Prepared in cooperation with the
U.S. ENVIRONMENTAL PROTECTION AGENCY
and the
FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION

INTRODUCTION

Starting in July 1988, the U.S. Geological Survey, the U.S. Environmental Protection Agency, the Florida Department of Environmental Regulation, the Florida Electric Power Coordinating Group, and KBN Engineering and Applied Sciences undertook a study of the hydrologic and geochemical cycles of Lake Five-O to determine the effects of acidic precipitation on seepage lakes in northwestern Florida. Seepage lakes, as used in this report, refer to lakes that have no channelized surface inflow or outflow and, as a result, their water levels and volumes are controlled by precipitation, evaporation, and ground-water inflow and outflow.

Lake Five-O is a small seepage lake with an average surface area of 27 acres that is located approximately 18 miles north of Panama City, Fla., in north-central Bay County (fig. 1). Because the sands in the surficial aquifer surrounding Lake Five-O are highly weathered, there is very little acid neutralizing capacity (ANC) in the hydrologic system. The low ANC of the surficial aquifer and the low pH of the lake water make Lake Five-O ideal for studying the effects of acidic precipitation.

The U.S. Geological Survey's role in this cooperative study with the U.S. Environmental Protection Agency and Florida Department of Environmental Regulation of Lake Five-O, is to determine the hydrologic budget of the lake and to collect samples of lake water, adjacent ground water, and precipitation for chemical analysis.

Purpose and Scope

This report presents preliminary climatologic, hydrogeologic, limnologic, and water-quality data collected at Lake Five-O from July 1988 through October 1989. Continuous lake stage data were collected from July 1988 through October 1989. Collection of other types of hydrologic data began between July 1988 and February 1989. Data collected through October 1989 are presented in this report. Data presented to describe the hydrogeologic setting of Lake Five-O include a geologic column with gamma-ray log, an idealized cross section with ground-water flow patterns, a seismic reflection cross section, a bathymetric contour map of the lake, a graph showing monthly water levels in wells in the surficial aquifer and the Floridan aquifer system, daily rainfall and daily average lake level, and a table of hydraulic conductivity values based on slug tests for the surficial aquifer around the lake. Ground-water flow patterns around Lake Five-O are interpreted on the basis of water-table contour maps from a network of 53 observation wells. Water-quality data characterizing the chemical composition of Lake Five-O, ground water, and precipitation are also presented in this report.

Methods of Investigation

Between July 1988 and February 1989, 53 observation wells were installed in the study area to provide geologic information and water-level information on the underlying aquifers and to allow sampling of ground water. The locations of these wells are shown in figure 2. Most of the observation wells are installed into the upper part of the surficial aquifer and are used to monitor water-table elevations around the lake. In addition, deeper wells were drilled at four locations near the lake margin (piezometer clusters 1, 2, 3, 4) and at six sites (well clusters 1, 2, 3, 6, 13, and well 17) farther away from the lake. These wells are used to monitor head values deep in the surficial aquifer and in underlying hydrogeologic units. Grouped wells are indicated by a suffix of 1, 2, 3, 4, or 5 following the well number, for example, 13.1, 13.2, and 13.3. Near the lake margin, grouped wells are numbered sequentially with the prefix PZ, for example, PZ2.1 and PZ2.2. The third type of well is designated with the prefix LP, which indicates that the well is in the lakebed and completed at a depth of 5 to 15 feet below the lakebed. Monthly synoptic water-level measurements of the wells began in November 1988.

Other hydrologic and climatic data are also being collected at the site. A continuous-stage recorder and staff gage were installed in Lake Five-O in July 1988. Weekly collection of precipitation samples for water-quality analyses and semiquarterly sampling of ground water and lake water for analysis of selected constituents began in February 1989. Collection of climatologic data also began in February 1989 at two stations, a raft station on the lake and a land station northwest of the lake. Vertical water-temperature profiles of the lake were also recorded from the raft station.

PHYSICAL SETTING

Climate

Bay County has a humid climate with an annual average temperature at Panama City of 67 °F during the years 1968 through 1987. Mean monthly temperatures during the same period ranged from 51 °F in January to 81 °F in July. The mean annual rainfall from 1968 through 1987 at Panama City was 66 inches, with June, July, and August being the wettest months. The mean annual class A pan evaporation from 1963 to 1987 at the Milton Experiment Station in Escambia County, west of the study area, was 59.5 inches. Figure 3 shows the mean monthly rainfall at Panama City and uncorrected pan evaporation at the Milton Experiment Station from January 1960 through March 1989 (National Oceanic and Atmospheric Administration, 1960-89).

Physiography

Lake Five-O is in the Crystal Lake Karst area of the Dougherty Karst District of the Florida section (Brooks, 1981). This area consists of coastal "terrace" deposits that have lost their identity because of weathering and extensive karst development (Brooks, 1981). Irregularly shaped sinkholes and seepage lakes in the area discharge to the underlying Upper Floridan aquifer. These sinkhole features were developed by solution of the underlying limestone and collapse of overlying material into the solution chambers (Musgrove and others, 1965, p. 5).

As a result of karstic dissolution of underlying limestones, the originally flat to gently sloping coastal plain deposits of the study area, which now form a plateau, have been modified by irregularly distributed sinkholes that form nearly circular topographic depressions, many of which contain lakes. The plateau elevation in the study area averages 90 feet above sea level and the sinkhole lake elevations range from 45 to 53 feet above sea level. Slopes in the study area range from 0 to 5 percent on the plateau to 8 to 12 percent on the sides of the lake basin.

The steep-sided, nearly cone-shaped bathymetry of Lake Five-O is characteristic of a sinkhole lake. The lake depth increases steadily from the lake margin inward to a relatively flat bottom where the depth ranges from 40 to 45 feet (fig. 4). The mean lake depth at a stage of 48.0 feet above sea level was 30.8 feet and the maximum lake depth recorded was 48.5 feet in the southeast quadrant of the lake. At a presumed lake stage of 42.0 feet above sea level, the lake volume was calculated to be 800 acre-ft (acre-feet) based on a surface area of 24.8 acres that was determined from an aerial photograph taken during October 1986. The relation between lake volume and lake stage, extrapolated to a lake stage of 50.0 feet above sea level, is shown in figure 5.

A lobe-shaped rise in the lake bottom that originates on the north shore and continues into the center of the lake may be the result of sand erosion from access roads on that side of the lake.

Soils

The soils in the study area are predominantly the Lakeland soil series, a thermic, coated Typic Quartzipsamment. The Lakeland series soils are deep, well drained, very permeable, strongly acid to very strongly acid, and are formed on thick deposits of sandy marine or eolian sediment. The silt and clay content of these soils ranges from 5 to 10 percent and there are sporadic, organic-rich sand layers at depth (Duffee and others, 1984, p. 72).

Land Use

Land use in the study area is almost exclusively dedicated to pine tree cultivation with widely spaced homesteads. Although residential development is occurring around some lakes in the general area, development around lakes in the study area has been negligible and none has occurred around Lake Five-O. The forest in the study area was clearcut in the spring of 1988 and was replanted with sand pine (*Pinus clausa*) trees in January 1989.

HYDROGEOLOGIC SETTING

Geologic and borehole geophysical data collected at well 1.5, one of the deepest wells in the network, were used to construct a geologic column that describes the principal geologic and hydrogeologic units in the uppermost 140 feet of the strata of the study area (fig. 6). Using geologic data from a series of wells and a siesmic reflection survey, a hydrogeologic section (fig. 7) was constructed along section A-A′ (fig. 2) showing the hydrogeologic units in the basin and the probable direction of ground-water flow along a section transecting Lake Five-O. The three hydrogeologic units that influence the hydrology of Lake Five-O are the surficial aquifer, the intermediate confining unit, and the Upper Floridan aquifer. These units are described in the following sections.

Surficial Aquifer

Pliocene to Holocene-aged sands, which form the unconfined surficial aquifer in the study area, are composed of very porous and permeable unconsolidated white to light-tan silty quartz sands whose grains are fine to coarse and subangular with medium sphericity. Silt and clay-sized particles make up approximately 5 to 10 percent of the deposits. The surficial aquifer averages about 60 feet in thickness on the plateau of the study area.

Horizontal hydraulic conductivity (K) of surficial aquifer sediments was estimated from slug tests using the method of Bouwer and Rice (1976). The results of the test for selected wells are summarized in table 1. The distribution of hydraulic conductivity in the basin is relatively consistent and generally agrees with qualitative assessments of the drill cuttings. Northwest of the lake, the surficial sands are finer and generally have lower hydraulic conductivity values. South of the lake, the surficial sands are very coarse and have the highest hydraulic conductivity values in the study area. The mean of all values is 73 ft/d (feet per day), whereas the median is 59.5 ft/d. The range of hydraulic conductivities was 25 to 243 ft/d, and 19 of 22 values were between 33 and 96 ft/d.

Intermediate Confining Unit

In the study area, the surficial aquifer is underlain by the Jackson Bluff Formation of Pliocene age, which is approximately 40 feet thick, comprised of olive-green calcareous, sandy clay to clayey sand with large quantities of mollusk shell material. Seams of gray to white fossiliferous sandy limestone are present within the unit and phosphate and heavy minerals are commonly present in small quantities.

The gamma-ray borehole geophysical data for well 1.5 (fig. 4) shows the depths and thicknesses of clayey confining units above and below the limestone in the formation. The two peaks in gamma radiation shown in figure 6 correspond to elevated concentrations of potassium, radium, and other radionuclides that are commonly associated with phosphatic materials and clay minerals in these units.

Although the entire Jackson Bluff Formation is referred to as an intermediate confining unit, the confining properties may not be equally distributed in the formation. The calcareous shelly unit that occurs in the middle part of the Jackson Bluff Formation has hydraulic head values similar to those of the surficial aquifer. A large head difference occurs across the vertical interval that spans the lower clayey unit. This unit is a thin, dense, black, shelly clay layer occurring from 7 to 12 feet below sea level (fig. 4). The thin member at the base of the Jackson Bluff Formation seems to be the most effective confining unit in the study area because the head values in the Upper Floridan aquifer, which lies immediately below this unit, are 7 to 14 feet lower than those in the limestone that overlies the basal clay unit.

Floridan Aquifer System

The Floridan aquifer system, composed of up to 1,200 feet of Tertiary limestones and dolomites, underlies the intermediate confining unit in the study area from 100 to 120 feet below land surface. In the study area, the Floridan aquifer system is composed of, in descending order, the Bruce Creek Limestone, the Tampa Stage limestones, the Suwannee Limestone, and the Ocala Limestone (Schmidt and Clark, 1980, p. 74). The term "Bruce Creek Limestone" was used by the Florida Geological Survey (Schmidt and Clark, 1980); the term "Tampa Stage limestone" also is usage of the Florida Geological Survey. The transmissivity of the Floridan aquifer system in the study area is estimated to be 250,000 to 1 million ft^2/d (feet squared per day) (Bush and Johnston, 1988, pl. 2).

The Bruce Creek Limestone is the only formation of the Floridan aquifer system penetrated by wells in the study area. In Bay County, the Bruce Creek Limestone is a white to light yellow-gray moderately indurated, granular to calcarenitic micrite-cemented limestone containing up to 20 percent quartz sand and minor amounts of phosphorite, glauconite, and pyrite. The Bruce Creek Limestone strikes northwest-southeast, dips to the southwest, and pinches out in the northeastern corner of the county (Schmidt and Clark, 1980, p. 39-40).

HYDROLOGY OF LAKE FIVE-O

The basin that Lake Five-O occupies was formed either by gradual basinwide subsidence or by abrupt cover collapse of material overlying the Floridan aquifer system into one or more vertical dissolution channels in the limestone. The second process, in which clays and sands suddenly collapse into underlying voids in karstic limestones, can be catastrophic and is commonly associated with recently formed sinkholes in Florida (Sinclair and Stewart, 1985, Beck and Sinclair, 1986, p. 4).

The type of sinkhole formation affects the degree of hydraulic connection between the surficial and Floridan aquifers beneath the lake. A gradual subsidence of the basin would leave the beds overlying the Floridan relatively intact whereas the sudden collapse of overburden into solution channels in the limestone would produce large breaches in the intermediate confining unit, allowing unconsolidated material to move downward and greater seepage through the lake bottom. The region encompassing Lake Five-O has been described as an area where cover-collapse sinkholes dominate (Sinclair and Stewart, 1985).

Because of the presumed origin of Lake Five-O as a sinkhole, the geologic structure beneath the lake cannot be extrapolated from lithologic data gathered in the surrounding basin. The continuity of the intermediate confining unit beneath the lake was in question because the lake bottom is at a lower elevation than the top of the intermediate confining unit away from the lake (fig. 7). Therefore, a high-frequency seismic-reflection survey, adapted for use over water bodies, was conducted at Lake Five-O to determine the depth of the intermediate confining unit beneath the lake.

Data were collected along eight seismic lines across the lake. Penetration of more than 150 feet below the bottom of the lake— well below the top of the Floridan aquifer—was achieved on all lines. Figure 8 is a photograph of the seismic reflection trace that follows the same line across the lake as section A- A′ (figs. 2 and 7). The reflective surface indicated by this trace is interpreted to be the contact between the unconsolidated surficial sand and the clay-rich beds of the Jackson Bluff Formation. Preliminary evaluation of the data indicates that the confining unit is not continuous (fig. 6). Collapse features seem to be present in several locations, indicating that the basin was not formed by basinwide subsidence. The presence of collapse features indicates that the confining unit has been breached and that there probably is better hydraulic connection between the surficial aquifer and the Floridan aquifer beneath the lake than in the area surrounding the lake.

Heads within the surficial aquifer are consistently higher than the level of the lake and they form steep hydraulic gradients toward the lake in all areas except to the northwest of the lake (figs. 9 and 10). From the steep hydraulic gradients in the surficial aquifer around the lake and the high hydraulic conductivities of these deposits, one can infer that a large part of the water in the lake is derived from ground water from the surficial aquifer (see figs. 7, 9, 10, and table 1).

The daily stage of Lake Five-O, the daily rainfall in inches, and the vertical distribution of hydraulic head in hydrogeologic units underlying the study area are shown in figure 11. The lake stage fluctuated about 5 feet seasonally between a minimum value of 44.47 feet in the late spring of 1989 to a maximum of 50.29 feet in October 1989. The seasonal variations in lake stage and ground-water levels respond to the seasonal distribution of rainfall, but in a delayed manner, indicating the importance of ground water inflow in the hydrologic budget of the lake (fig. 12).

Ground-water levels indicate there is little vertical head gradient in the surficial aquifer (indicating primarily lateral flow), and that heads in the permeable zones of the intermediate confining unit are nearly the same as in the surficial aquifer. Heads in the Upper Floridan aquifer in the study area range from 5 to 19 feet below heads in the overlying surficial aquifer, which indicates that the Upper Floridan aquifer is recharged through any breaches in the intermediate confining unit which separate it from the overlying surficial aquifer.

Preliminary information on the areal and vertical distribution of heads in the aquifers surrounding Lake Five-O indicates that the lake receives ground-water inflow from the surrounding surficial aquifer. Both the lake and the surrounding surficial aquifer are recharging the Upper Floridan aquifer. The probability of breaches in the confining unit below the lake indicates that the bottom of Lake Five-O is a preferential area of recharge to the Upper Floridan aquifer.

WATER QUALITY

The mean concentrations of selected dissolved constituents in precipitation, lake water, and ground-water samples collected at Lake Five-O between July 1987 and November 1989 are shown in table 2. The most chemically dilute water in the study area is, as expected, precipitation. Precipitation collected at the site was acidic, with a mean pH of 4.6, and its dissolved constituents are predominantly sulfate, nitrate, sodium, and chloride. Sulfate and nitrate in precipitation are usually related to fossil fuel combustion byproducts, whereas sodium and chloride are often related to proximity to oceanic bodies such as the Gulf of Mexico.

Because ground water from the surficial aquifer is a major contributor to the water budget of the lake, the quality of water in the lake is strongly influenced by the quality of ground water in the surficial aquifer. Water in Lake Five-O has higher concentrations of calcium, magnesium, sodium, potassium, chloride, sulfate, and nitrate, but lower concentrations of ammonium than wet precipitation. Mean concentrations of selected chemical constituents in 22 lake samples from the epilimnion above the thermocline and 2 from the hypolimnion below the thermocline are shown in table 2. The term "thermocline" describes a layer of water where the temperature gradient is greater than in the warmer layer above and in the colder layer below. Higher concentrations of calcium, magnesium, and sodium in the lake water may be due to evapoconcentration and enrichment from inflowing ground water from the surficial aquifer. Higher concentrations of nitrate, sulfate, dissolved organic carbon, and potassium in ground water may be due to leachates from timber residues on the land surface enriching shallow ground water with these nutrients. Lower concentrations of ammonium in the lake than in precipitation may be due to plant uptake, nitrification to nitrate, or algal uptake of ammonium in the lake.

The lake is of sufficient depth to develop thermal stratification in the summers and winters. Three thermal profiles of Lake Five- O, based on daily mean thermocouple data, are shown in figure 13. These profiles show warming throughout the lake from early spring to summer and subsequent cooling of the epilimnion in the autumn. As water temperature increased during spring and summer, a steeper thermocline occurred at progressively greater depths. The fluctuations in temperature between depths of 7.5 and 13.5 feet on March 22, 1989, may be caused by mixing between a rapidly warming epilimnion and the cooler hypolimnion. On October 24, 1989, the temperature of Lake Five-O was nearly uniform with depth and the lake was probably well mixed.

Ground water in the surficial aquifer is low in dissolved inorganic solids, and the major differences between the water quality of the aquifer and the lake are higher concentrations of calcium, silica, and dissolved organic carbon in water from the aquifer.

Waters from the intermediate confining unit, because of contact with its calcareous materials and clay minerals, have much higher concentrations of calcium, sulfate, silica, potassium, and aluminum than waters of the surficial aquifer. Water in the intermediate confining unit has lower concentrations of chloride, nitrate, and dissolved organic carbon than waters of the surficial aquifer. Water in the Upper Floridan aquifer in the study area is similiar in quality to that from the intermediate confining unit. The major difference is a higher concentration of sulfate in water from the Upper Floridan aquifer.

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Conversion Factors and Abbreviations

The inch-pound units used in this report may be converted to metric (International System) units by the following factors:

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
foot/day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
square foot (ft^2)	0.0929	square meter (m^2)
acre	0.4047	hectare (ha)
acre-foot (acre-ft)	1,233.5	cubic meter (m^3)
mile (mi)	1.609	kilometer (km)

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows: °C = 5/9 (°F-32)

µS/cm = microsiemens per centimeter.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

Table 1.—Hydraulic conductivity values for selected wells in the surficial aquifer, Lake Five-O

Well number (in fig. 2)	Hydraulic conductivity K (feet per day)
1.1	68
1.2	69
2.1	243
2.2	60
3.1	47
3.2	186
4	91
5	72
6.2	85
7	40
8	40
12	79
13.2	59
16	96
18	49
21	41
23	33
25	66
26	33
27	44
29	71
31	25
Mean	73
Median	60

Table 2.—Mean concentrations of selected dissolved constituents and mean values of physical properties of wet precipitation, lakewater, and ground water at Lake Five-O

[Results in micrograms per liter except for pH and conductance]

Chemical constituent or property	Precipitation[1]	Lake[2]	Surficial[3] aquifer	Confining[4] unit	Floridan[5] aquifer system
Calcium[6]	91	360	580	15,950	13,200
Magnesium[6]	59	270	400	494	683
Sodium[6]	380	1,160	1,430	1,570	1,575
Potassium[7]	34	150	300	892	623
Chloride[8]	767	2,180	2,070	1,735	1,790
Sulfate[8]	1,470	2,140	1,530	5,222	10,655
Nitrate[8] (as NO_3)	738	160	2,850	808	0
Ammonium[9] (as NH_4)	170	6	5	9	12
Aluminium[10]	-	19	22	67	71
Manganese[6]	-	3	13	0	1
Iron[6]	-	1	2	0	0
Silica[6]	-	150	1,280	4,050	4,950
Dissolved organic carbon[11]	-	1,200	2,030	600	1,050
Specific conductance (microsiemens per centimeter at 25 °C)	16.5	16.1	20.4	95.9	84.8
pH (units)	4.6	5.1	4.6	9.5	9.3

[1]Volume weighted weekly samples from 5/30/89 to 11/29/89
[2]Samples from 7/87 to 10/11/89
[3]Samples from surficial aquifer wells 13.2, 20, PZ1.1, PZ2.1, PZ2.2, PZ3.1, LP1, PZ4.1, and PZ4.2 from 3/22/89 to 10/11/89
[4]Sample from confining unit well 17 on 7/19/89, and 10/11/89
[5]Sample from Floridan aquifer system well 13.3 on 7/19/89 and 10/11/89
[6]Inductively-coupled plasma method
[7]Flame emission method
[8]Ion chromatography method
[9]Autoanalyzer colorimetric method
[10]Graphite furnace method
[11]Ultraviolet persulfate method

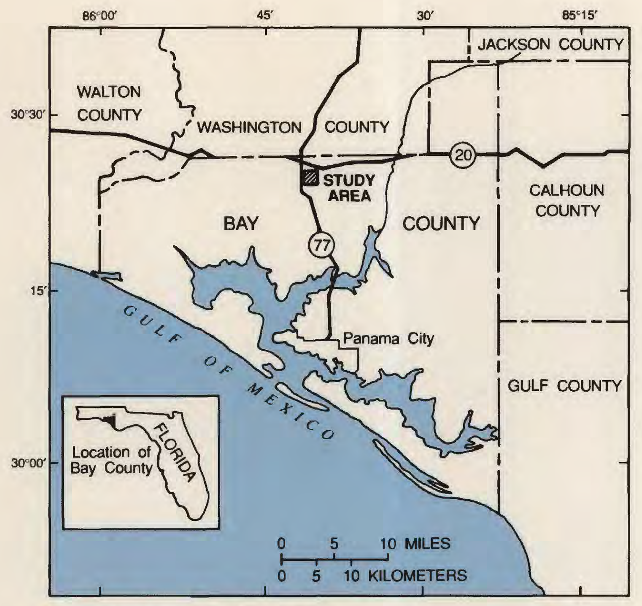

Figure 1. Location of study area.

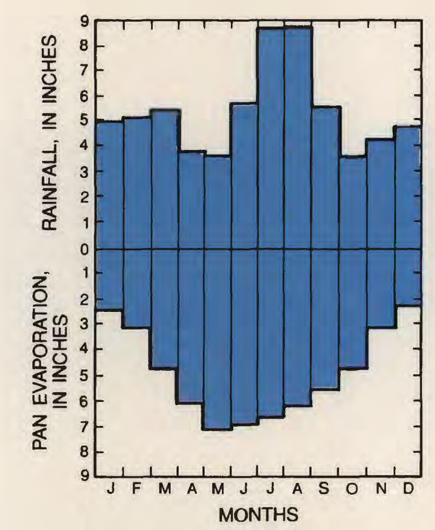

Figure 3. Mean monthly rainfall at Panama City and pan evaporation (uncorrected) at Milton Experiment Station.

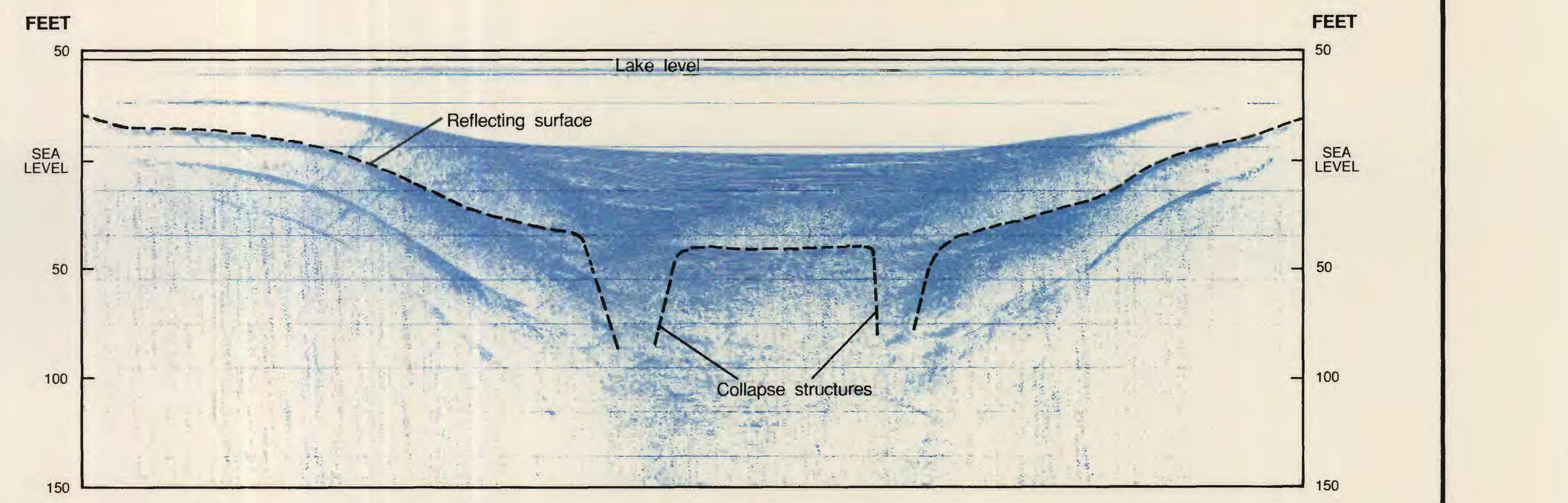

Figure 8. Seismic reflection returns along section A-A′ across Lake Five-O.

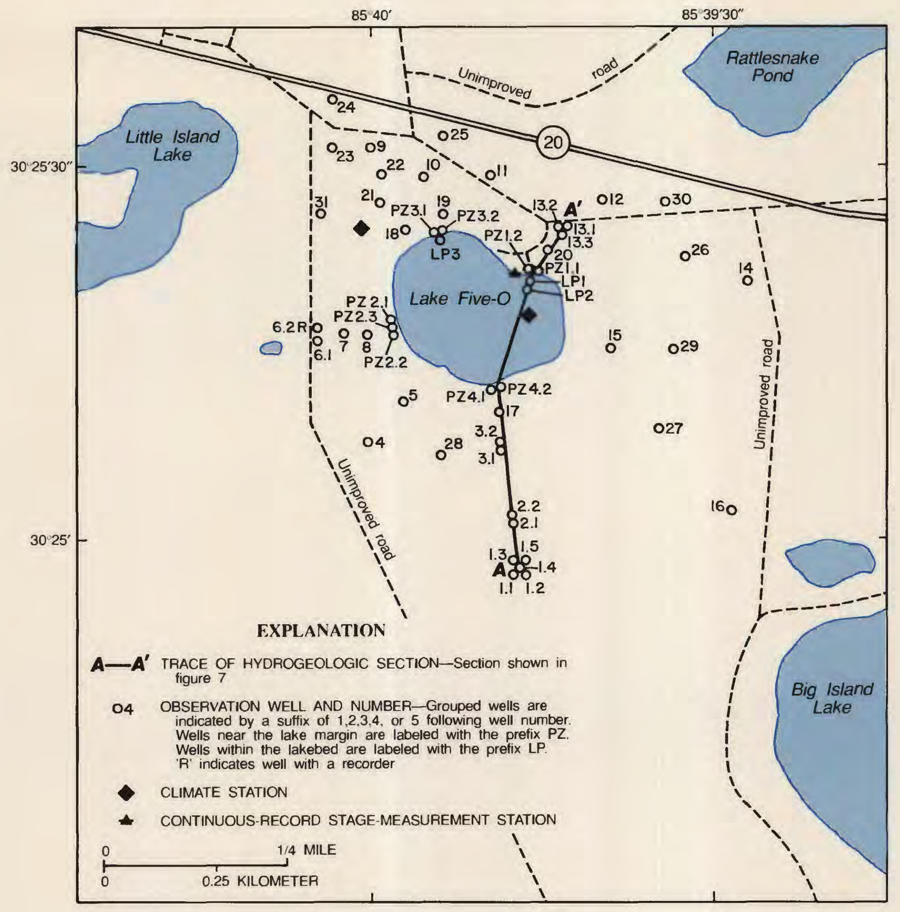

Figure 2. Study-area features and data-collection sites.

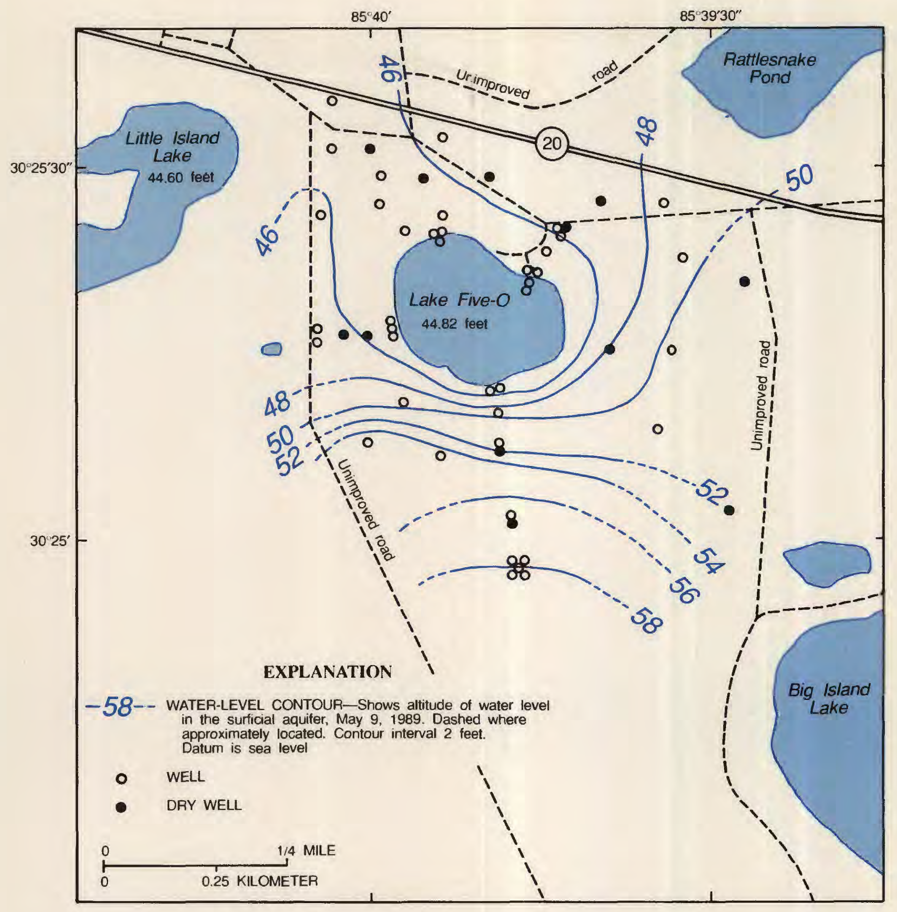

Figure 9. Water levels in the surficial aquifer, May 9, 1989.

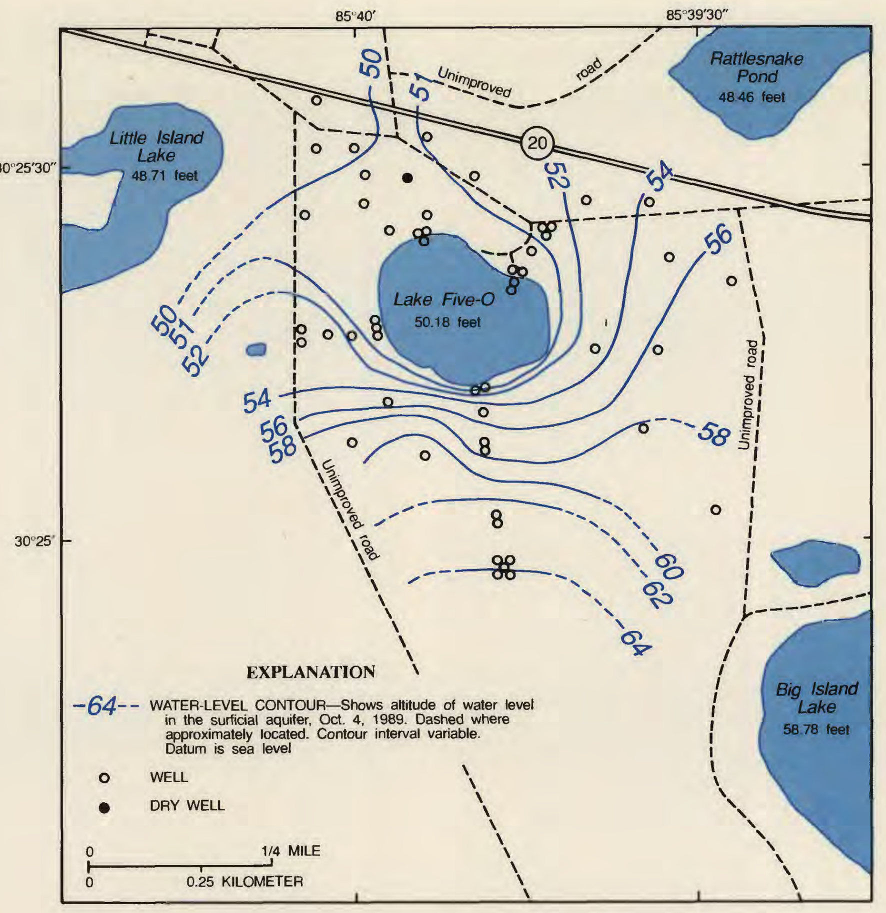

Figure 10. Water levels in the surficial aquifer, October 4, 1989.

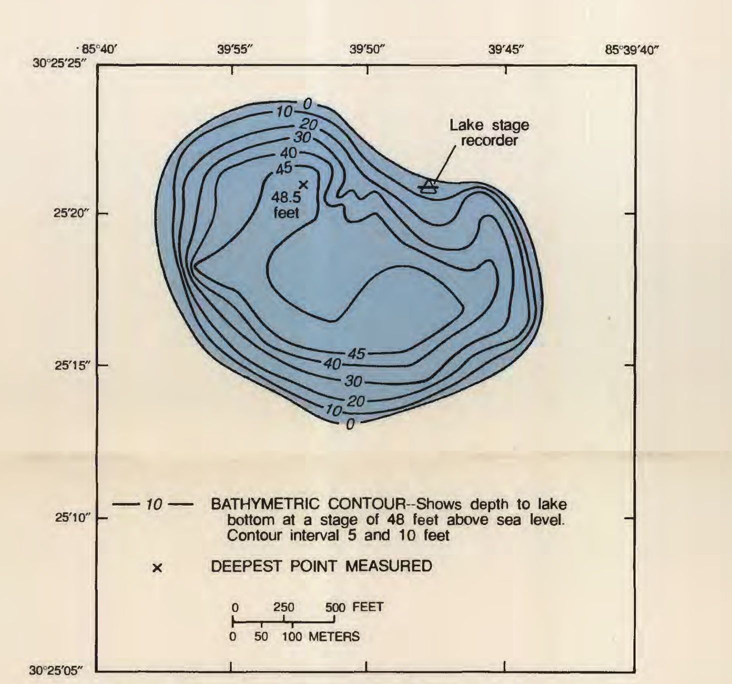

Figure 4. Bathymetric contours of Lake Five-O.

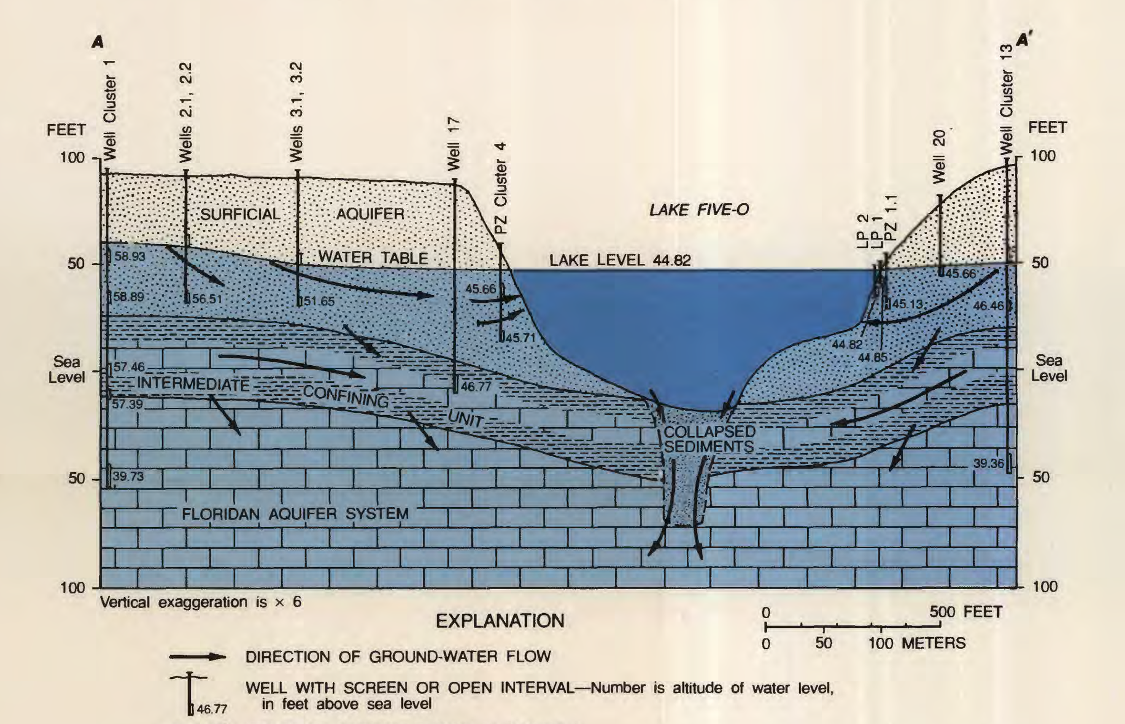

Figure 7. Hydrogeologic section A-A′ and generalized flow system, based on water levels on May 9, 1989, Lake Five-O and vicinity.

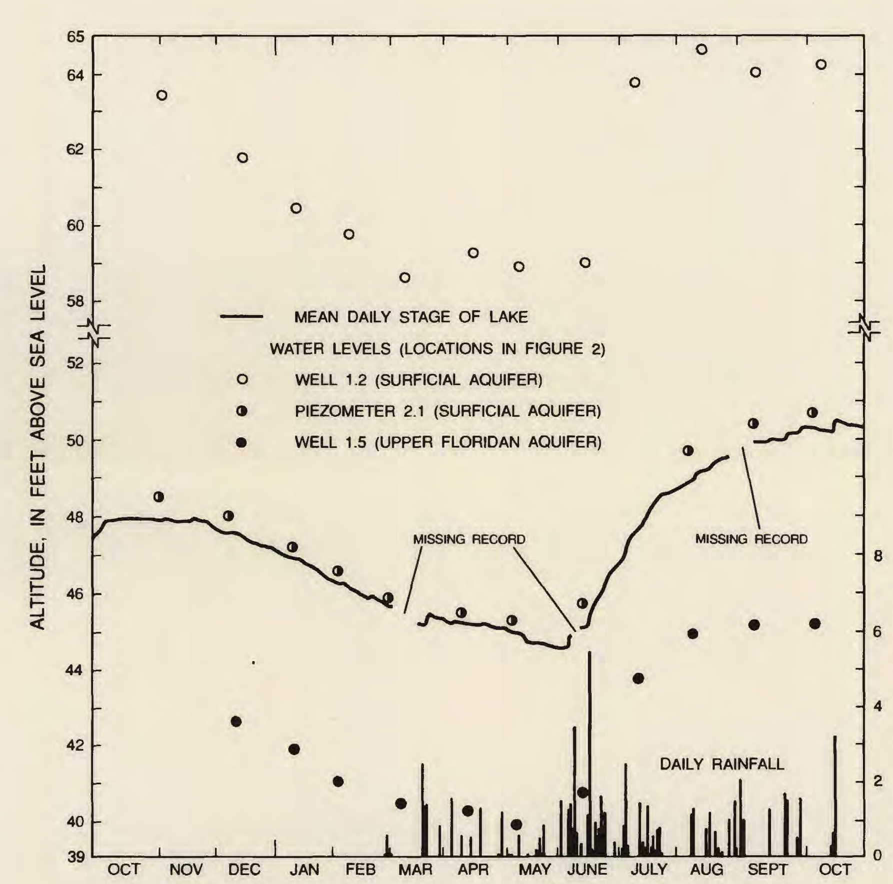

Figure 11. Water stage and rainfall at Lake Five-O and ground-water levels in the vicinity of the lake.

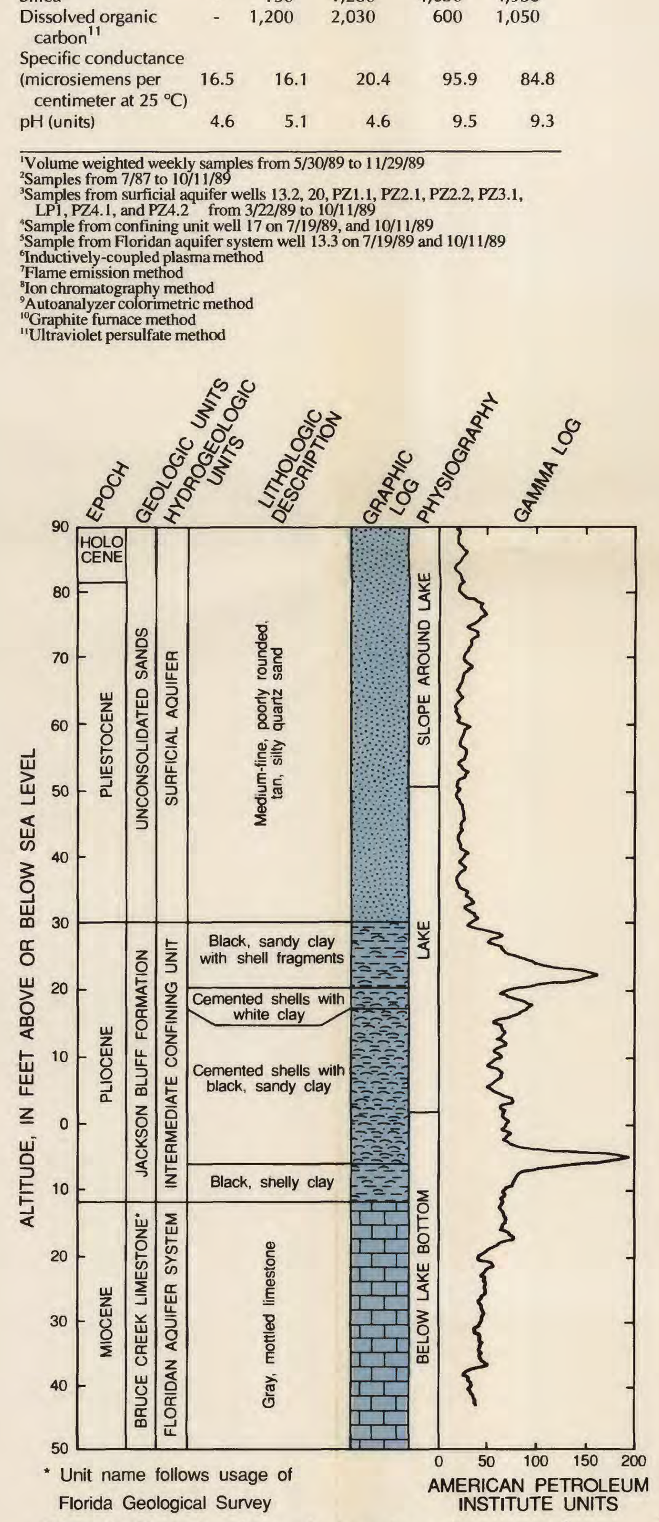

Figure 6. Geologic column, physiography, and gamma-ray log at well 1.5.

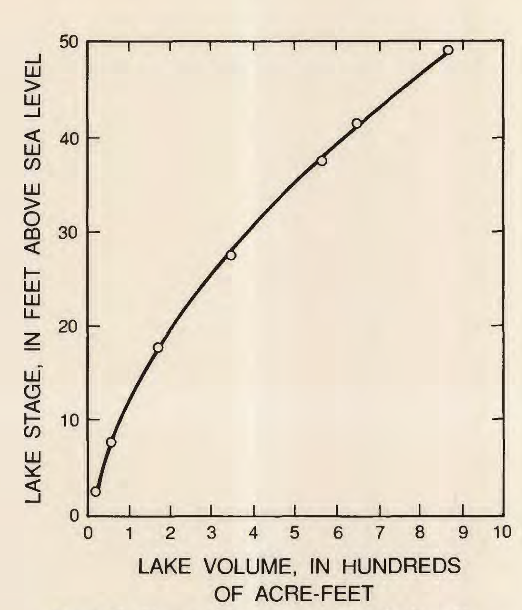

Figure 5. Stage-volume relation for Lake Five-O.

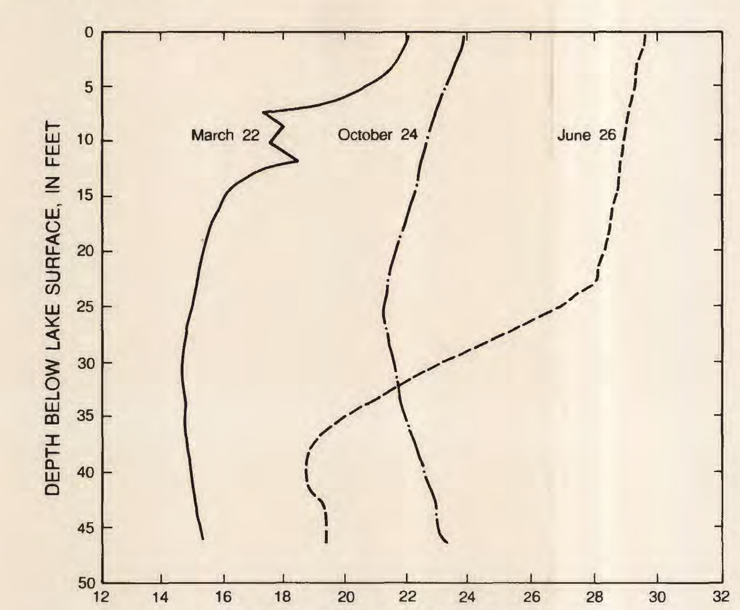

Figure 13. Temperatures and depths in Lake Five-O on March 22, June 26, and October 24, 1989.

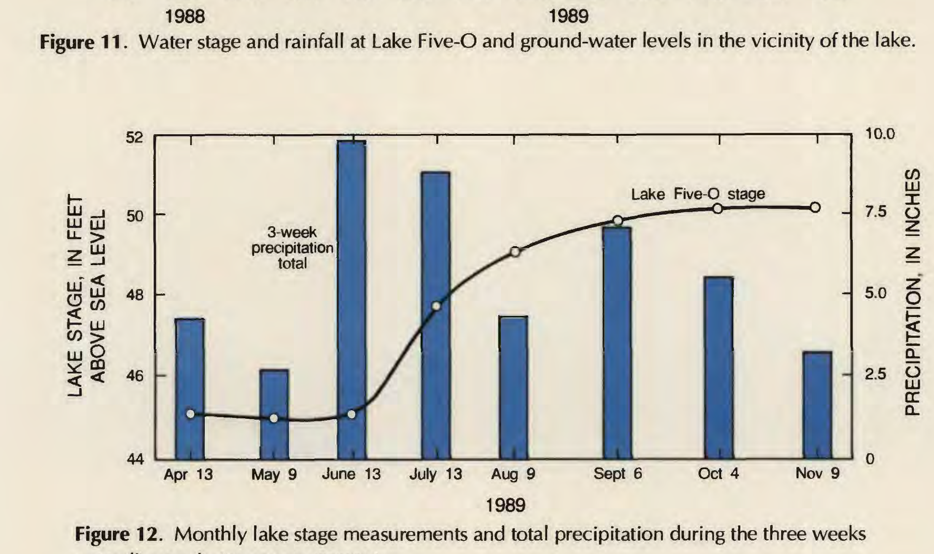

Figure 12. Monthly lake stage measurements and total precipitation during the three weeks preceding each stage measurement.

PRELIMINARY REPORT ON THE HYDROGEOLOGY OF LAKE FIVE-O AND VICINITY, BAY COUNTY, FLORIDA

By William J. Andrews, James P. Oliveros, and Jerilyn J. Collins

1990

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