected stations shown in figure 2 are listed in table 1. From the data in table 1 it was determined that of the maximum recorded rainfall in 24 hours, more than 90 percent fell during 12 hours, and except at the Hialeah station, more than half of the 24-hour rainfall fell during 2 hours.

The amount of rainfall that infiltrates the aquifer during any particular storm depends on factors such as the infiltration capacity of the materials above the water table, their effective porosity and their specific retention, the intensity and duration of the rainfall, and the antecedent weather conditions, causing the materials above the water table to be dry, moist, or wet.

In a study relating water-table rises to rain storms Cross and others (1940, p. 80) indicated that between 61.5 and 81.5 percent of the rainfall would reach the water table. Porosity of the water-yielding materials in the area of their study, an area hydrologically similar to the Snapper Creek drainage basin, ranges from 20 to 30 percent and they concluded that a rise of 3 to 5 inches in the water table could be expected for every inch of rainfall reaching the water table.

Figure 2.-- Southeast Florida showing the configuration of the coastal ridge, the natural drainageways cutting through it, and the location of rainfall station.

Table 1.--Maximum recorded rainfalls.

The porosity of the aquifer materials in the Pompano-Cypress and Snake Creek drainage basins is 15 to 20 percent and the rise in the water level in the aquifer would therefore range from 5 to 6.5 inches for each inch of rainfall that reaches the aquifer.

The maximum expected rainfall (table 2), its duration, and an arithmetic average of the foregoing data for aquifer porosity can be used to determine the expected rise in water level, due solely to rainfall in the three drainage basins (table 3). The values in table 3 apply while the water level is below land surface. Because of the low topography the water level rise would be inch-for-inch when the water level is at or above the land surface.

Table 2.--Maximum expected rainfalls.

Table 3.--Maximum expected rise of the ground-water table from rainfall in the three drainage basins.

Topography and Drainage

The major topographic features in southeast Florida are the coastal ridge and the shallow natural drainageways that cut through it (fig. 2). The canals that drain the area have been largely constructed in the channels of these natural drainageways. West of the coastal ridge the land is of low relief and naturally prone to flooding. Only through the water management system are most areas west of the ridge kept dry.

Flow in the canals is maintained chiefly by ground-water discharge from the highly permeable Biscayne aquifer, the only source of potable water in Dade and Broward Counties. Some of the flow is from the water conservation areas and some is overland flow which occurs during heavy rainfall. Overland flow is quantitatively significant in the Pompano-Cypress Creek Canal and the Snake Creek Canal basins where sandy material of relatively low permeability comprises the top of the aquifer.

Flow in the canals is regulated by automatic or manually operated control structures near the coast (fig. 2). These structures are opened during heavy rainfall to provide flood protection by releasing excess water. They are closed during the dry season to protect the aquifer and the fresh water reaches of the canals from salt-water encroachment by maintaining a positive fresh-water head. During the dry season infiltration from the canals in the coastal areas provides much of the fresh-water replenishment to the aquifer.

Snapper Creek and Snake Creek Canals are each controlled by one coastal structure. These structures are manipulated to maintain ground-water levels inland and assist in providing water to recharge the aquifer near municipal well fields.

Cypress Creek Canal is controlled by two structures, S-37A, near the coast, and S-37B, 3.2 miles farther upstream (fig. 1). Gates in the two structures are manipulated to maintain high water levels in the inland area and an intermediate level between the two, similarly providing water to recharge the aquifer near Fort Lauderdale's municipal well field south of the canal.

METHOD OF INVESTIGATION

Tests were made in each of the three canal basins to determine the areal extent and magnitude of hydrologic changes effected by manipulation of the coastal control structures.

Before testing each basin the gates at the control structures were closed to establish hydraulic equilibrium throughout the drainage basin. The pattern and distribution of flow required for equilibrium with the gates closed were determined by discharge measurements at selected locations in the canal system. When equilibrium had been reached and the tidal stage was low enough to permit maximum canal discharge at the structure, the gates were opened. Discharge measurements in the canals and water-level measurements in wells were made after the control was opened. A third set of measurements was obtained after the control was closed at the end of the test. These data were used to determine the magnitude and rate of hydrologic changes within the basin.

Identical test procedures were attempted for all three basins. Only for Snapper Creek basin, however, was it possible to follow procedures to satisfactory completion. In testing the other two basins the controls could not be closed long enough to establish equilibrium, and at the end of the tests they could not be kept closed long enough to achieve a full recovery of water levels to pre-test levels.

The chloride content of the water at the control structure was continuously monitored during the tests to insure that no salt water intrusion occurred.

Raingages were in operation near the west edge, the center, and the east edge of the basins during the test.

THE SNAPPER CREEK CANAL BASIN

The Snapper Creek Canal drains an area underlain by solution riddled limestone. The canal is cut almost totally into this limestone (fig. 3) of the highly permeable Biscayne aquifer where the transmissivity ranges from 3 million to about 5 million gallons per day per foot. Throughout the basin, interconnection between the canal system and the aquifer is very good. The degree of interconnection and the permeability of the upper 20 feet of the aquifer are of major importance in the effect that control operations on the canals have on water levels in the basin.

Collection of Data

The ground-water level monitoring program for the Snapper Creek Canal basin included 55 observation wells located throughout the basin. Three continuous stage-discharge stations (fig. 3) were used to determine flow in the canal.

Seven additional wells (G-1519 - G-1525) were drilled and equipped with recorders in the western segment of the basin (fig. 4).

Figure 3.--Lithologic section parallel to Snapper Creek Canal.

Figure 4.--Part of the western segment of the Snapper Creek Canal basin showing the location of the ground-water wells and the surface water measuring sites.

Flow in Snapper Creek was measured at four locations; control structure S-22, Galloway Road (S.W. 87th Avenue), Miller Drive, and the Tamiami Trail (fig. 3). Flow measurements also were made in the seven major tributaries west of Galloway Road (S.W. 87th Avenue) to determine their contribution to flow in Snapper Creek and to determine their effectiveness in draining the sub-basins.

Rainfall during the test period October 27-29, 1970, was not enough to affect water-level changes caused by manipulation of the structure gates.

Data Analysis

The water-level contour map for October 27, 1970 (fig. 5), shows the position of the water table before opening the controls. The gradients shown by the water-level contours indicate that the canal is recharging the aquifer near the coast while draining the aquifer farther inland from the coast. The steepest gradients, and thus the greatest seepage from the canal, occur near the Alexander Orr well field and the salinity control S-22.

On October 28, control structure S-22 was open for nearly 6 hours. The effect of the discharge of fresh water from the basin is shown in figure 6. A comparison between the contour maps of October 27 and October 28 shows that in the eastern part of the basin and adjacent to the canal in the interior part of the basin water levels were lowered as a direct result of the control operation.

Figure 5.-- Part of the eastern segment of the Snapper Creek Canal basin showing contours on the water table on October 27, 1970.

Figure 6.-- Part of the eastern segment of the Snapper Creek basin showing contours on the water table on October 28, 1970.

On October 29, 1970, 24 hours after the gates were closed on October 28 discharge and water levels were again measured throughout the basin. The canal system had reverted to a recharging system near the coast and levels had recovered to virtual predischarge conditions (fig. 7).

The effect of the control operation is shown by the change in the altitude of the water table from October 27 (before opening the control) to October 28, when drawdown was maximum (fig. 8). Most of the change occurred near the coast and adjacent to the canals.

Hydrographs of Snapper Creek Canal at seven locations and seven selected observation wells (see fig. 9), show not only magnitude of water level change but also lag time in the canal at different points upstream from the control and in the aquifer response at different distances from the canals.

The hydrographs for Snapper Creek at S-22 and at the Tamiami Trail (U.S. Highway 41) show a 1¼-hour lag between the opening of S-22 and a detectable decline at the Tamiami Trail site. A similar time lag is noticed when the control is closed. The time lag between the opening of S-22 and the effect at site 4 in a tributary to Bird Drive Canal is about 1 hour.

Figure 7.--Part of the eastern segment of the Snapper Creek Canal basin showing contours on the water table on October 29, 1970.

Figure 8.--Part of the eastern segment of the Snapper Creek Canal basin showing the change in the water table between October 27 and 28, 1970.

Figure 9.--Hydrographs of selected wells and selected parts of the canal in the Snapper Creek Canal basin.

The hydrographs for wells G-1519 and G-1524, 1 mile on either side of the Bird Drive Canal, are similar in both the magnitude of the water-level decline and the shape of the curves representing the decline. The hydrographs for G-1520 and G-1525, half a mile from the canal, show both a greater drop in the water level and a shorter time lag between the water-level decline in the canal and the decline in the aquifer.

The hydrographs in figure 9 also show that originally the water level in well G-1520 was higher than at G-1519. This is due to the effect of a lower stage in Tamiami Canal than in Bird Drive Canal. The effect of the Tamiami Canal together with the Snapper Creek Canal caused ground water to flow toward the northeast. However, when the control is opened at S-22 the time lag is longer through the Snapper-Tamiami system than through the Snapper-Bird Drive system, and thus the hydrograph for well G-1520 crosses that for well G-1519, indicating that flow to the south is being established.

The level in well G-1522 declined during the test and the configuration of the hydrograph paralled more closely the pattern of the hydrograph of Snapper Creek Canal at Miller Drive than that of Bird Drive Canal at 127th Avenue. Thus it seems that this well is also responding much more directly to changes in level of Snapper Creek than to changes in Bird Drive Canal. Water level in well G-1522 dropped 0.24-foot compared to a drop of 0.44 foot in Snapper Creek at Miller Drive, a 0.28 foot drop in the Bird Drive Canal at 117th Avenue, and a 0.18 foot drop in the Bird Drive Canal at 127th Avenue.

Well G-1523 also shows a more direct response to changes in level of Snapper Creek at Miller Drive and its tributary canal at site 1 than to changes in level of Bird Drive Canal. The time lag for well G-1525 is longer than for well G-1524 even though both wells are the same distance from Snapper Creek Canal. A probable explanation for this is that the aquifer-canal interconnection of the tributary canal south of Miller Drive and west of Snapper Creek is better than the aquifer-canal interconnection of the Bird Drive Canal.

The discharge data in table 4 indicate that the tributary canal was flowing to the west before the opening of the gate at S-22. This was caused by the pumping at the Southwest well field but 40 minutes after the gates at S-22 were opened the canal at site 1 started to flow eastward. Bird Drive Canal at site 2 started to flow 5 minutes later.

This tributary to Snapper Creek is 14 feet deep, Bird Drive Canal at site 1 is only 6½ feet deep, and at site 3 even less. The tributary canal is draining sections 24, 25, and 26 and possibly sections 27 and 23 more effectively than is the Bird Drive Canal. Section 13 is drained primarily by the Snapper Creek Canal. (See fig. 4.)

Table 4.--Summary of discharge measurements at the Snapper Creek Canal basin.

The effect of Snapper Creek Canal on the water level of the aquifer is further emphasized by examining the record for well G-1522. Levels in the well respond to water-level changes in the Snapper Creek Canal so much more rapidly than to changes in the Bird Drive Canal that at one point early in the test its water level was below the level in Bird Drive Canal at site 3. This indicates that if enough time elapses, Snapper Creek Canal could conceivably remove water from section 24 south of the Bird Drive Canal by inducing flow from the Bird Drive Canal to the aquifer, thence to Snapper Creek Canal.

During the test, the discharge from the area drained by the Bird Drive Canal ranged from 136 to 180 ft^3/s, with an average of 167 ft^3/s for the period of the test. (See table 4.) Table 4 shows that before the opening of the structure the average of the measurements for Bird Drive Canal was 98 ft^3/s, which is representative of the base flow at site 2; the difference, 69 ft^3/s, between the averaged base flow and the averaged flow when the control was open, was the average induced discharge through site 2 during the 6-hour test. At site 3 the average test flow minus the average base flow was 39 ft^3/s. The pickup of 30 ft^3/s from the adjacent land north and south of Bird Drive Canal between site 3 and site 2 is the direct result of the control operation. This represents 648,000 ft^3 of water removed from that adjacent land during the test.

Bird Drive Canal is controlled by a log dam at site 5. The water level in well G-1521, 1 mile west of site 5, was more than 5 feet above sea level, but the hydrograph of this well (fig. 9) shows that because of the phasing pattern its water-level changes are directly attributed to the control operation at S-22.

At site 5 fluctuations in discharge at first did not seem to be caused by operating the gates at S-22. The fluctuations of discharge at the dam indicated that at first the canal level was relatively high and that a steady rate of water interchange with the aquifer had been established. When the ground-water levels adjacent to the canal dropped, the seepage from the canal to the aquifer increased and at the same time caused a decrease in flow at the dam. As the ground-water levels recovered the seepage from the canal to the aquifer decreased and the flow at the dam then increased. After a steady condition was reached the system reverted to the original condition and the flow at the dam decreased.

The average discharge at site 2 was 167 ft^3/s and at site 3 was 155 ft^3/s. The total pickup from the 2-mile reach between sites 3 and 5 was 107 ft^3/s if the 46 ft^3/s from site 4 is considered to come from areas that would not otherwise be drained by Bird Drive Canal. This represents a 54-ft^3/s-per-mile pickup. A comparison of this figure with the 12 ft^3/s picked up between sites 3 and 2 indicates that Snapper Creek Canal is withdrawing ground water from sections 13 and 24.

A similar analysis for the tributary to Snapper Creek Canal at site 1 indicates an average pickup of 87 ft^3/s per mile, 30 ft^3/s more than the pickup calculated for the Bird Drive Canal. This indicates that Bird Drive Canal is not as effective as the other tributary to Snapper Creek Canal in draining water from the aquifer. The reason is that the Bird Drive Canal is only half as deep as the other tributary and therefore does not provide as great an interconnection with the aquifer.

A comparison of the water-table map for October 27, 1970 with the one for October 28, 1970 (figs. 5,6), shows a general westward shift of the 3.5-feet contour on the October 28 map, indicating the effect of drainage by Snapper Creek and its tributaries when the control of S-22 is open. The October 28 map shows only minimal change in the position of the 4.0-feet contour at the head end of Bird Drive Canal. The contour patterns in the northwest part of the area indicates that inflow from the tributaries there, are contributing much of the flow in Snapper Creek Canal. The 3.0-feet contour west of Snapper Creek Canal (fig. 6) is shown very close to Snapper Creek Canal and to its tributary to the southwest. The direction of ground-water flow, perpendicular to that contour, indicates that most of the drainage from that area is going into these canals. This is further indicative of the greater effectiveness of this tributary than of the Bird Drive Canal.

Hull and Wimberly (1972) show that the average high ground-water levels in the interior areas range from 5.5 to 6.5 feet above mean sea level or about 1.5 feet below land surface.

Table 3 indicates that once every 10 years the maximum rainfall in 1 day would raise the water table nearly 3 feet if there were no drainage canals. This would place the water table at land surface with 1.5 feet to spare. This 1.5 feet of water-table increase is equivalent to 4.5 inches of rainfall when the aquifer has a porosity of 25 percent.

Because some drainage canals do exist and because as the water level rises they counteract some of the rise, keeping the area dry would require lowering the water table slightly less than 1.5 feet The present capability of the drainage system to dewater is less than 0.5 foot through two tidal cycles based on the restrictions caused by the transmissivity and the absence of more effective secondary canals.

THE SNAKE CREEK CANAL BASIN

The Snake Creek Canal basin is underlain mostly by sandy material in the eastern part of the basin and limestone in the western part. In the sandy areas the connection between the canal system and the aquifer is poor and consequently the effect that control operations have on the aquifer is minimized.

The cross section along the Snake Creek Canal (fig. 10) indicates that the canal cuts through limestone in the westernmost reaches and then cuts through either sandy limestone or sand in the coastal reaches.

Collection of Data

In the Snake Creek Canal basin the continuing ground-water-level monitoring network consists of 34 observation wells. Two continuous stage-discharge stations measure flow in the canal. One surface-water station is at Dixie Highway west of Structure 29 and the other is at N.W. 67th Avenue. Seven additional wells were drilled and equipped with recorders for use during the test. These seven wells are located in the western half of the drainage basin, the rapidly developing area where the study effort was concentrated.

Figure 10.-- Lithologic section parallel to Snake Creek Canal.

During the test, flow in the Snake Creek Canal was measured at four locations; the control structure, N.W. 37th Avenue (Douglas Road), N.W. 67th Avenue, and site 1 near the confluence of Snake Creek Canal and North Fork Snake Creek Canal (figs. 10 and 11). The flow in all the major tributaries west of 67th Avenue was also measured to determine their contribution to total flow and to help determine the effect of these secondary canals in draining these western areas.

Precipitation in the southeast Florida area for September 15-17, 1971, was insufficient to cause extraneous effects in the Snake Creek Canal basin, and there was no measurable precipitation in the basin during the 3 days of the test.

Data Analysis

Flood control requirements in the Snake Creek Canal area did not permit the closing of the gates at structure 29 long enough, to establish hydraulic equilibrium in the basin prior to the test. Nor was it possible to maintain the gates closed after the test. The gates were also closed earlier than planned because the chloride concentration of the canal water increased abruptly from 75 to 6,100 mg/l (milligrams per liter).

Figure 11.-- Part of the western segment of the Snake Creek Canal showing the location of the surface water measuring sites and the ground water wells.

Three water-level contour maps were prepared from measurements made on September 15, 16, and 17, 1971. Ideally the September 15 and 17 measurements would have been made with the S-29 control fully closed and after the ground-water-levels had reached a stable high water level condition but this was not possible. The contours in figures 12, 13, and 14 show little change from one day to the next because this stable condition was not reached. The recovery map of September 17 (fig. 14) is in general representative of lower water levels in the aquifer than the supposedly minimum levels at the point of maximum drawdown during the September 16 test (fig. 13). This indicates a lowering of the water table during the 3 days. There was a higher rate of decline introduced on September 16 during the test but because the S-29 control was not fully closed after the test, the water levels continued to drop the following day. The contours in all three maps parallel the canal channel and decrease in altitude toward the canal indicating a discharging regimen caused by ground-water levels being higher than canal levels.

Only in the coastal reaches of the basin was there a change in ground-water levels during the test, and near the coast this change was due more to tidal fluctuation than to the lowering of the canal level.

The hydrographs of the wells and canal sites west of 67th Avenue in figure 15 show a continuous general decline. In this investigation there was no rise in the water table at the end of the test, only small changes in the rate of decline. It is impossible to determine from the data available which of the changes is the result of which change in the control.

Figure 12. Part of the eastern segment of the Snake Creek Canal basin showing contours on the water table on September 15, 1971.

Figure 13. Part of the eastern segment of the Snake Creek Canal basin showing contours on the water table on September 16, 1971.

Figure 14. Part of the eastern segment of the Snake Creek Canal basin showing contours on the water table on September 17, 1971.

Figure 15. Hydrographs of selected wells and selected parts of the canals in the Snake Creek Canal basin.

Changes in the water levels in the aquifer would be expected to be preceded by changes in the canal level; however, on the far inland reaches of the canal no effect occurred. During the test canal levels declined 1.9 feet at S-29, 0.9 foot 3 miles upstream, 0.4 foot 7.5 miles upstream, 0.2 foot 9.5 miles upstream and the effect was negligible 13 miles upstream (fig. 16).

On September 18 the control gates at structure 29 on the Snake Creek Canal were closed for more than 9 hours (longer than during the test on September 16). The change in ground-water-level on September 18 was greater than during the recovery segment of the test; however, even then the wells failed to show any clearly defined response. It has not been possible to determine the time lag between aquifer response and control operations in the canal, but even if conditions had been steady before and after the test, a water-level decline of 1.9 foot, as at S-29, would not have affected water levels 13 miles inland and therefore it would have been impossible to cause water-level declines in the aquifer that far inland in a 7-hour test.

It can be concluded that there were only minor changes in the water level of the aquifer, except near the coast and adjacent to the canal banks, from the manner of operation followed during the test. To create a measurable effect on water levels 13 miles or more inland it would be necessary to establish equilibrium in the basin to

Figure 16.--Change of water level in Snake Creek Canal as a function of distance from the control.

nullify the effect of previous control operations which could lag by more than a day.

The conclusions that can be drawn from the test are very limited and more qualitative than quantitative. There is an extremely low degree of interconnection between the canal and the aquifer except in the limestone areas near the inland end of the canal and very close to the coast. There is a time lag of 2 hours between structure 29 and N.W. 67th Avenue in the drawdown cycle and almost 4 hours in the recovery cycle probably because of the large area of the surface water bodies. The time lag in the aquifer half a mile from the canals in the areas west of 67th Avenue is probably measurable in days rather than in hours as in south Dade County.

The discharge at N.W. 67th Avenue averaged about 528 ft^3/s during the test and the flow from the North Fork of Snake Creek Canal at N.W. 67th Avenue averaged 54 ft^3/s (table 5). This represents a total inflow from the Snake Creek Canal Extension of 474 ft^3/s. Assuming an average width of 80 feet for the canal reach from N.W. 67th Avenue to U.S. Highway 27; the total area of the water surface would be 3,355,000 ft^2. The drop in the canal water level during the test was 0.40 foot at 67th Avenue and 0.08 foot at U.S. 27. This would indicate a total volume of water removed from the canal of 738,000 ft^3.

Table 5.--Summary of discharge measurements at the Snake Creek Canal Basin.

During the declining stage period a total of 11,945,000 ft^3 of water passed under the bridge at 67th Avenue from the Snake Creek Canal extension. This indicates a flow of more than 11,000,000 ft^3 from aquifer storage or from surface flow from the tributary canals.

Flow at site 5 averaged 54 ft^3/s. The portion of the North Fork of the Snake Creek Canal from Hollywood Blvd. to the Dade-Broward line is similar in width, length, and depth to five other canals running in a north-south direction at 2-mile intervals west of 67th Avenue but it is twice as wide as three other canals located between the other north south canals at 2-mile intervals. If we consider each of the wide canals to drain as much water as the North Fork Snake Creek Canal, and the other three canals half as much, the total discharge from these canals into the Snake Creek Canal Extension would be 350 ft^3/s which would leave only 126 ft^3/s as the actual volume of aquifer storage removed during the test by the Snake Creek Canal Extension.

If a drawdown of 0.4 foot is assumed for areas adjacent to the canal at 67th Avenue and 0.08 foot for areas adjacent to the canal at U.S. 27 and an effective porosity of 25 percent a wedge extending from the N.W. 67th Avenue site to the end of the canal at U.S. 27 would need be only 890 feet wide on either side of the canal to provide the actual measured discharge. This is a very small effect when compared to the 5,000 feet effective distance in the Bird Road Canal area of South Dade County.

THE POMPANO-CYPRESS CREEK CANAL TEST

The drainage basin of the Pompano-Cypress Creek Canal overlies some of the sandiest parts of the Biscayne aquifer; consequently, the degree of interconnection between the canal system and the aquifer is very poor except in the extreme inland reaches of Pompano Canal.

Figure 17 shows how the Pompano Canal is cut into hard limestone at its western end. This limestone gradually becomes thinner towards the east and about 2 miles west of State Road 7 it is replaced locally by sand. This sandy section continues for about 2 miles to State Road 7. From this point the canal cuts through very sandy limestone for the next 3 miles. From there to the confluence with Cypress Creek Canal, the canal is again cut into sand. Downstream from the confluence with Pompano Canal, Cypress Creek cuts through sand or sandy limestone.

Figure 17.--Lithologic section parallel to Pompano-Cypress Creek Canal.

Collection of Data

The continuing monitoring network in the Pompano Cypress Creek Canal basin consists of 30 observation wells and 1 continuous stage-discharge station in the Cypress Creek Canal near the S-37A control.

For use during the test 15 additional wells were drilled and 7 were equipped with recorders. These wells were located in the western areas of the drainage basin and they form the basis for the evaluation of aquifer response in that rapidly developing area (fig. 18).

Flow in the canal system was measured at Dixie Highway near S-37A, at S-37B, at State Road 7, and at University Drive (fig. 17). Flow in most of the major tributaries was also measured during the test to determine their effective contribution to flow and to help determine the effect of these secondary canals in lowering the water table in the western areas.

Figure 18.-- Part of the western segment of the Pompano-Cypress Creek Canal basin showing the location of the surface water measuring sites and the ground-water wells.

Data Analysis

On July 23 and 24, 1972, the flood control operations required the control at S-37A to be set on automatic operation so that any unpredicted rainfall would not cause flood damage. The drainage basin therefore did not achieve a condition of equilibrium between the canal system and the aquifer prior to the test. Further complication resulted from two automatic control operations on the day of the test just prior to the opening of the controls. In fact the gates had been closed only 1½ hours before they were opened for the test.

Figures 19, 20, and 21 show the ground-water contours at different times during the test. The contours of figure 19 represent the conditions early in the morning of July 24 just before the opening of the control. The contours of figure 20 were drawn for the time of maximum drawdown of the water table during the test, and the contours of figure 21 show the altitude of the water-level contours on the morning of July 25 after the gates had been closed more than 12 hours.

Figure 19.--Part of the Pompano-Cypress Creek basin showing contours on the water table on July 24, 1972, before the control had been opened.

Figure 20.--Part of the Pomapno-Cypress Creek basin showing contours on the water table on July 24, 1972, after the control had been opened.

Figure 21.--Part of the Pompano-Cypress Creek basin showing contours on the water table on July 25, 1972.

These three mpas show no changes in the water table as a result of the control operations during the test; indicating a poor interconnection between the canals and the aquifer. The canal-aquifer interconnection is poor only when a small time period is used because with sufficient time the canal system is capable of totally draining the area to levels below those set in the current flood criteria.

Water levels in the canal system were dropped much lower for this test than for the Snake Creek test but the decline in ground-water levels was no more perceptible than in the Snake Creek test.

The observation wells for this test were drilled closer to the canals than in the Snake Creek area to insure that ground-water levels would react to changes in canal stage. However, because ground-water levels were declining, any decline that could have been brought on by the control operation could not be separated from the general decline.

The hydrographs for selected observation wells and canal sites in figure 22 show that there is a time lag of 1 to 1½ hours between an operation of the control at S-37A and the time when the effect is felt at the University Drive bridge (site 7). This time lag compares closely to the time lag in the Snake Creek Canal although in Cypress Creek at S-37A the decline in stage of 3.6 feet was about twice as large as the decline in stage of 1.9 feet of Snake Creek Canal at S-29.

Figure 22.--Hydrographs of selected wells and selected parts of the canal in the Pompano-Cypress Creek Canal basin.

Table 6.--Summary of discharge measurements at the Pompano-Cypress Creek Canal basin.

This large decline resulted in the effect being felt throughout the canal system. In this test, the dampening effect of distance from the control on the change in water levels in the canal (fig. 23) was much less than in the Snake Creek Canal test. The changes in the canal level are noticeable in the inland reaches of the canal system partly because of the much greater drawdown at the coast, but the fact that this system is much shorter and smaller than the Snake Creek Canal system is probably more important.

The opening of the control had very little effect on the ground-water level, but the recovery noted early in the morning of July 25 for some of the wells is definite enough to attribute this change to the closing of the control on July 24. This is especially evident in the hydrographs of wells G-2041, G-2059, and G-2044.

Figure 23.--Change of water level in Pompano-Cypress Creek Canal as a function of distance from the control.

CONCLUSIONS

Tests in three major canal basins indicate that the control operation criteria effective in providing flood control protection for the present population centers do not conform to the flood control needs in the newly developing inland areas because of the low effectiveness of the secondary canal system, or lack of it. The time lapse from the moment a control operation is effected and the water-level changes in the inland reaches of the canals is less than 2 hours at all sites measured, but the time required for any given place in the aquifer to respond to that change can vary from a few hours to days depending on the distance from the canal and the degree of connection between the canal and the aquifer.

Half a mile from the canals the lag varies from 1½ hours in the Snapper Creek Canal basin where the permeability of the aquifer is high to more than 9 hours in the Pompano-Cypress Creek Canal basin where the permeability of the upper strata of the aquifer is low.

To prevent flooding by a 1-in-10 year storm additional secondary drainage canals would be required in all three basins to adequately lower the water table in 1 day. If the operations criteria are such that 2 days are available to lower the water table, then the Snapper Creek Canal system appears adequate to protect areas as far as 1½ miles west from Kendall Drive to Tamiami Trail.

If it is necessary to lower the water table in the Snapper Creek Basin by half a foot in sections 22 and 23, additional drainage canals would be necessary. These canals would be more effective if they drained into Snapper Creek rather than into Bird Drive Canal. Another alternative would be to extend the tributary west of S.W. 127th Avenue because this tributary can remove more water than the Bird Drive Canal at its present depth.

The north-south tributary to Bird Drive Canal which discharges at site 4 appears to be only partly effective in draining its sub-basin. Its ability to lower the ground-water levels in sections 15 and 10 by more than 0.2 foot is limited by the inability of the Bird Drive Canal to drain section 14 effectively.

If Bird Road Canal is deepened to 12 feet it would be possible, with a single control operation of 6 hours duration, to drain the adjacent sections within 1½ miles of the canal. A 6-hour control operation is presently effective at less than half a mile from the canal.

In the time frame of the test, the control operation failed to show any appreciable effect in the western reaches of the Snake Creek Canal drainage basin. There was however a noticeable effect in the water level in the canals and in the aquifer at secs. 26 and 34, T. 51 S., R. 40E. This, of course, points to a need for secondary drainage similar to that of those sections if an effective lowering of the water table is desired in a period measurable in hours rather than days.

It has not been possible to determine the length of time required to lower the water table sufficiently to prevent flooding in the Snake and Pompano Canal basins for a 1-in-10-year storm, but it is obvious from the Snapper Creek results that it would be much more than 2 days with the present drainage system (1973).

The only way to compensate for the poor aquifer-canal connection in the Snake and Pompano Canal basins would be by increasing the density of secondary drainage canals but this would be at the expense of reducing total water supplies, lowering water levels in recharge areas of the aquifer, and increasing eastward seepage from the water conservation areas.

REFERENCES

Cross, W.P., and others, 1940, Progress report on the investigation of water resources in southeastern Florida: U.S. Geol. Survey mimeographed report.

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

Klein, Howard, and Sherwood, C.B., 1961, Hydrologic conditions in the vicinity of Levee 30, northern Dade County, Florida: Florida Geol. Survey Rept. Inv. 24, pt. I.

Leach, S.D. and Sherwood, C.B., 1963, Hydrologic studies in the Snake Creek Canal area, Dade County, Florida: Florida Geol. Survey Rept. Inv. 24, pt. III.

Parker, G.G., and others, 1955, Water resources of southeastern Florida: U.S. Geol. Survey Water-Supply Paper 1255.

Sherwood, C.B., and Leach, S.D., 1962, Hydrologic studies in the Snapper Creek Canal area, Dade County, Florida: Florida Geol. Survey Rept. Inv. 24, pt. II.

Stallman, R.W., 1956, Preliminary findings on ground-water conditions relative to Area B flood-control plans, Miami, Florida: U.S. Geol. Survey open-file report.

State of Florida Board of Conservation, 1955, Water Survey and Research Paper No. 13.

REFERENCES (Continued)

U.S. Army Corps of Engineers, 1953, Design Memorandum - Central and Southern Florida Project: pt. VI, sect. 6.

______________, 1954, Design Memorandum - Central and Southern Florida Project, pl. 71.

______________, 1968, Design Memorandum - Central and Southern Florida Project, figs. I 44, I 45.

Table 1.--Maximum recorded rainfalls. (Updated from State of Florida Board of Conservation, 1955).

Basin	Station name	Period of record examined	The greatest amount (in inches) recorded in: 1 hour	2 hours	3 hours	6 hours	12 hours	1 day	1 month
Snapper Creek	Tamiami Canal at Dade-Broward Levee (Trail-Glades Ranges)	1940-72	5.30 (10/11/47)	7.70 (10/11/47)	7.85 (10/11/47)	8.00 (10/11/47)	9.52 (10/11/47)	9.98 (10/11/47)	23.79 (5/58)
	Subtropical Experiment station (Homestead)	1940-72	4.60 (10/11/47)	5.25 (10/11/47)	5.30 (10/11/47)	7.00 (10/11/47)	9.08 (10/11/47)	9.60 (10/11/47)	23.98 (9/48)
Snake Creek	Miami Canal at Pennsuco (Broken Dam - Thompson Park)	1940-72	3.00 (7/ 9/49)	5.00 (10/11/47)	5.75 (10/11/47	6.70 (10/11/47)	8.18 (10/11/47)	8.63 (10/11/47)	25.61 (8/56)
	Miami Canal at Water Plant (Hialeah)	1940-72	5.60 (10/11/47)	6.00 (10/11/47)	6.24 (10/11/42)	11.00 (4/16/42)	13.22 (4/16/42)	13.68 (4/16/42)	22.01 (6/68)
Pompano-Cypress Creek	North New River at S-7 (County line No. 2)	1940-72	3.09 (6/30/58)	4.27 (8/19/63)	5.26 (8/19/63)	5.72 (8/19/63)	5.98 (8/19/63)	6.02 (8/19/63)	21.38 (6/55)
	Boca Raton	1940-72	5.90 (1/18/42)	8.27 (1/18/42)	9.15 (1/18/42)	9.69 (1/18/42)	11.96 (1/18/42)	12.80 (1/18/42)	29.69 (10/65)

Table 2.--Maximum expected rainfalls (in part from U. S. Army Corps of Engineers, 1953).

Location	The greatest amount (in inches) which can be expected in: 1 day	2 days	10 days	1 month	Frequency of occurrence
Homestead	4.38	5.74	9.77	14.98	Once in 2 yrs.
	6.25	8.06	13.12	18.69	Once in 5 yrs.
	7.62	9.75	15.32	21.03	Once in 10 yrs.
	9.12	11.49	17.42	23.16	Once in 20 yrs.
	11.26	13.62	20.04	25.90	Once in 50 yrs.
	13.37	16.18	22.06	27.81	Once in 100 yrs.
Miami	4.80	6.10	9.89	14.26	Once in 2 yrs.
	7.21	8.80	13.91	19.11	Once in 5 yrs.
	9.05	10.77	16.74	22.44	Once in 10 yrs.
	11.12	12.79	19.46	25.35	Once in 20 yrs.
	14.15	15.42	22.92	29.29	Once in 50 yrs.
	17.16	18.36	25.74	32.26	Once in 100 yrs.
Fort Lauderdale	4.13	5.29	8.92	12.93	Once in 2 yrs.
	6.33	8.23	12.47	18.10	Once in 5 yrs.
	8.03	10.52	14.94	25.21	Once in 10 yrs.
	9.96	12.95	17.23	24.80	Once in 20 yrs.
	12.83	16.04	20.27	29.25	Once in 50 yrs.
	15.76	20.01	22.54	32.46	Once in 100 yrs.
Hillsboro - Plantation	3.74	4.79	8.60	11.71	Once in 2 yrs.
	5.62	6.86	11.07	14.11	Once in 5 yrs.
	7.06	8.33	12.64	15.60	Once in 10 yrs.
	8.68	9.81	14.06	17.01	Once in 20 yrs.
	11.05	11.71	15.91	18.67	Once in 50 yrs.
	13.46	14.00	17.23	19.92	Once in 100 yrs.

Table 3.--Maximum expected rise of the water table from rainfall in the three drainage basins.*

Location	The greatest amount (in inches) which can be expected in: 1 day	2 days	10 days	Frequency of occurrence
Snapper Creek Canal Basin	18.7	24.2	40.1	Once in 2 yrs.
	27.5	34.4	55.1	Once in 5 yrs.
	34.0	41.9	65.4	Once in 10 yrs.
	41.3	49.5	75.2	Once in 20 yrs.
	51.8	59.2	87.6	Once in 50 yrs.
	62.3	70.5	97.5	Once in 100 yrs.
Snake Creek Canal Basin	21.2	27.1	44.7	Once in 2 yrs.
	32.2	40.4	62.6	Once in 5 yrs.
	40.6	50.6	75.2	Once in 10 yrs.
	50.1	61.1	87.1	Once in 20 yrs.
	64.1	74.7	102.7	Once in 50 yrs.
	78.2	91.1	114.7	Once in 100 yrs.
Pompano-Cypress Creek Canal Basin	21.4	27.4	47.6	Once in 2 yrs.
	32.5	41.0	63.9	Once in 5 yrs.
	40.9	51.2	74.9	Once in 10 yrs.
	50.6	61.8	85.0	Once in 20 yrs.
	64.8	75.3	98.2	Once in 50 yrs.
	79.3	92.3	108.0	Once in 100 yrs.

* Using the averages of: Homestead and Miami for the Snapper Creek Canal basin.
Miami and Fort Lauderdale for the Snake Creek Canal basin.
Fort Lauderdale and Hillsboro-Plantation for the Pompano-Cypress Creek Canal basin.

Table 4.--Summary of discharge measurements at the Snapper Creek Canal basin.

Measured site	Discharge (in ft³/s)											
	Control closed		Control open								Control closed	
Snapper Greek at U.S. Highway 41	31	36	-	-	-	-	-	-	-	-	-	-
Tributary to Snapper Creek at site 7	8.4	7.4	3.4	-	-	-	-	-	-	-	-	-
Bird Road Canal at site 5	2.1	2.1	2.0	2.0	2.0	1.9	2.2	2.1	2.0	1.8	2.1	3.3
Tributary to Bird Road Canal at site 4	32	30	31	40	39	43	45	49	49	56	51	36
Bird Road Canal at site 3	115	119	130	144	157	160	162	164	172	121	-	-
Bird Road Canal at site 2	98	97	136	160	166	167	179	176	180	172	102	-
Tributary to Snapper Creek Canal at site 1	-19	-17	0	0	22	80	80	86	91	83	79	-
Tributary to Snapper Creek at site 6	147	124	32	-	-	-	-	-	-	-	-	-
Snapper Creek Canal at S.W. 87th Avenue	748	764	837	805	455	-	-	-	-	-	-	-
Snapper Creek Canal at S-22	-	-	1,125	1,080	1,045	1,020	1,010	995	875	860	-	-

Table 5.--Summary of discharge measurements at the Snake Creek Canal basin.

Measured site	Discharge (in ft^3/s)								
Tributary to Snake Creek at site 4	8.6	8.7	7.3	4.8	3.2	2.7	2.4	2.1	-
Tributary to Snake Creek at 148th Avenue (site 3)	0	0	0	0	0	0	0	0	-
41st Street Canal at site 2	8.8	9.2	9.4	7.6	8.4	8.0	7.6	7.2	-
41st Street Canal at site 1	20.1	18.2	20.8	21.2	22.1	21.8	22.6	23.4	-
North Fork of Snake Creek Canal at site 5 (N.W. 67th Avenue)	20.9	38	50	64	70	64	62	59	-
Snake Creek Canal at 37th Avenue (Douglas Road)	435	632	715	785	858	922	920	945	813
Snake Creek Canal at S-29	1,980	2,150	2,100	2,250	2,220	1,670	905	-	-
Snake Creek Canal at N.W. 67th Avenue	405	415	475	535	565	600	635	595	-

Table 6.--Summary of discharge measurements at the Pompano-Cypress Creek Canal basin.

Measured site	Discharge (in ft^3/s)																
Cypress Creek at S-37A	4,230	2,010	2,160	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cypress Creek at S-37B	250	1,770	1,905	1,730	1,640	1,520	1,575	1,315	-	-	-	-	-	-	-	-	-
Pompano Canal at U.S. Hyway 441 - Site 1	265	245	310	825	1,005	1,265	1,250	1,300	1,325	1,305	1,230	1,340	1,250	1,170	1,070	980	-
Pompano Canal at University Drive - Site 7	135	135	130	255	270	460	505	480	485	505	510	490	480	465	560	445	430
Tributary to Pompano Canal at Site 3	105	65	215	150	165	155	155	200	130	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 2	5	50	90	65	70	65	60	145	40	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 4	0	4.1	0	1.6	1.2	0	0	-	-	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 5	4.6	4.7	4.8	4.5	4.6	4.5	4.3	-	-	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 6	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 8	2.0	1.8	4.0	5.0	4.5	4.0	3.3	-	-	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 9	74	9.8	120	115	205	175	180	-	-	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 10	0	1	1	0	0	0	0	-	-	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 11	20	22	20	19	17	20	-	-	-	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 12	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-
Tributary to Pompano Canal at Site 13	4	5	5	5	5	5	5	5	4	-	-	-	-	-	-	-	-

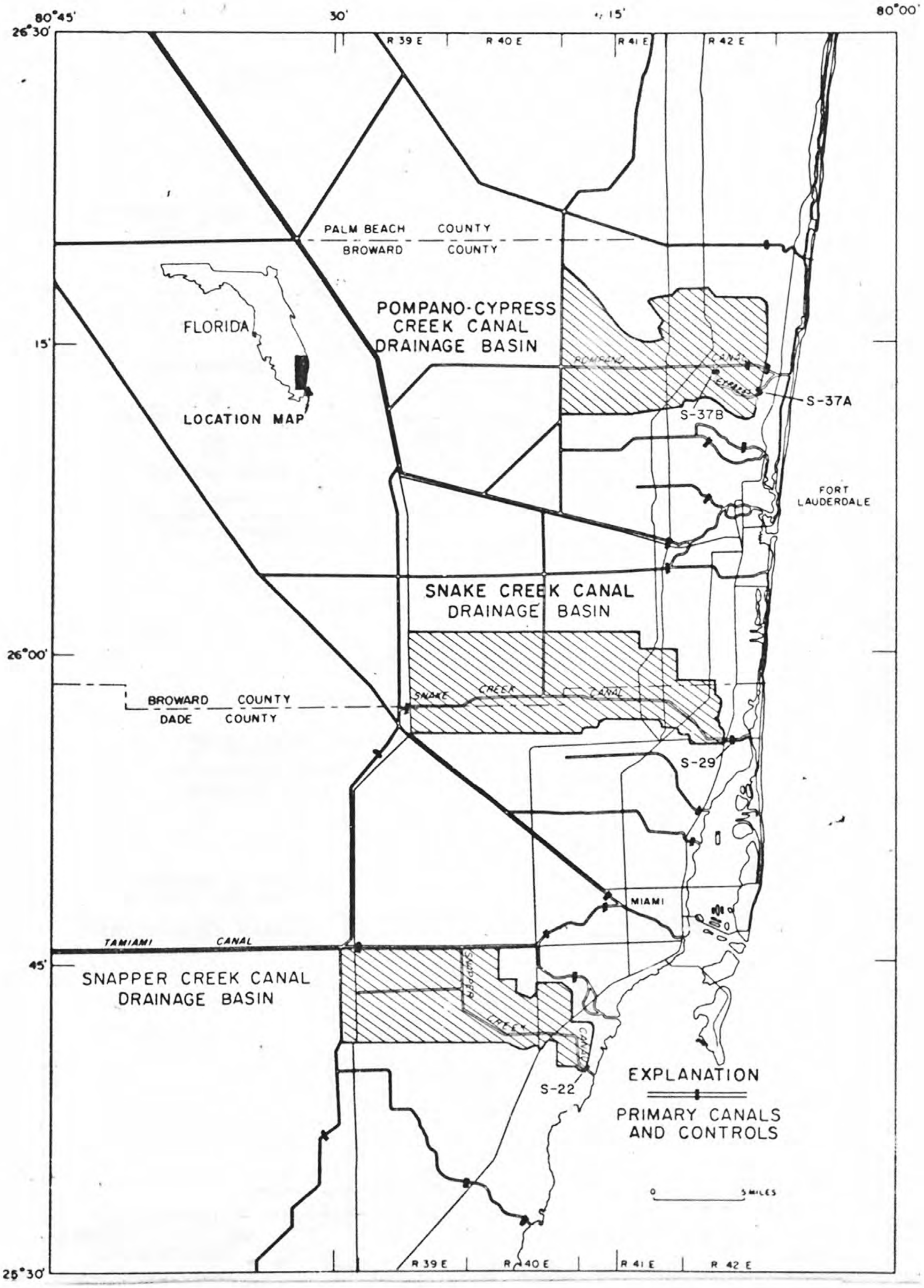

Figure 1. Southeast Florida showing the drainage basins investigated.

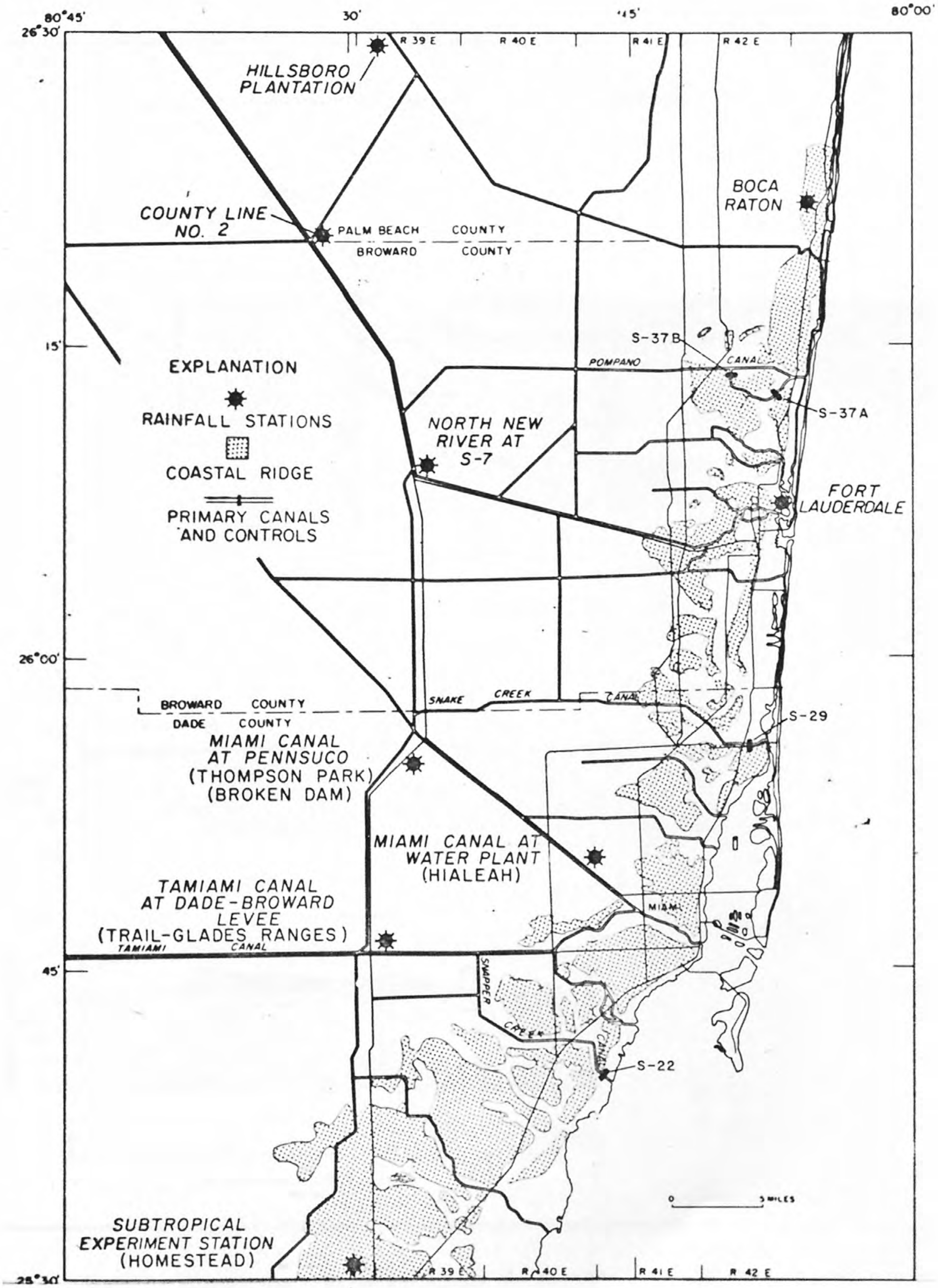

Figure 2. Southeast Florida showing the configuration of the coastal ridge, the natural drainageways cutting through it, and the location of rainfall stations.

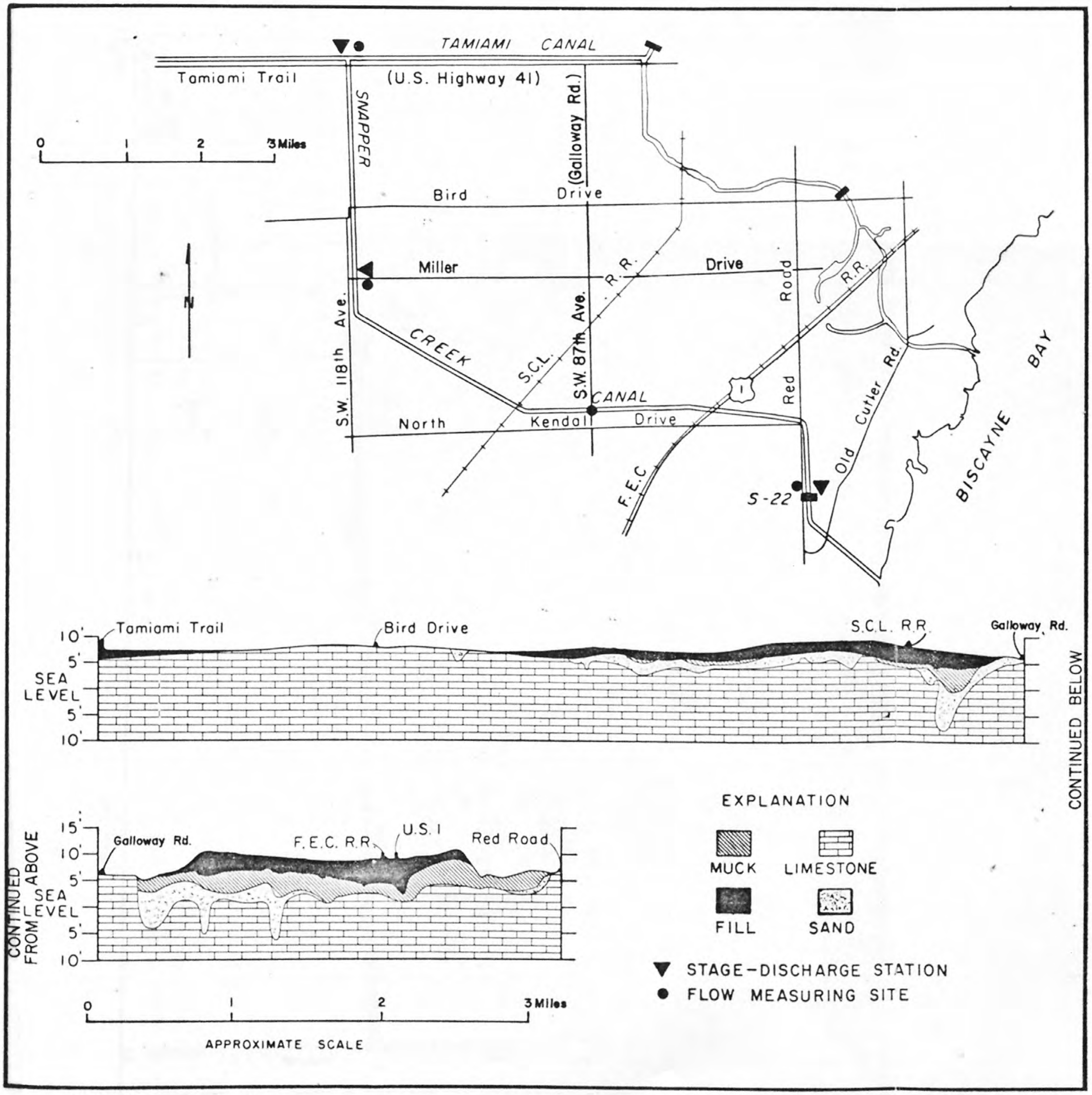

Figure 3. Lithologic section parallel to Snapper Creek Canal.

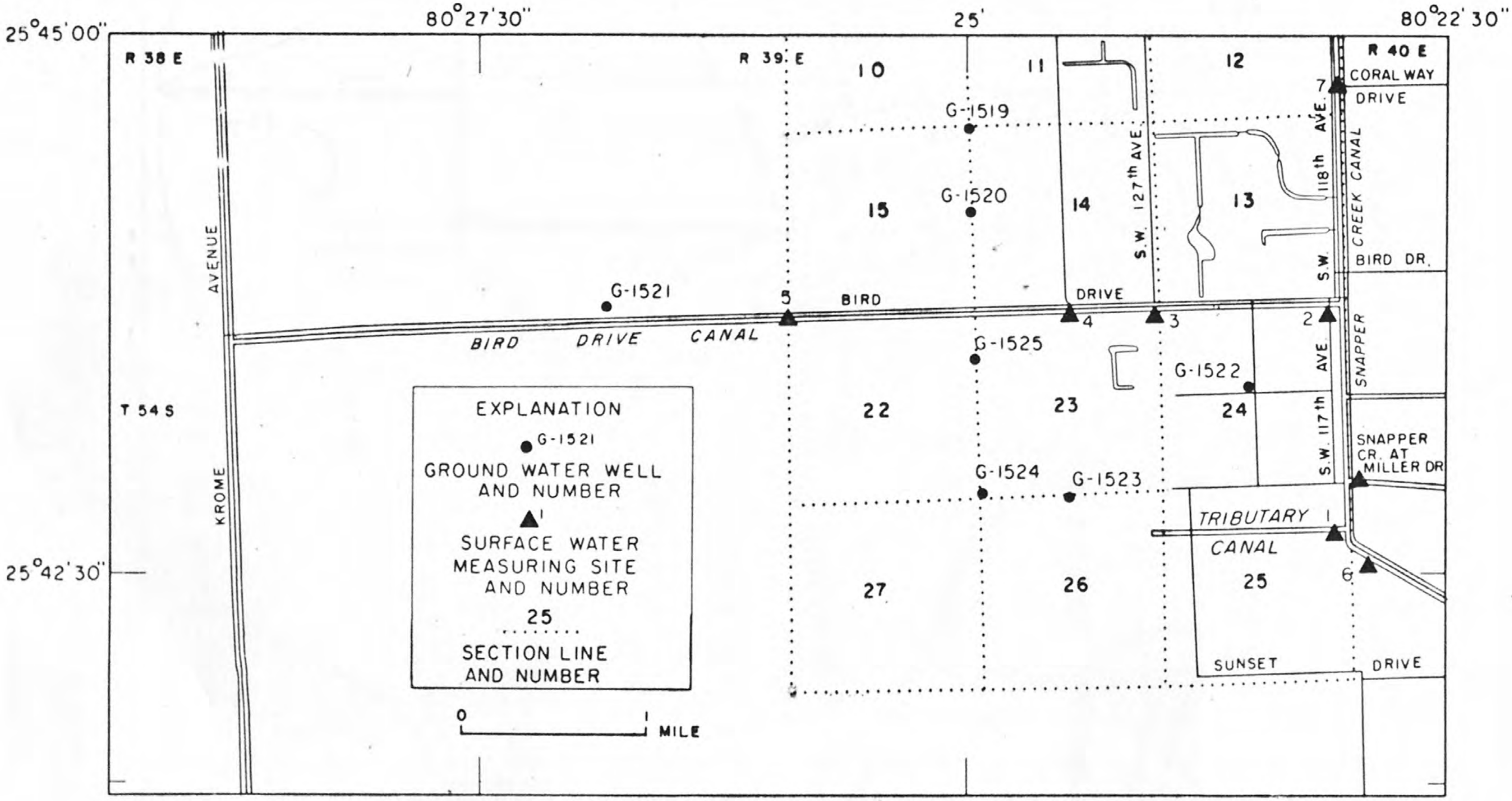

Figure 4. Part of the western segment of the Snapper Creek Canal basin showing the location of the wells and the surface-water measuring sites.

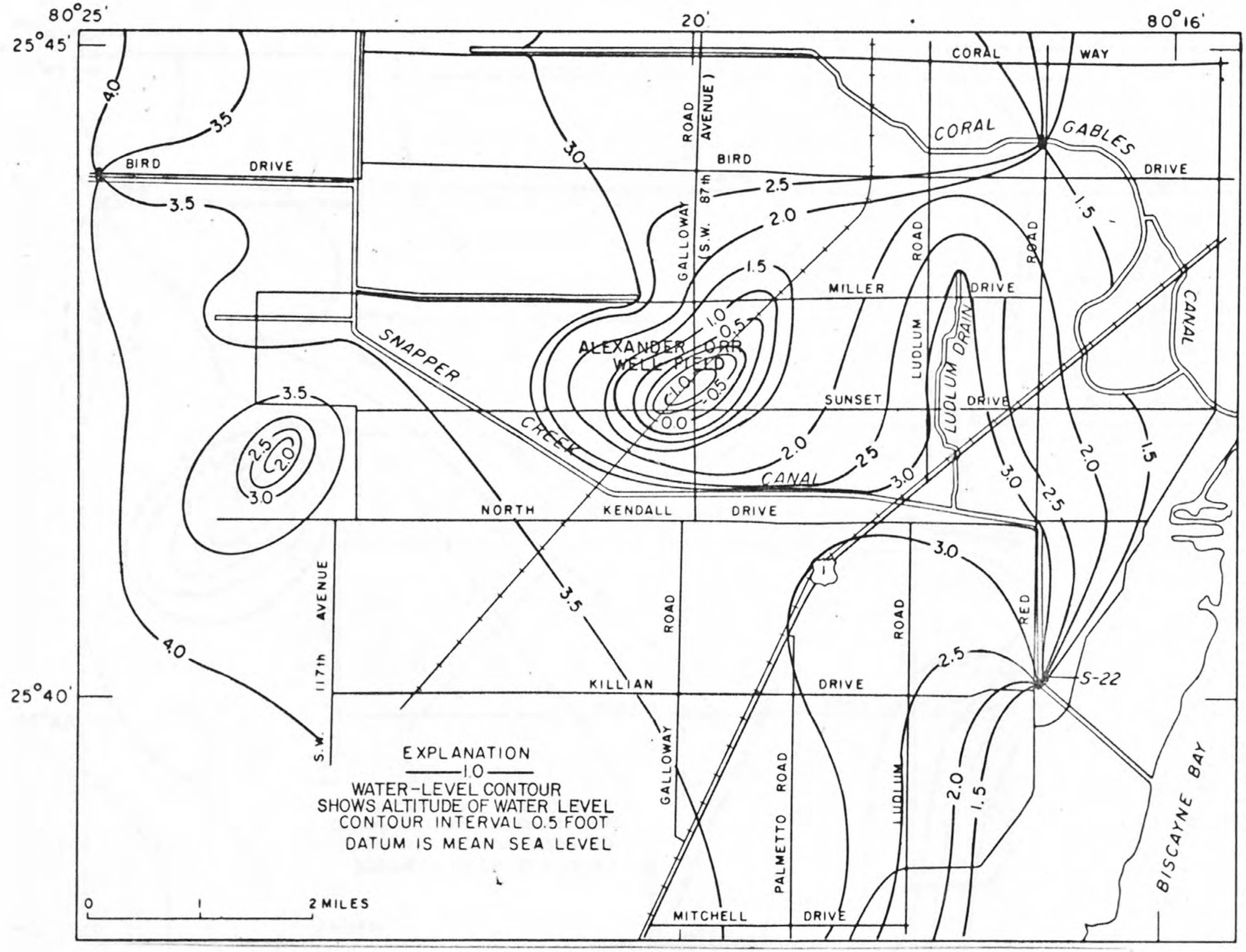

Figure 5. Part of the eastern segment of the Snapper Creek basin showing contours on the water table on October 27, 1970.

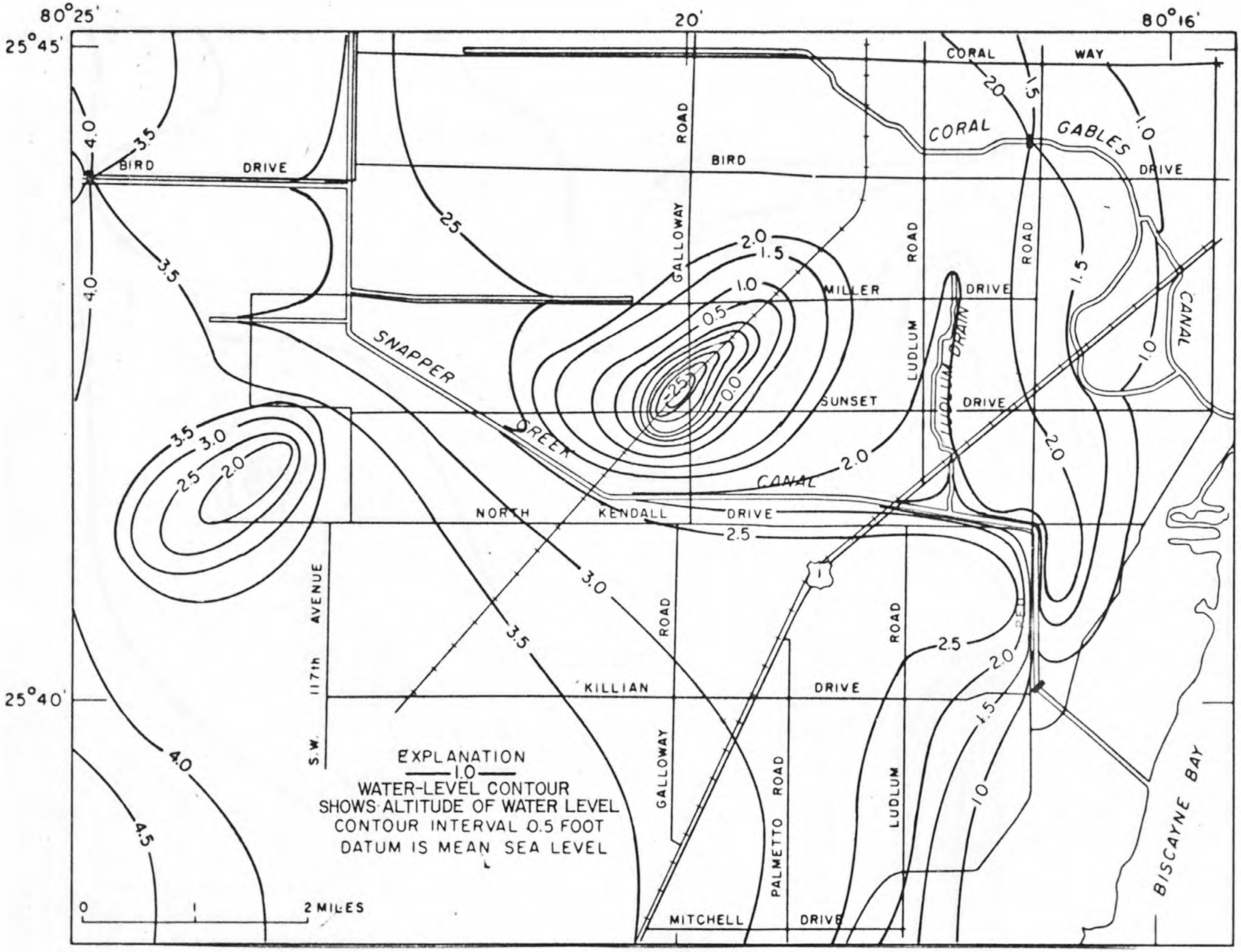

Figure 6. Part of the eastern segment of the Snapper Creek basin showing contours on the water table on October 28, 1970.

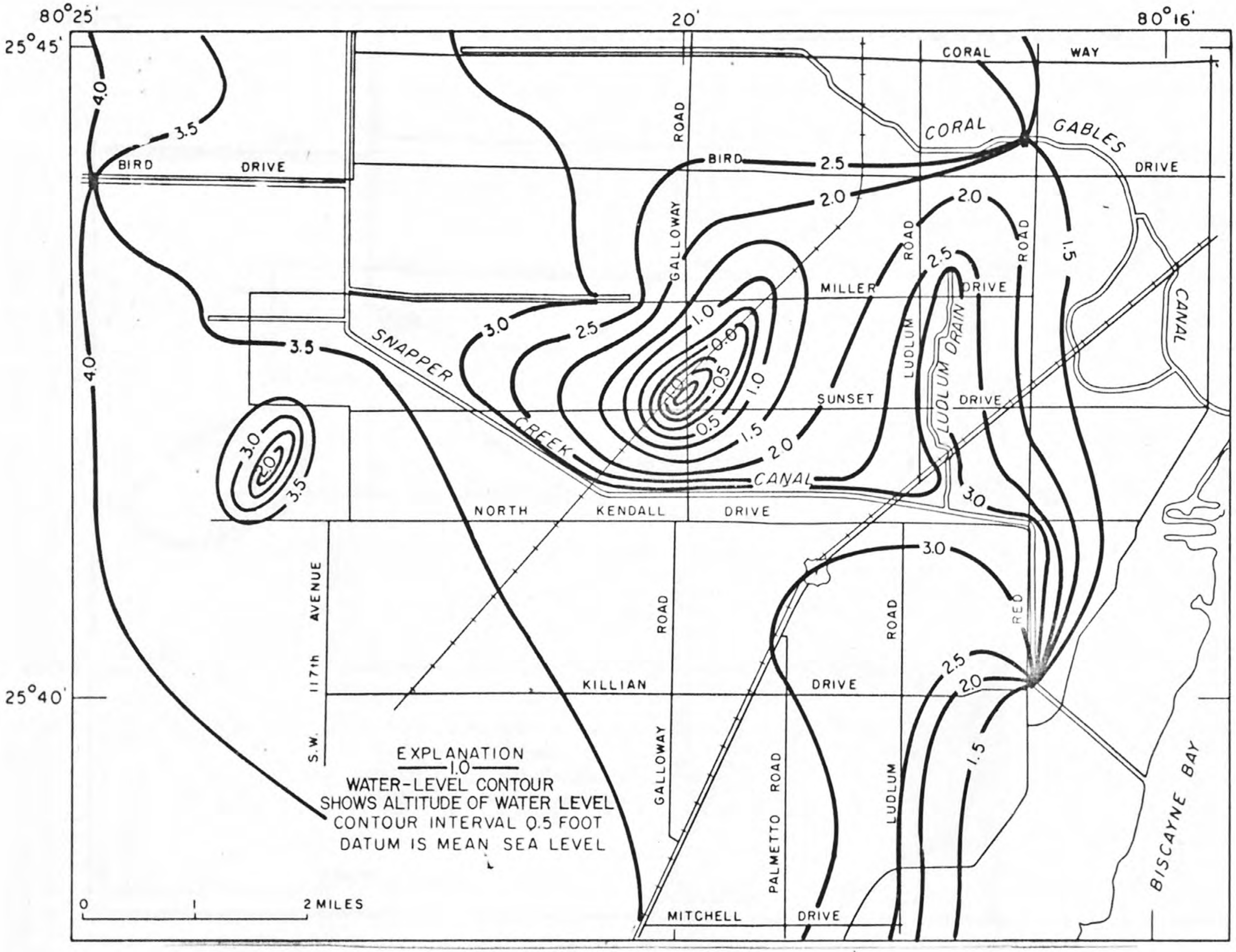

Figure 7. Part of the eastern segment of the Snapper Creek basin showing contours on the water table on October 29, 1970.

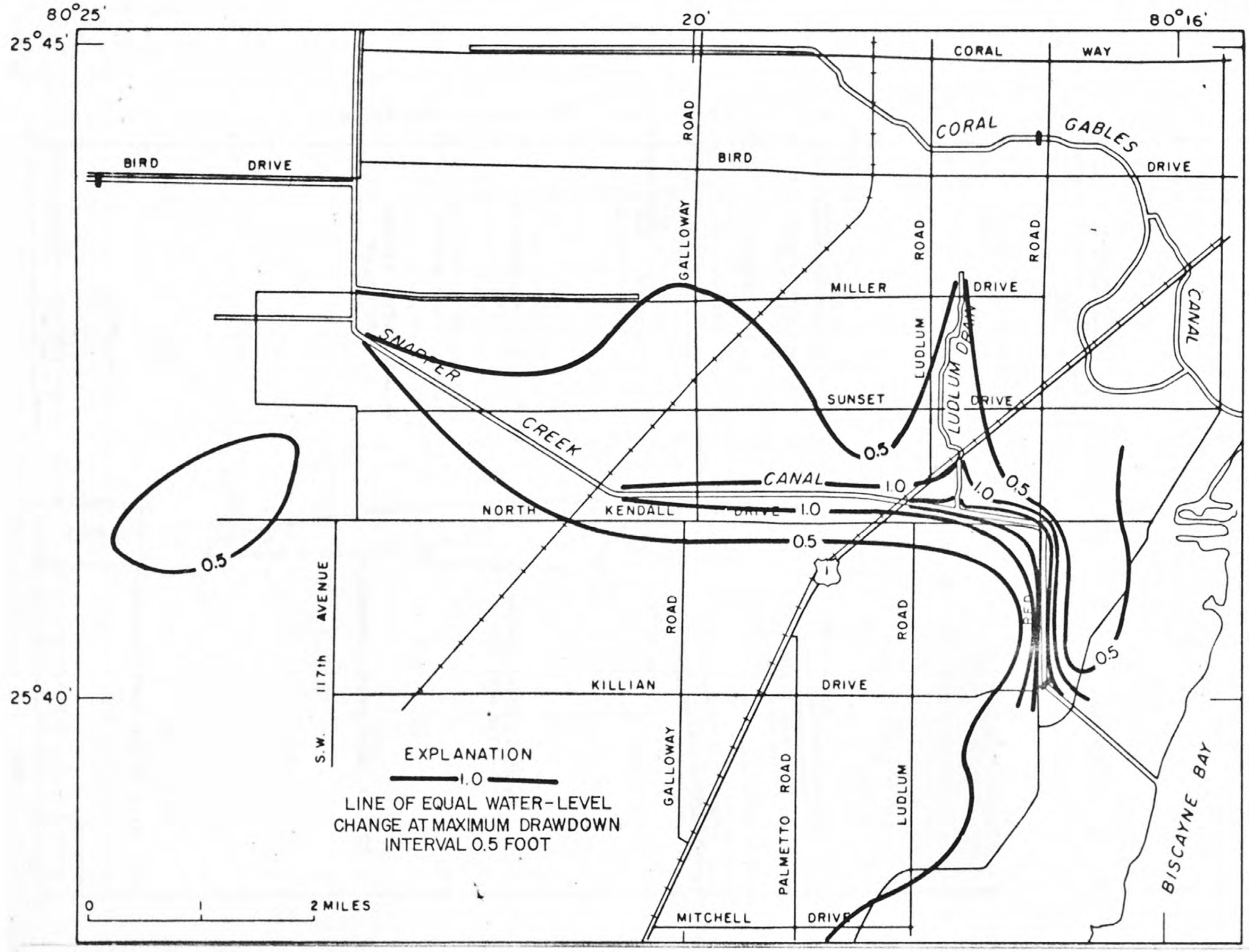

Figure 8. Part of the eastern segment of the Snapper Creek basin showing the change in the water table between October 27 and 28, 1970.

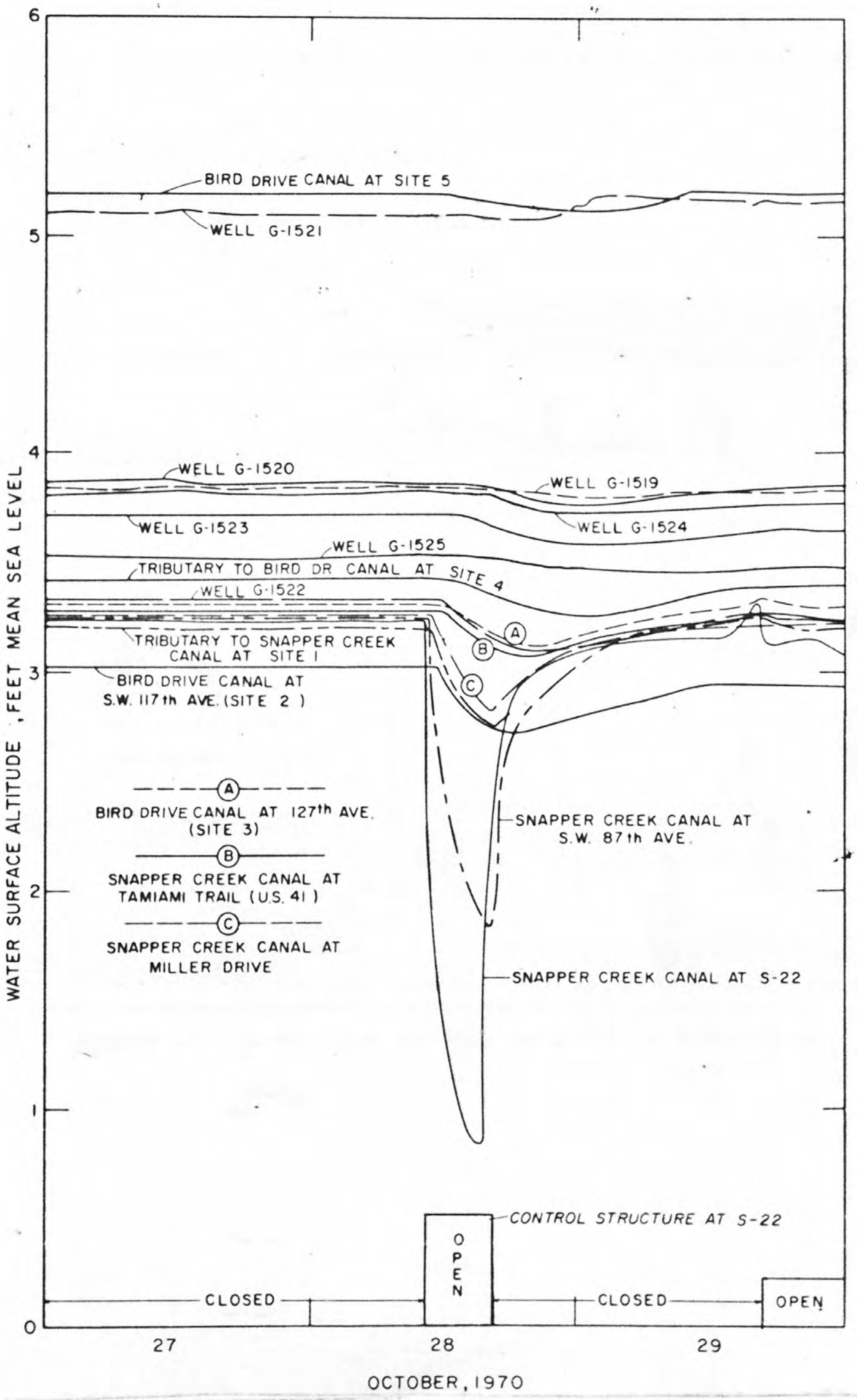

Figure 9. Hydrographs of selected wells and selected parts of the canal in the Snapper Creek Canal basin.

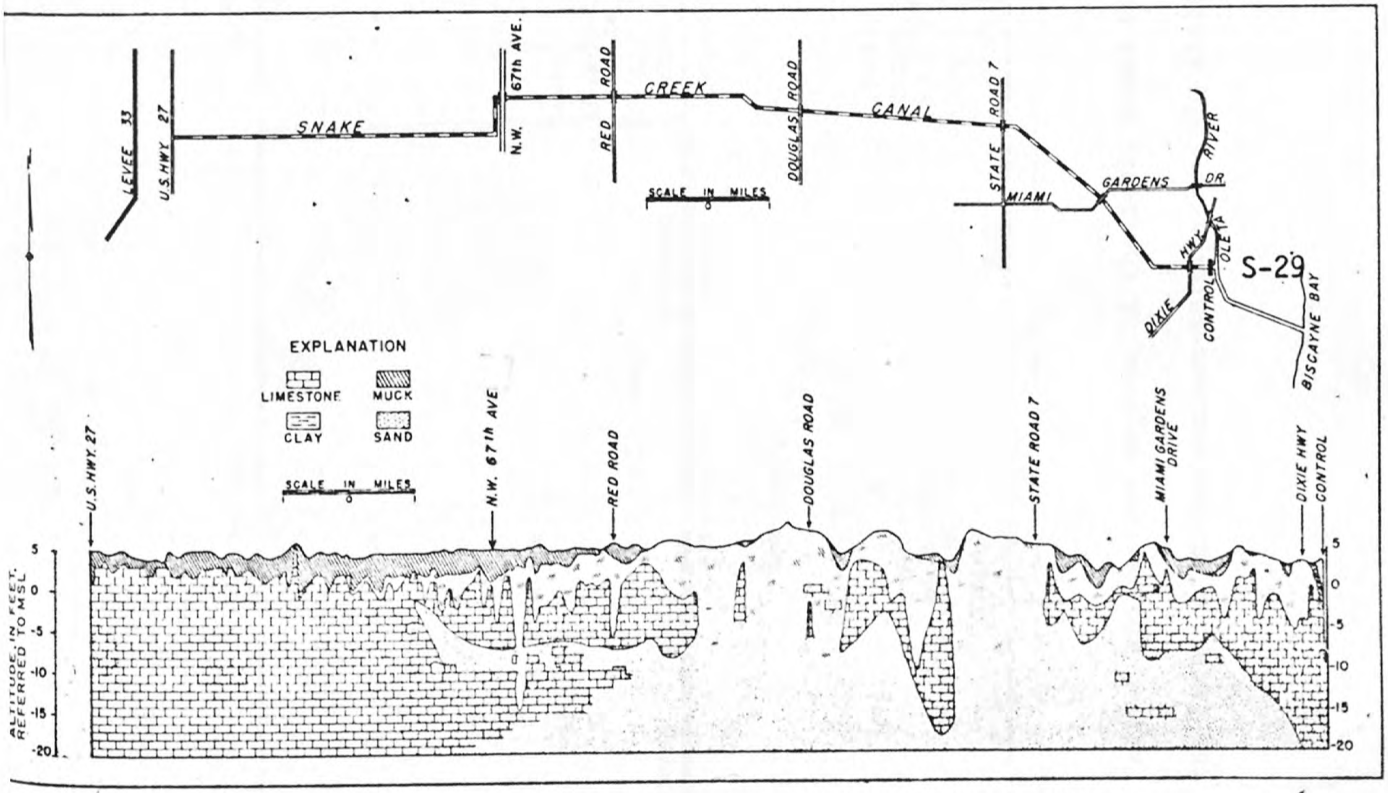

Figure 10. Lithologic section parallel to Snake Creek Canal

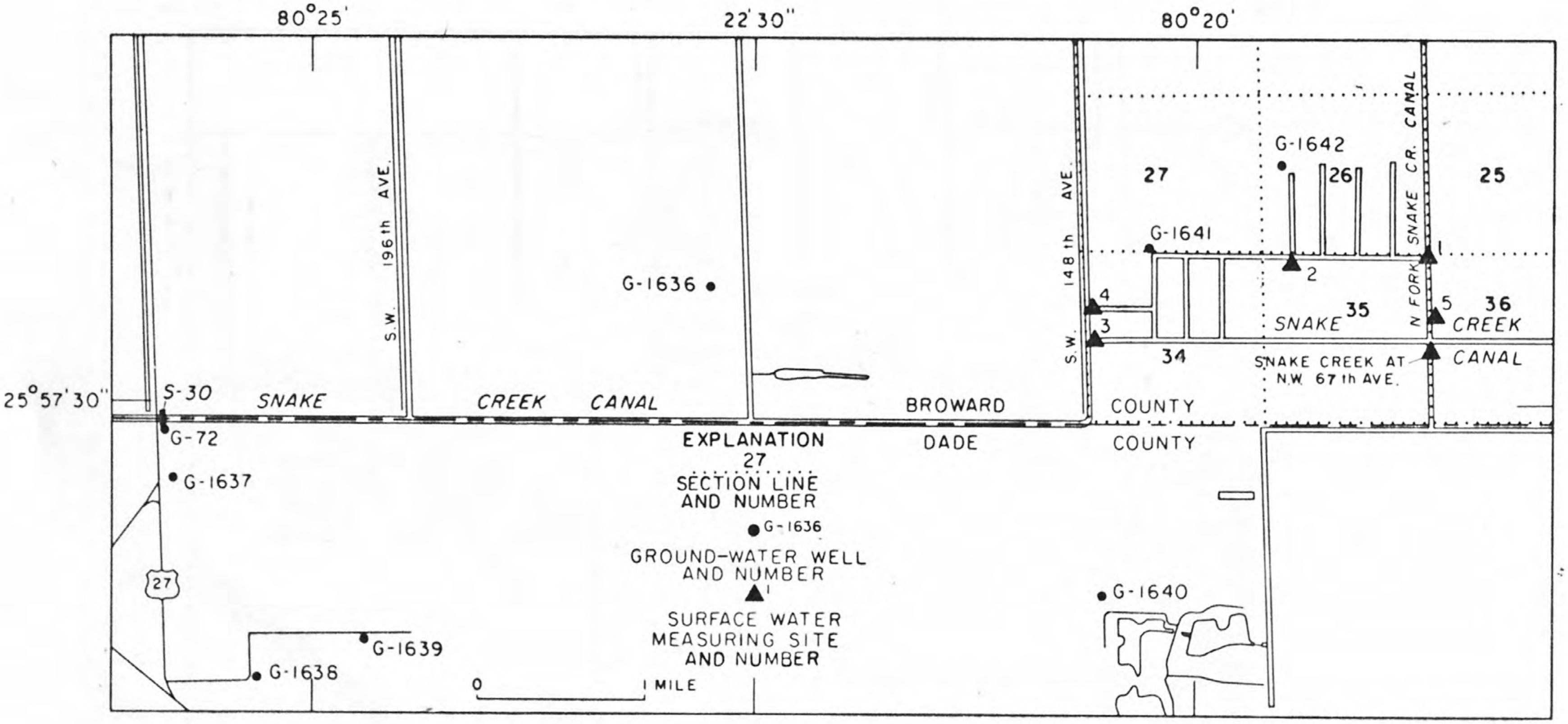

Figure 11. Part of the western segment of the Snake Creek Canal basin showing the location of the surface-water measuring sites and the wells.

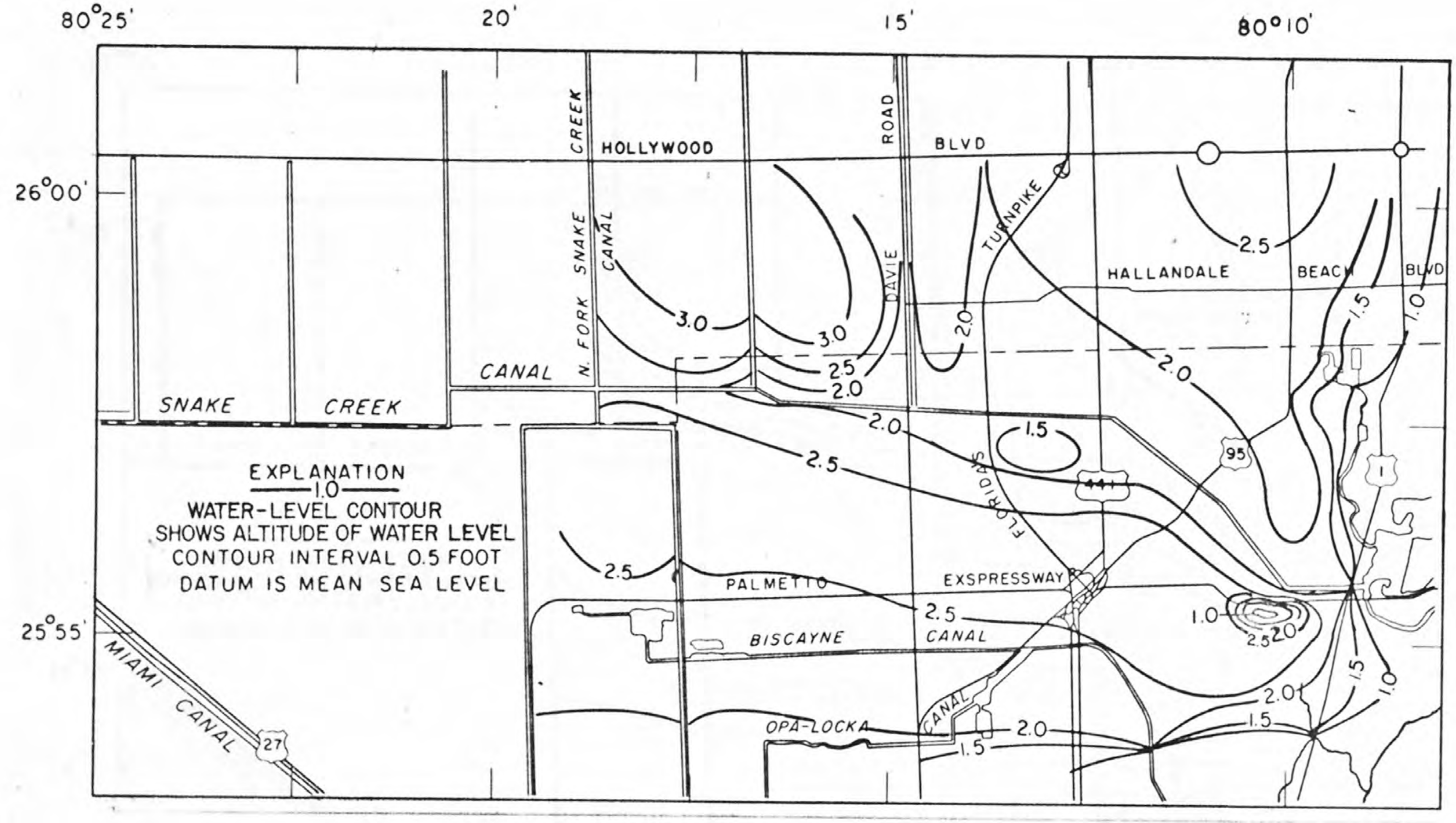

Figure 12. Part of the eastern segment of the Snake Creek Canal basin showing contours on the water table on September 15, 1971.

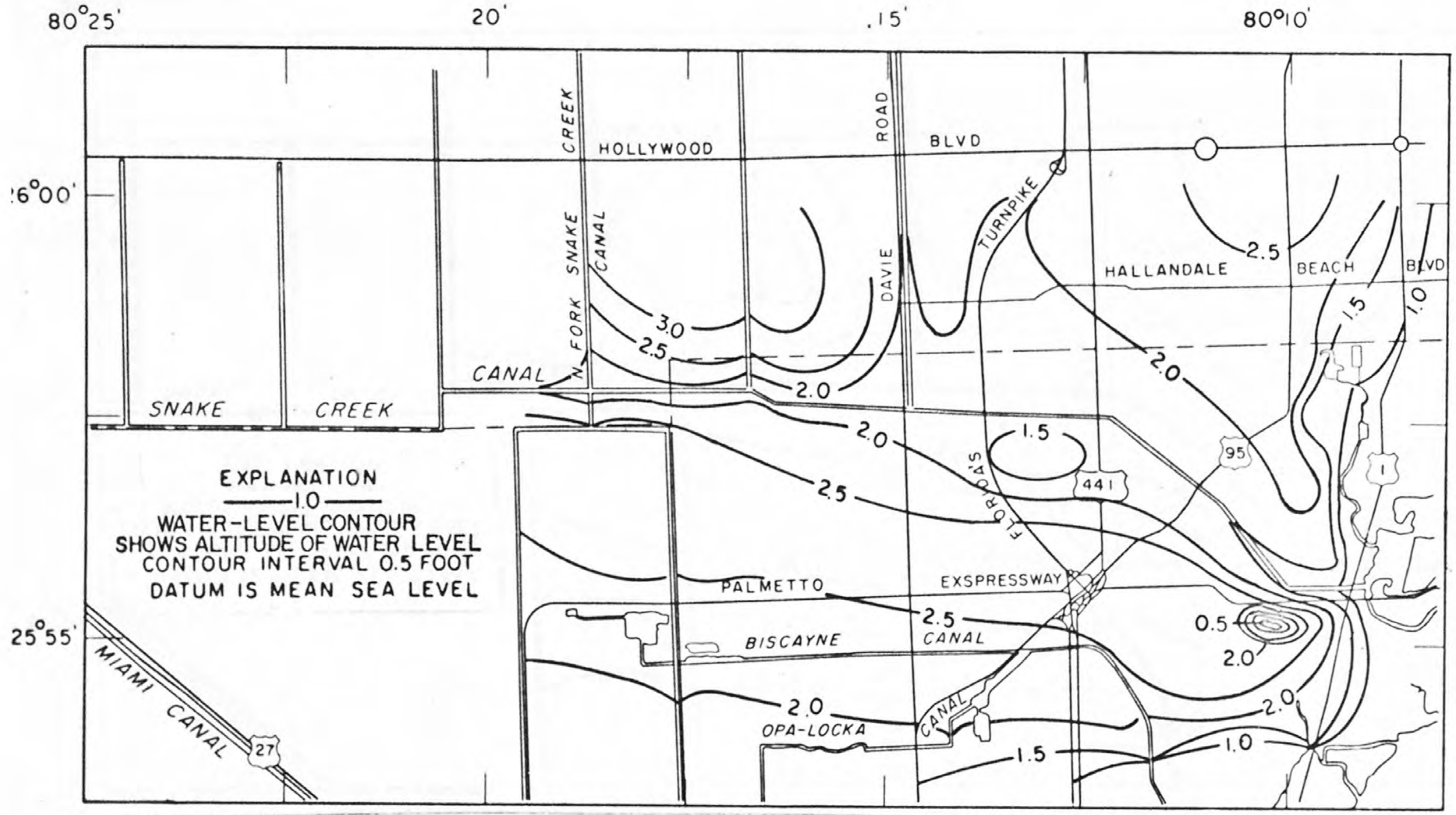

Figure 13. Part of the eastern segment of the Snake Creek Canal basin showing contours on the water table on September 16, 1971.

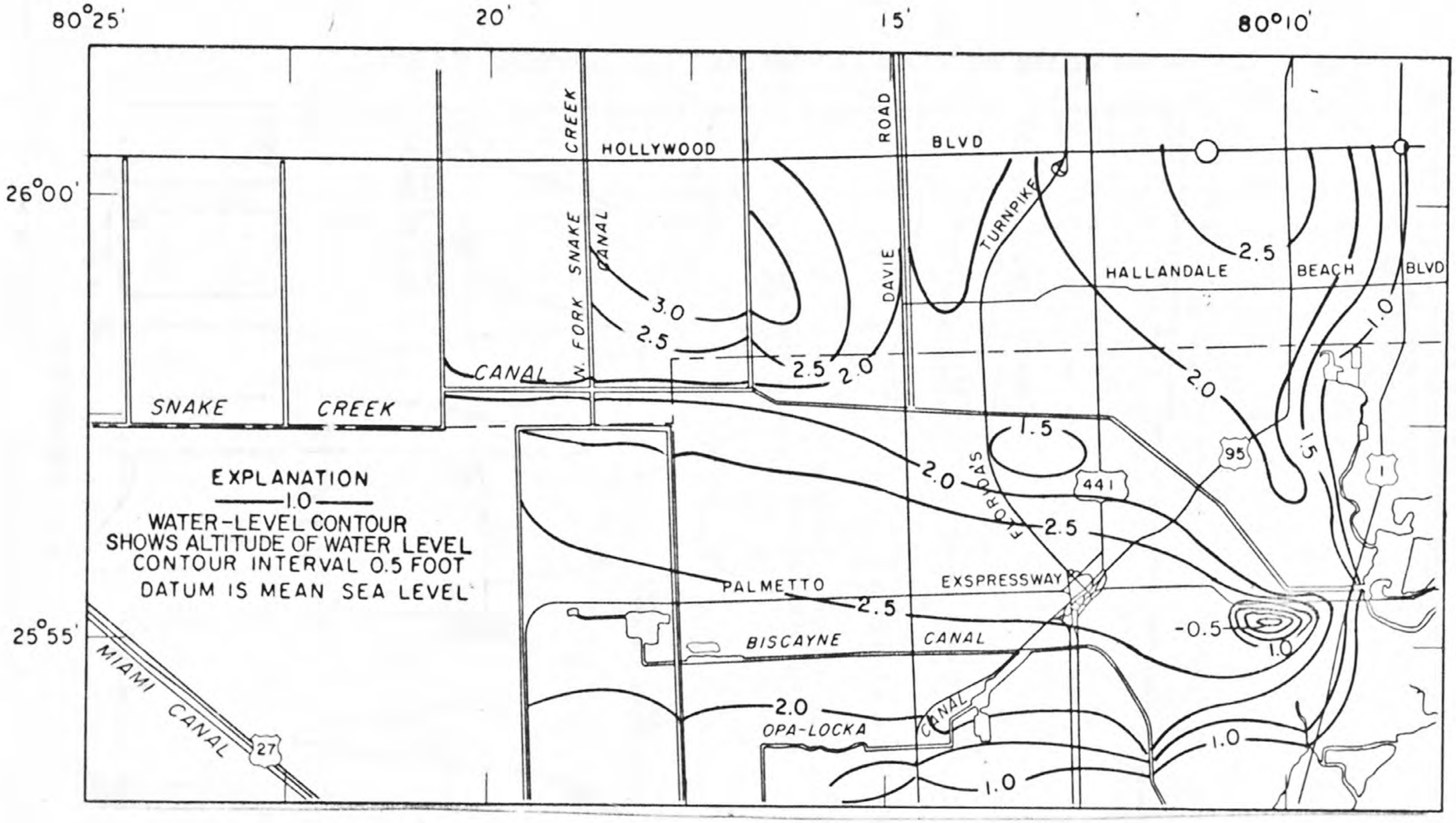

Figure 14. Part of the eastern segment of the Snake Creek Canal basin showing contours on the water table on September 17, 1971.

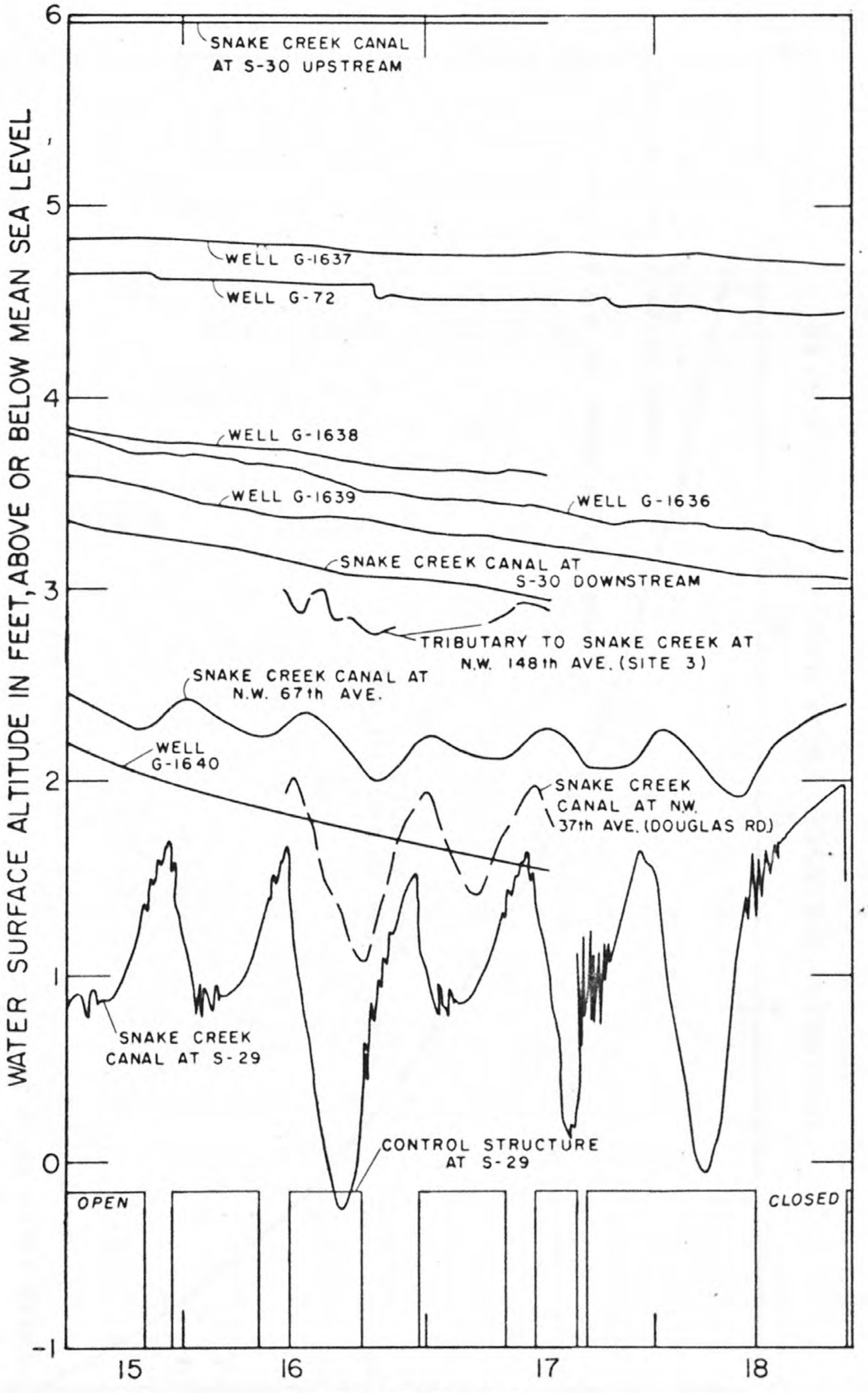

Figure 15. Hydrographs of selected wells and selected parts of the canals in the Snake Creek Canal basin.

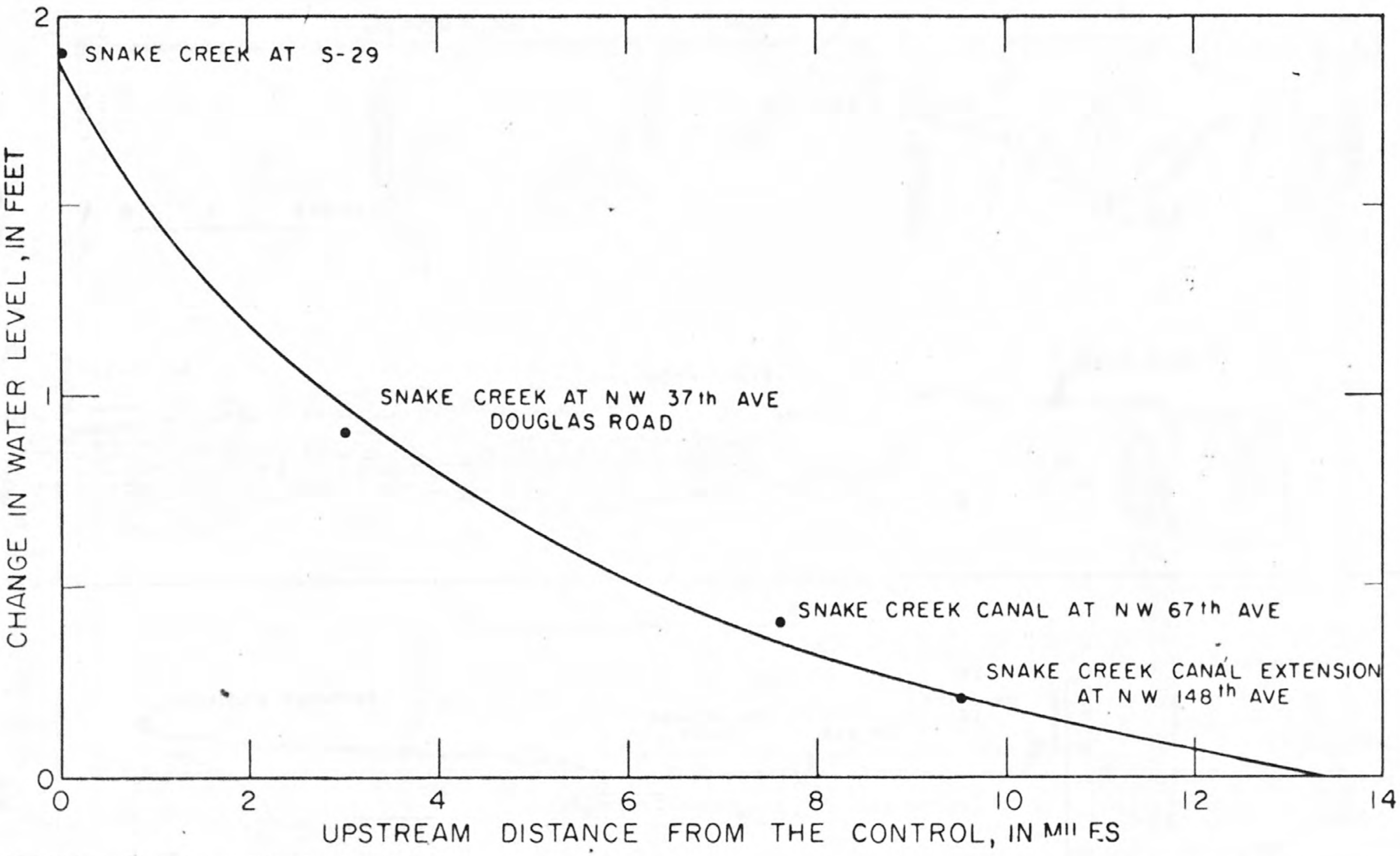

Figure 16. Change of water level in Snake Creek Canal as a function of distance from the control.

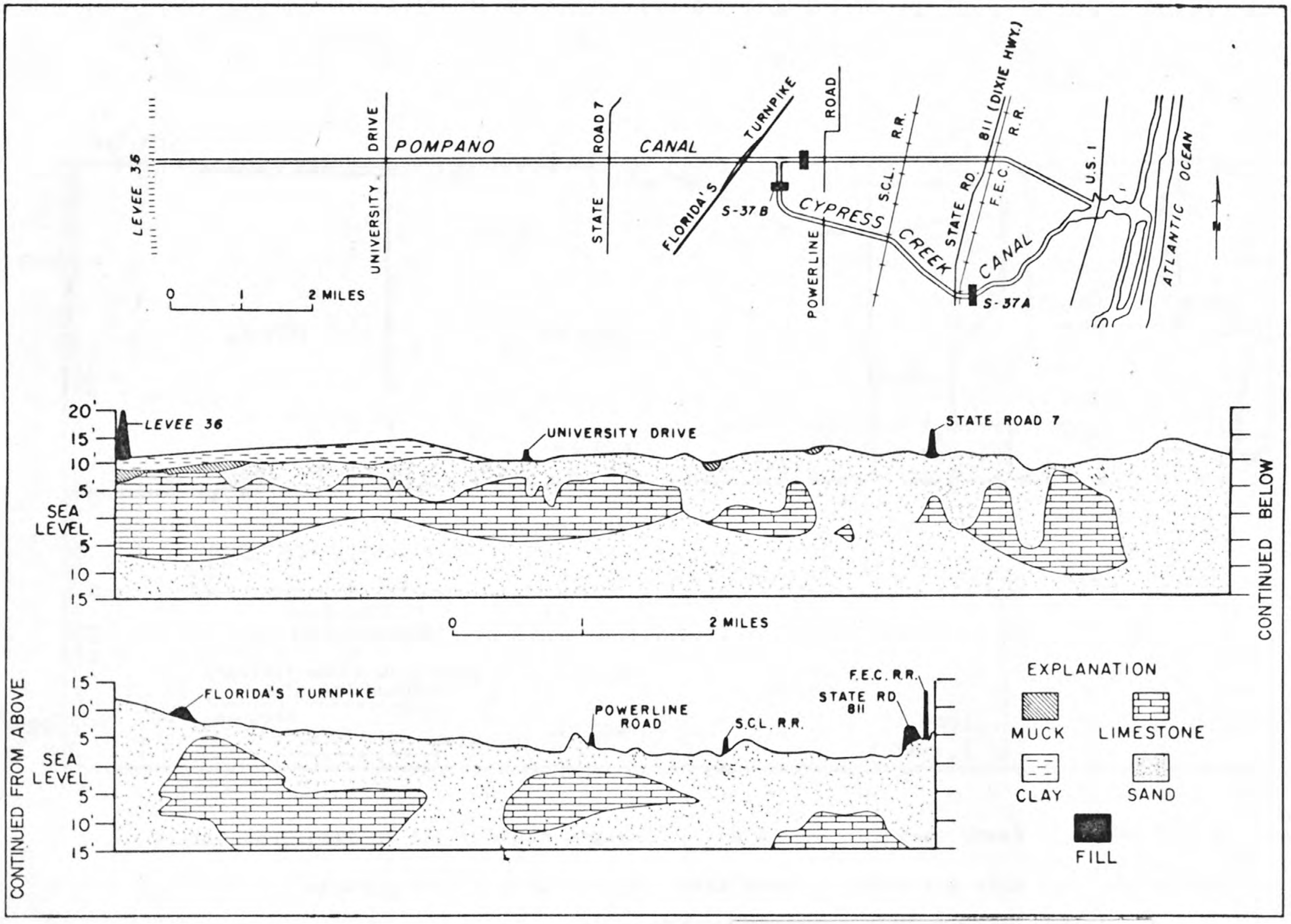

Figure 17. Lithologic section parallel to Pompano-

Cypress Creek Canal .

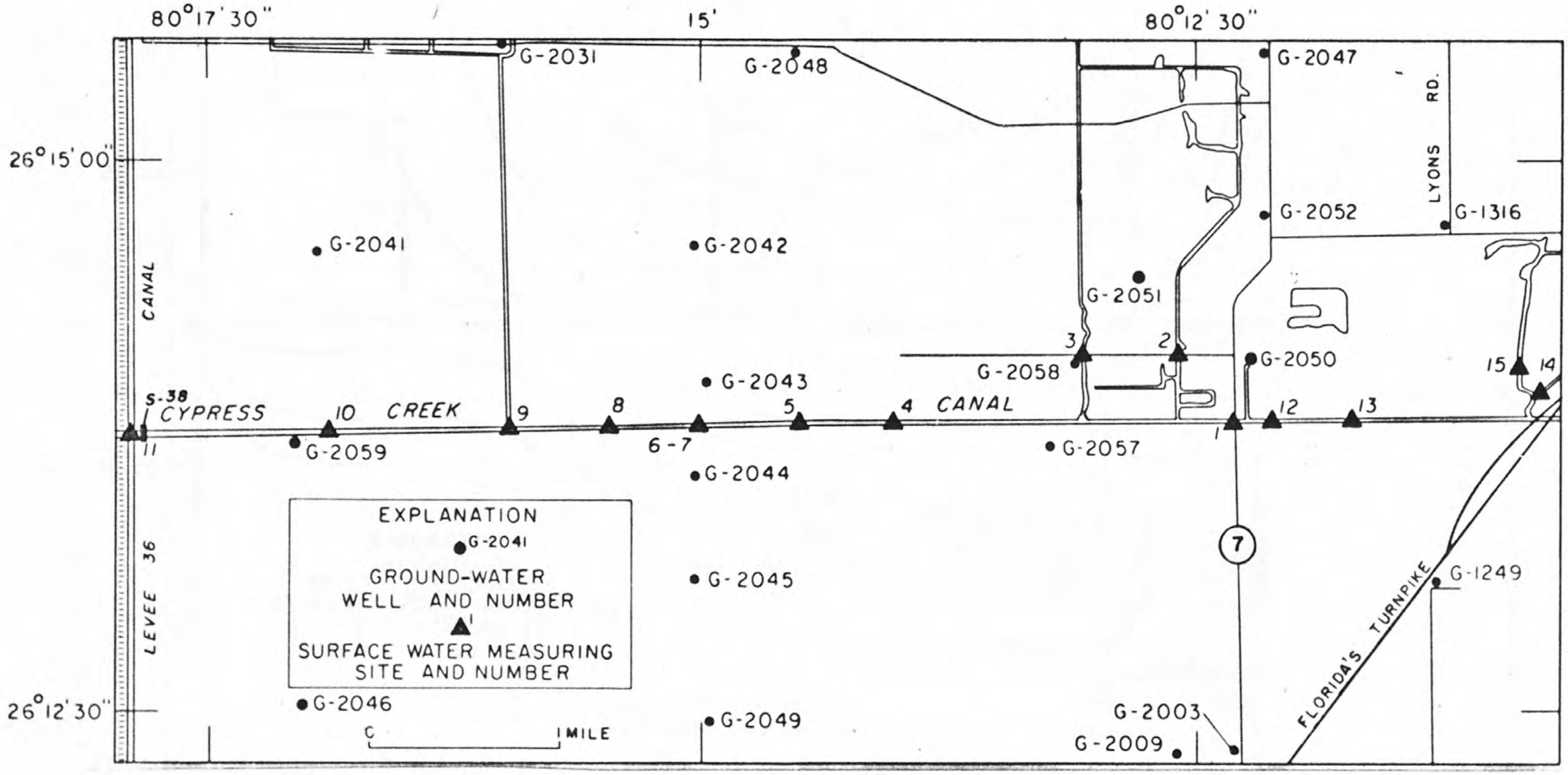

Figure 18. Part of the western segment of the Pompano-Cypress Creek Canal basin showing the location of the surface-water measuring sites and the wells.

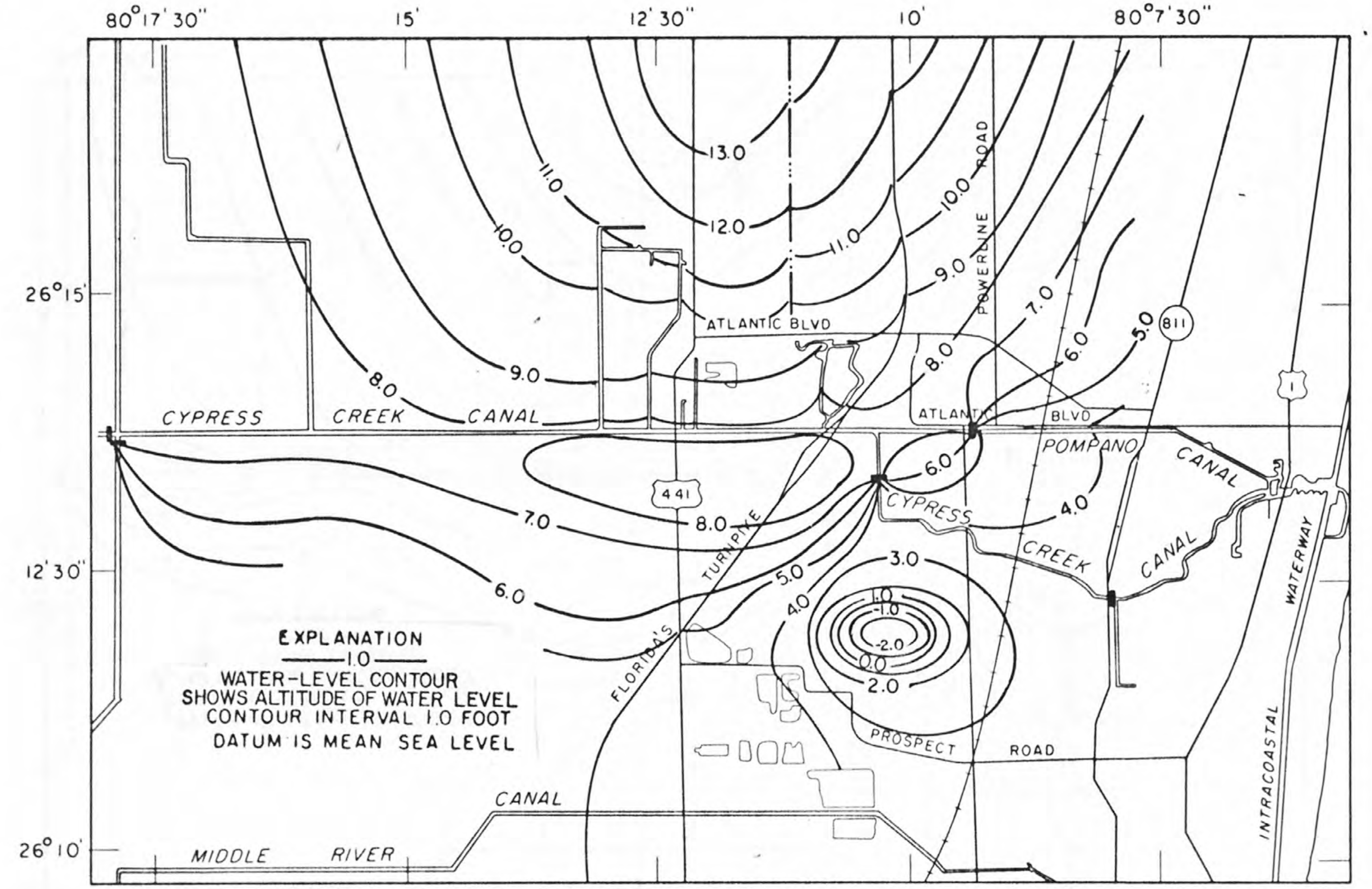

Figure 19. Part of the Pompano-Cypress Creek basin showing contours on the water table on July 24, 1972, before the control had been opened.

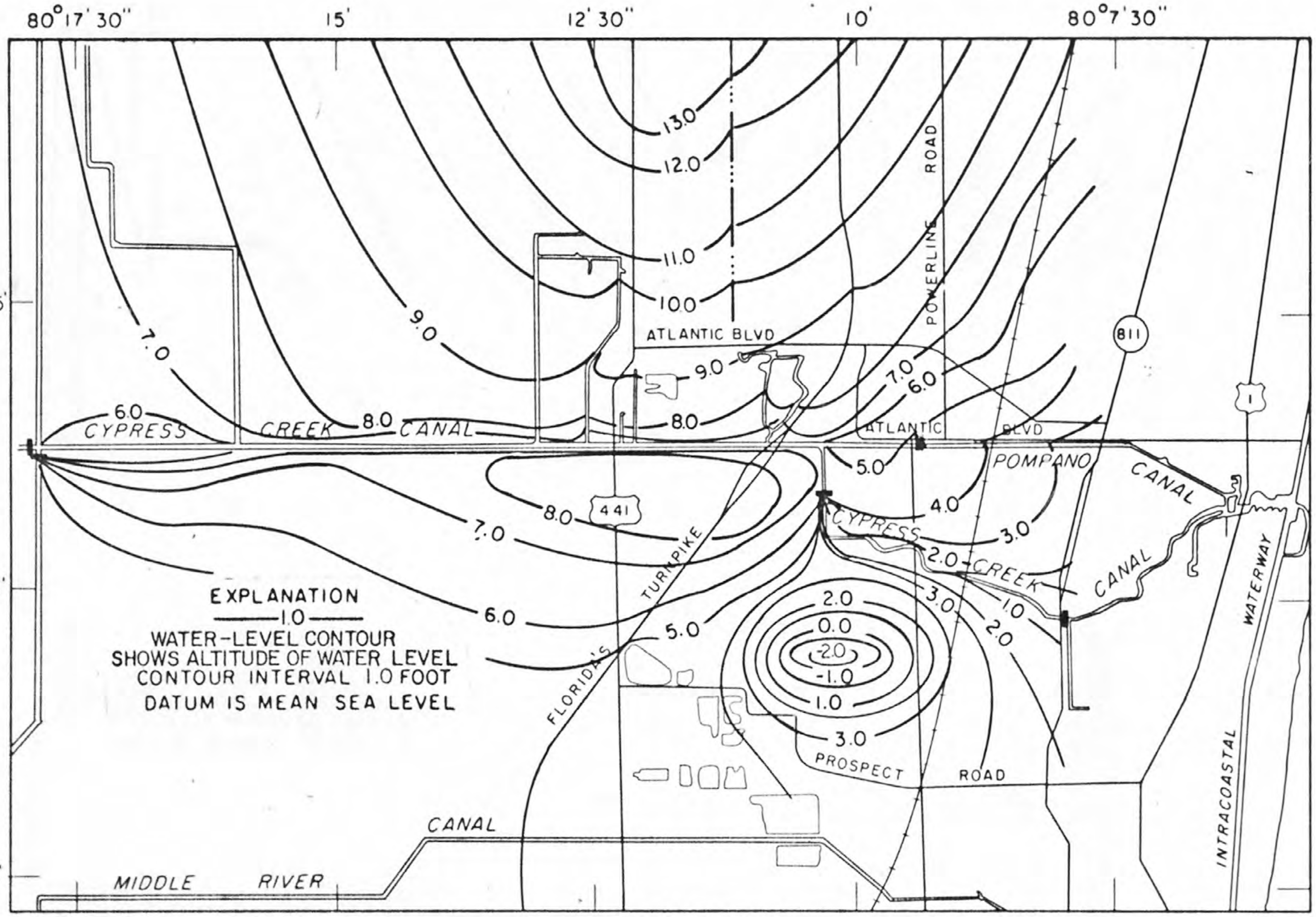

Figure 20. Part of the Pompano-Cypress Creek basin showing contours on the water table on July 24, 1972, after the control had been opened.

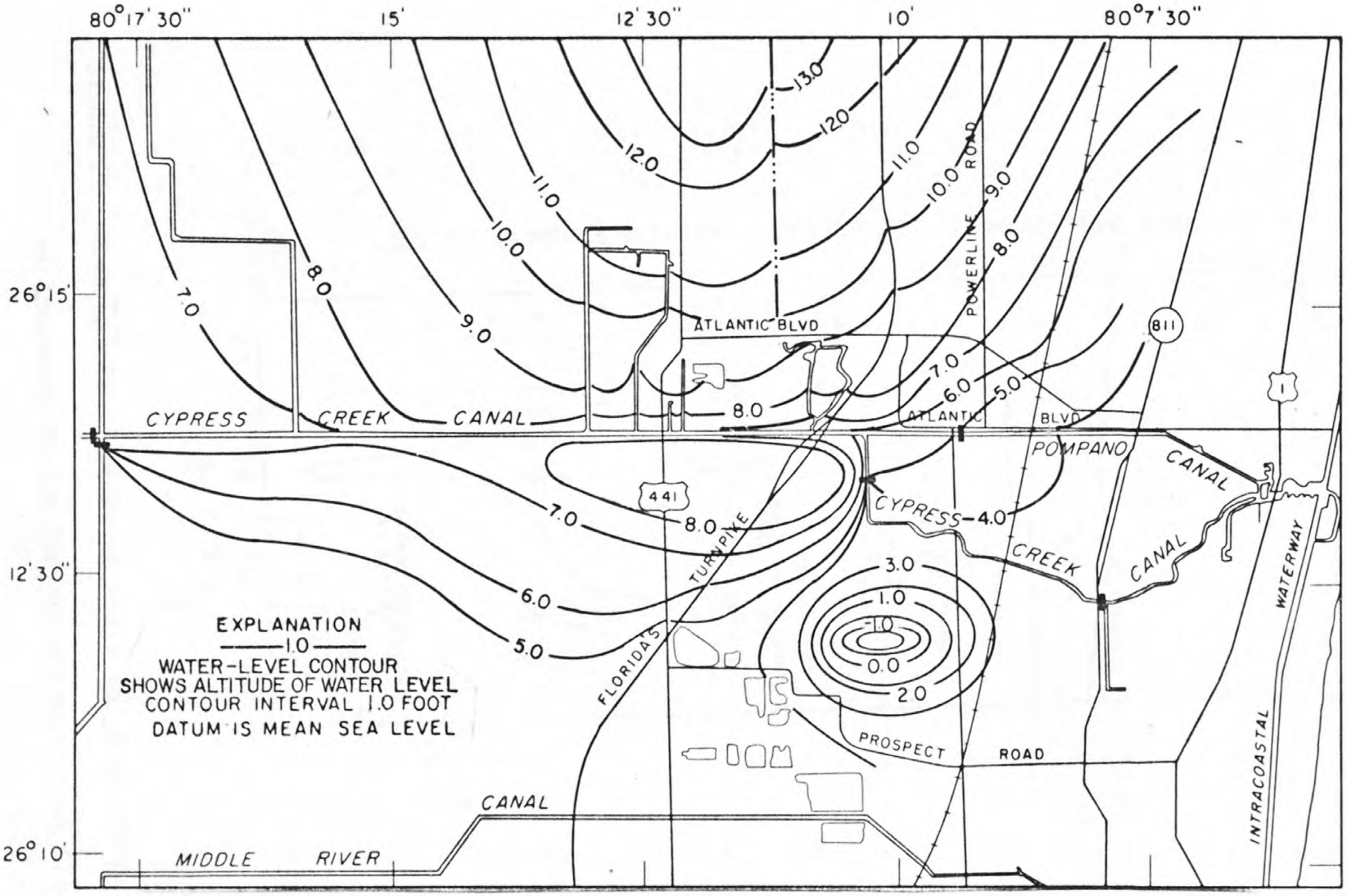

Figure 21. Part of the Pompano-Cypress Creek basin showing contours on the water table on July 25, 1972.

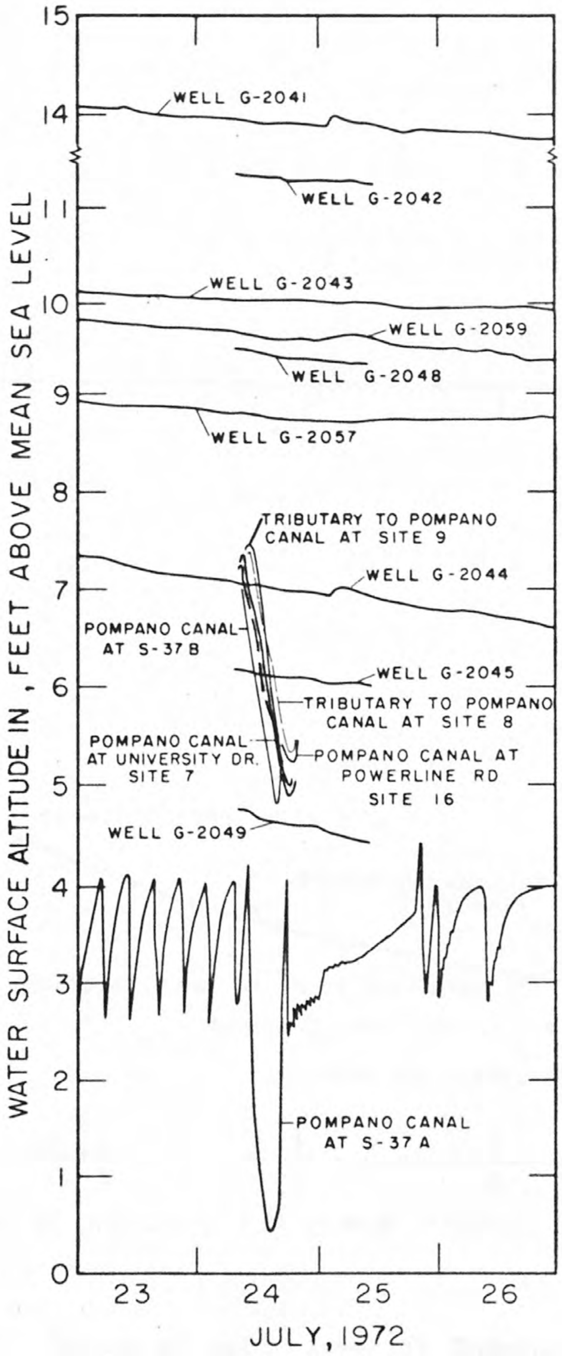

Figure 22. Hydrographs of selected wells and selected parts of the canal in the Pompano-Cypress Creek Canal basin.

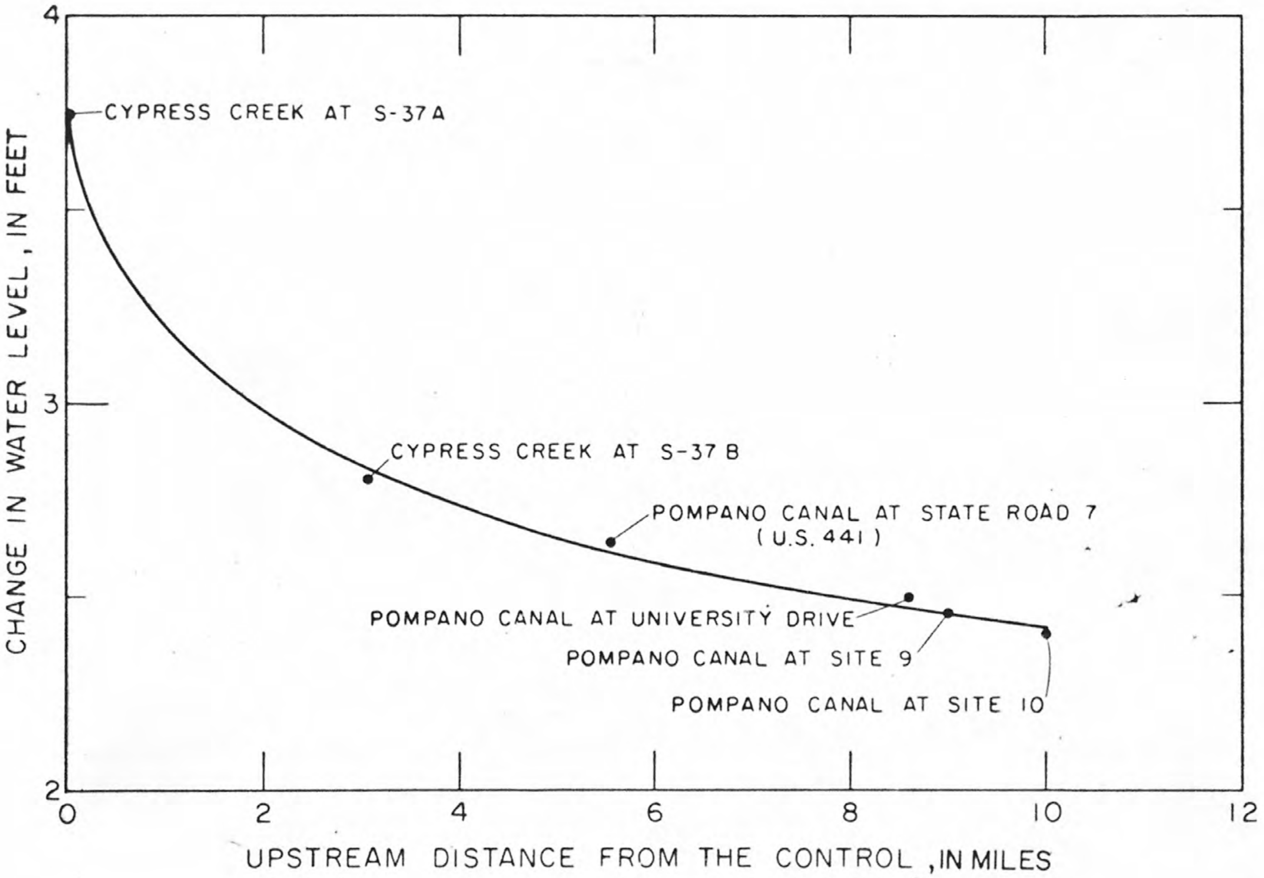

Figure 23. Change of water level in Pompano-Cypress Creek Canal as a function of distance from the control.