STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Harmon Shields, *Executive Director*

DIVISION OF RESOURCE MANAGEMENT
Charles M. Sanders, *Director*

BUREAU OF GEOLOGY
Charles W. Hendry, *Chief*

REPORT OF INVESTIGATIONS NO. 81

HYDROLOGY OF THREE SINKHOLE BASINS IN SOUTHWESTERN SEMINOLE COUNTY, FLORIDA

By
Warren Anderson and G. H. Hughes
U. S. Geological Survey

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
BUREAU OF GEOLOGY
DIVISION OF RESOURCE MANAGEMENT
FLORIDA DEPARTMENT OF NATURAL RESOURCES
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LETTER OF TRANSMITTAL

Bureau of Geology
Tallahassee
November 3, 1975

Governor Reubin O'D. Askew, Chairman
Florida Department of Natural Resources
Tallahassee, FL 32304

Dear Governor Askew:

The Bureau of Geology, Division of Resource Management, Department of Natural Resources, is publishing as its Report of Investigations No. 81, the "Hydrology of Three Sinkhole Basins in Southwestern Seminole County, Florida".

The recent spread of urban development has tended to encroach on the flood plains of lakes in these sinkhole basins and cause concern over the flood hazard that results. The purpose of this investigation was to document or evaluate 1) the highest known lake levels in the sinkhole area; 2) the interrelation of topography, geology, climate, and hydrology as they pertain to water level fluctuations; 3) the effects of cultural development on water levels, and 4) the possible methods of controlling lake levels.

This report contains information that should be useful to local officials in planning for maximum utilization of land resources of the area with minimum risk of flood damage to the attendant cultural development or of degradation of the hydrologic system.

Sincerely,

C. W. Hendry, Jr., *Chief*

Completed manuscript received
June 16, 1975

Printed for the

Florida Department of Natural Resources
Division of Resource Management
Bureau of Geology

Tallahassee
1975

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HYDROLOGY OF THREE SINKHOLE BASINS IN SOUTHWESTERN SEMINOLE COUNTY, FLORIDA

by

Warren Anderson and G. H. Hughes

ABSTRACT

The southwestern part of Seminole County—in east-central Florida—is characterized by sinkholes formed by the subsidence of surficial deposits into solution cavities in the underlying limestone deposits. The area includes three sinkhole basins created by such subsidence: Cranes Roost, Palm Springs, and Grace Lake.

Cranes Roost basin (drainage area, 5.02 square miles) contains a closed drainage system of lakes and swamps—including Lakes Adelaide, Florida, and Mobile—that terminates at Cranes Roost sink. It also contains Lake Orienta and two unnamed sinks which do not overflow into Cranes Roost sink.

Palm Springs basin (drainage area, 1.77 square miles) includes Lake Marion, Eleventh Hole Pond, and several small unconnected sinks.

Grace Lake basin (drainage area, 1.64 square miles) includes Island Lake which overflows into Grace Lake.

The recent spread of urban development has tended to encroach on the flood plains of lakes in these sinkhole basins and cause concern over the flood hazard that results. An investigation was made of the area to document the highest known lake levels, to examine possible effects of urbanization with regard to increasing the flood hazard, and to appraise the possibilities of controlling lake levels to reduce or limit the flood hazard.

The highest lake stages of record in the three sinkhole basins occurred in September 1960. Analyses of the hydrologic relations between lake stages, ground-water levels, stream discharges, and rainfall in the area indicated that the lake stages of September 1960 probably were the highest attained since at least 1895.

Cultural development that increases the percentage of a sink basin covered by impervious materials will cause more rapid runoff of a larger part of the rainfall in the basin. Thus, as development progresses, lake stages seldom reached under natural conditions may be reached more frequently unless the lake levels are controlled.

In Cranes Roost basin, the levels of Lakes Mobile, Adelaide, and Florida could be controlled by enlarging their surface outlets and adding control structures; however, such measures might be ineffective unless the level of Cranes Roost also was controlled. The level of Cranes Roost could be controlled by removal of water by pumping or by providing a surface outlet; pumping might be ineffective during extreme wet periods because of the sudden surface inflow from upstream lakes and the potential for ground-water inflow from the Floridan aquifer. The level of Lake Orienta could be controlled by removal of water by pumping or by providing a surface outlet.

In the Palm Springs sink basin, the levels of Lake Marion and the several small sinks could be controlled by removal of water by pumping or by providing surface outlets. For the several sinks, however, providing a surface outlet would require an extensive excavation and pumping might prove impractical because of seepage induced from the Floridan aquifer.

The level of Island Lake—in Grace Lake sink basin—could be controlled by enlarging its surface outlet and providing a control structure. The peak stage of Grace Lake could be reduced by lowering its outlet to the north, but release of water during wet periods might cause downstream flooding.

INTRODUCTION

Seminole County, an area of 321 square miles in east central Florida, has developed rapidly since the mid-1960's, especially in the southern part adjacent to the Orlando metropolitan area in Orange County. Land values are rising with consequent pressure to develop land in the limestone sinkhole area in southwestern Seminole County. Knowledge of physiographic and hydrologic characteristics of this area is needed to evaluate both the suitability of the lands for cultural development and the measures that may be taken by local officials to enhance the suitability of the lands. Consequently, the U. S. Geological Survey in cooperation with the Board of County Commissioners conducted an investigation of the sinkhole area from October 1, 1970 to September 30, 1971.

Purpose and Scope

The purpose of the investigation was to document or evaluate:

(1) the highest known lake levels in the sinkhole area; (2) the interrelation of topography, geology, climate, and hydrology as they pertain to water-level fluctuations; (3) the effects of cultural development on water levels; and (4) the possible methods of controlling lake levels. This report contains information that should be useful to local officials in planning for maximum utilization of land resources of the area with minimum risk of flood damage to the attendant cultural development or of degradation of the hydrologic system.

The scope of the study was such that all pertinent available water-level, streamflow, and rainfall records were evaluated, but field work and collection of new water records were minimal. Periodic water-level data were obtained, however, for five surface-water bodies and one artesian well.

Acknowledgments

Special thanks are extended to William Bush, Jr., Seminole County Engineer, who provided valuable information throughout the study and to Julian Johnson of the County Engineer's Office, who determined the datums of the gauges and the altitudes of flood marks pointed out by local citizens. The authors appreciate the cooperation of the citizens of the area who gave information on high-water levels and obtained water-level data.

Many of the background data used in the preparation of this report are contained in an interim report by Heath and Barraclough (1954) and a comprehensive report by Barraclough (1962a) on the ground-water resources and geology of Seminole County. These reports contain references to many reports by earlier investigators dating back to 1913.

The investigation and preparation of this report were under the direct supervision of Joel O. Kimrey, subdistrict chief, Winter Park, and under the general supervision of C. S. Conover, District Chief, Water Resources Division, U. S. Geological Survey, Tallahassee, Florida.

For the use of those readers who may prefer to use International System (metric) units rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	By	To obtain metric unit
inches	25.4	millimetres
	.0254	metres
feet	.3048	metres
miles	1.609	kilometres
acres	4047	square metres
square miles	2.590	square kilometres
cubic feet per second	.02832	cubic metres per second
acre-feet	1233	cubic metres

DESCRIPTION OF THE AREA

Location and Extent

The area of investigation, in the southwest part of Seminole County, is shown on figure 1. Within this area, the study was restricted to three sink

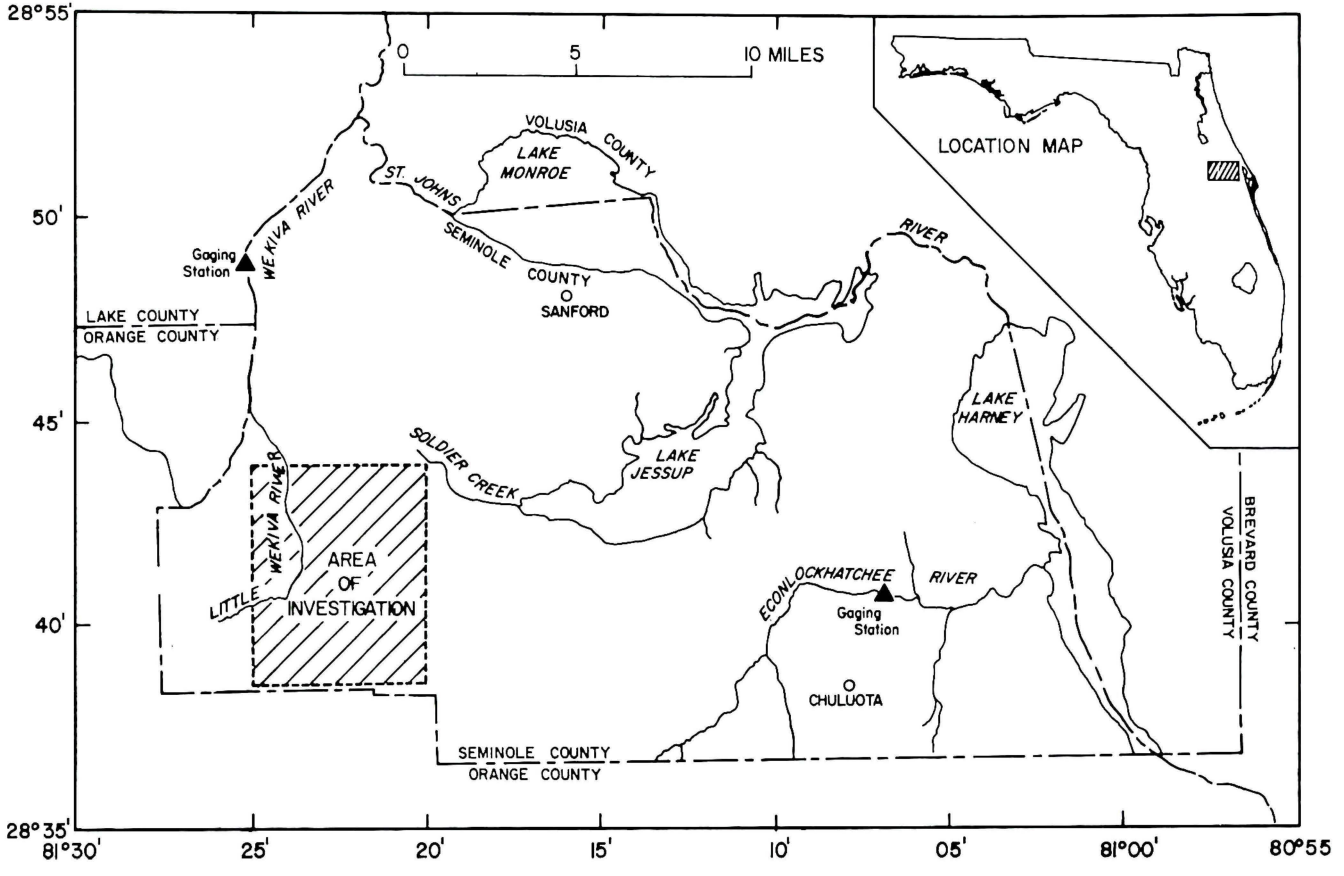


Figure 1.—Seminole County showing location of area of investigation.

basins, as delineated by the basin-boundary lines in figure 2. The three sink basins are called, in this report, Cranes Roost sink basin, Palm Springs sink basin, and Grace Lake sink basin, in order from south to north. In the aggregate, these basins occupy 8.43 square miles.

Geologic Setting

The area is underlain by limestone of Eocene age from about sea level to 70 feet below sea level. The limestone is overlain by about 80 to 150 feet of calcareous clay and sandy limestone of the Hawthorn Formation of Miocene age. The Hawthorn Formation is overlain by 10 to 60 feet of clay (Barraclough, 1962a, fig. 3). The Eocene limestone and hydrologically connected permeable zones in the lower part of the Hawthorn Formation are collectively known as the Floridan aquifer.

Topographic Setting

The area is a fairly level plain generally 85 to 100 feet above mean sea level except at the southern edge of the area where one sand hill exceeds 120 feet in altitude. The plain has been extensively altered by the subsidence of the surface materials into cavities in the underlying limestone of the Floridan aquifer. The cavities are caused by solution of limestone by water. The three sink basins studied in this report were formed by such subsidence.

In the three sink basins, circulation of water through the limestone is great because little of the rainfall there escapes as surface outflow. The rainfall which does not return to the atmosphere by evaporation eventually infiltrates to the Floridan aquifer and subsequently is discharged outside the area, mostly at Palm and Sanlando Springs. The voids and cavities, caused by water passing through the Floridan aquifer, in time are enlarged to such an extent that the overlying Hawthorn and younger deposits slump or collapse into them. Because of differences in permeability of the limestone and the overlying deposits, infiltration of water and the attendant land subsidence have been greater in the western parts of Cranes Roost and Palm Springs sink basins and in the northern part of Grace Lake sink basin than in other parts of the basins.

The extent and configuration of each of three sink basins was determined by the course that surface outflow would ultimately take if the water level in the individual sink basins were to reach a high enough stage to cause the basin to overflow (fig. 2). Cranes Roost sink basin, the southernmost of the three, is 5.02 square miles in area and consists of a system of lakes and sinks. Surface drainage begins in several swamps south of Lake Seminole, about halfway between Altamonte Springs and Longwood. This drainage is joined by overflow from Lake Mobile just before it enters Lake Florida. Overflow from Lake

Florida passes through Lake Adelaide which overflows into Cranes Roost. Lake Orienta and two smaller sinks, though not connected to Cranes Roost on the surface, would drain into Cranes Roost sink if their stages were to rise

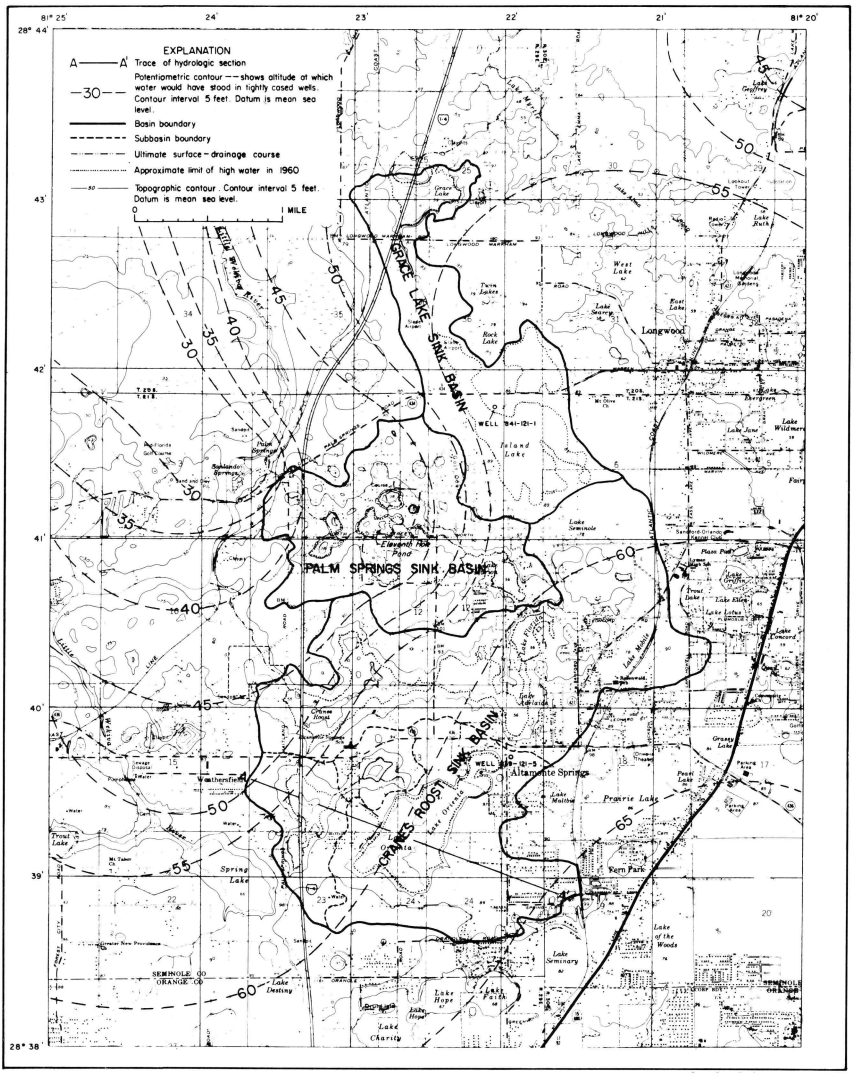


Figure 2.—Map of southwestern Seminole County showing the generalized configuration of the potentiometric surface of the Floridan aquifer September 30, 1960.

to about 77 feet above mean sea level. Although this basin does not overflow, Cranes Roost sink would flow into the Little Wekiva River 0.6 mile south of Sanlando Springs were the basin ever to fill.

Just north of Cranes Roost sink basin lies the Palm Springs sink basin, which contains Lake Marion and several smaller sinks. The area of this sink basin is 1.77 square miles. None of the sinks are connected on the surface, but if they were, they would constitute a drainage system which upon filling would overflow into the Little Wekiva River at Palm Springs. None of the smaller sinks are named on the map of figure 2. The pond for which stage data were obtained during this investigation is herein referred to as Eleventh Hole Pond because it is near the 11th hole of a golf course.

Grace Lake sink basin, the northernmost, contains Island and Grace Lakes and occupies 1.64 square miles in the northern part of the sinkhole area. Island Lake overflows into Grace Lake; Grace Lake at times overflows into Lake Myrtle and two intervening sinks which lie outside the area of investigation (fig. 2). Flow from Grace Lake sink basin, should it occur in sufficient quantity to cause the intervening sinks to overflow, would ultimately reach Soldier Creek, which is tributary to Lake Jessup and the St. Johns River.

Climatological Setting

The climate of the area is characterized by hot, humid summers and cool, dry winters that are separated by short periods of mild, dry weather in spring and fall. Wide deviations from these normal conditions occur, especially as regards rainfall. Any month can be extremely dry or wet.

Average rainfall, as measured at Orlando, is 51.37 inches per year. Since 1893, rainfall totals for water years (which begin October 1 of the year previous to the designated year and end September 30 of the designated year) have ranged from 18.31 inches below normal in 1927 to 21.94 inches above normal in 1905 (figure 3).

Mean monthly air temperatures range from 60.4°F in January to 81.8°F in August and average 71.5°F. The lowest recorded temperature was 20°F and the highest, 100°F. Evaporation from a water surface is estimated to average 50 inches per year. Departures of more than 2 inches from average during a year probably occur in less than 10 percent of the years (Anderson and others, 1965).

HYDROLOGIC RELATIONS

The pattern of fluctuation in the water level of a lake is the resultant of several climatological and physiographic factors. Some of these tend to cause a lake level to rise while others tend to cause it to fall. Lakes in the area of investigation gain water from rain on their surfaces; surface inflow; and ground water derived from the water table aquifer, the Floridan aquifer, or both aquifers. The lakes lose water by evaporation, transpiration, and seepage

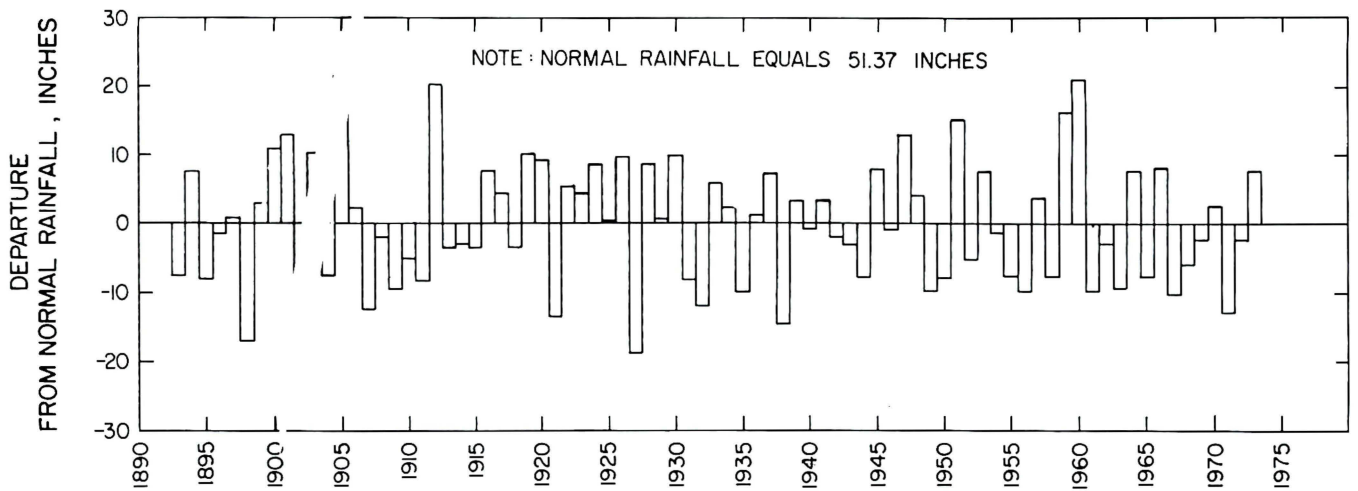


Figure 3.—Departure from normal rainfall, National Weather Service Office, Orlando, Fla., 1893-1973 water years.

to the aquifers; some of the lakes are landlocked but others overflow to another lake or sink at a lower altitude. The effects of rainfall and surface flow on lakes are extremely variable and intermittent whereas the effects of groundwater seepage, evaporation, and transpiration are relatively stable and continuous. The balance between input and output is continually changing; hence. the level of the lake is nearly always either rising or falling.

During and for a short time after rainfall. surface inflow to the lakes occurs as overland flow and street and sewer drainage; if the lakes are sufficiently filled, surface outflow occurs as overflow to down-gradient lakes or sinks.

Water moves from the lakes to the water-table aquifer if lake levels are above the water table. and moves into the lakes from the water-table aquifer if lake levels are below the water table. Similarly, water moves from the lakes into the Floridan aquifer if lake levels are above the potentiometric surface of the Floridan aquifer, and moves into the lakes from the Floridan aquifer if lake levels are below the potentiometric surface. Rates of flow vary with hydrostatic head and with the permeability of materials along the path of flow.

PEAK STAGES AND PROBABILITY OF OCCURRENCE

The approximate peak stages reached by one or more of the water bodies in the area of investigation in 1954. 1960, and 1970 are given in the table below. Highwater lines for the peak stages of 1960 are also indicated in figure 2. These data were obtained from a report of a previous investigation, records in the files of the Seminole County Engineer, highwater lines pointed out by local residents, and levels to stain marks and wash lines by the Seminole County Engineer's office.

Water Body	Altitude, feet above mean sea level		
	January 1954	September 1960	March 1970
Lake Orienta	60.5(a)	67.9(b)	61.8(b)
Cranes Roost		60.7(c)	55.3(d)
First sink south of Cranes Roost		61.4(c)	
Second sink south of Cranes Roost		64.1(c)	
Grace Lake		66 (c)	65.2(d)

(a) From Barraclough (1962a)

(b) High-water mark pointed out by Glen D. Humes, 134 Hattaway Drive. Altamonte Springs.

(c) From Department of Transportation plans for Interstate Highway 4. Data supplied by Seminole County Engineer.

(d) Stains on posts and wash lines on highway fills.

The available lake-stage data are insufficient for evaluating the frequency of occurrence of specific lake stages. However, lakes, streams, and aquifers are part of a hydrologic system, and rainfall provides the water than keeps the system viable. As a consequence, fluctuations of lake levels are tied to the fluctuations of ground-water levels and stream discharges. Therefore, some insight as to the frequency of occurrence of selected lake stages can be gained from a study of the available records of ground-water levels, stream discharges, and rainfall, which together span a large number of years and a wide range of hydrologic conditions.

From November 1953 to December 1956 the trend of the water level of Lake Orienta was generally the same as the trend of the level of the potentiometric surface of the Floridan aquifer, which is represented by the level of water in well 841-121-1 (fig. 4). The potentiometric surface of the Floridan aquifer was substantially higher in September 1960 than in January 1954, or in the last few months of 1953. This is consistent with the fact that the stage of Lake Orienta was substantially higher in September 1960 than in January 1954 as the table shows.

The flow of Wekiva River consists partly of overland runoff and partly of ground water discharged from the Floridan aquifer at various springs along the river, including Palm and Sanlando Springs (fig. 2) which discharge into the Little Wekiva River. The discharge of the Wekiva River follows the trend of the water level in well 841-121-1 (fig. 4). Sharp upswings of the discharge and water-level graphs generally correspond with large monthly rainfalls at Orlando and sustained downswings of the graphs generally corresponds with a series of small monthly rainfalls; the exceptions are an indication that rainfall over the drainage basin of concern was not uniformly the same as rainfall at Orlando.

The average annual discharge of Wekiva River near Sanford (fig. 5) was substantially greater in the 1960 water year than in any year since at least 1936. Similarly, the average annual discharge of Cypress Creek at Vineland in 1960 was the greatest measured since at least 1946 (fig. 6). The Cypress Creek drainage area above Vineland encompasses 30.3 square miles centered about 10 miles east of Orlando. About 25 percent of the Cypress Creek drainage area consists of lakes.

The average annual discharge of Econlockhatchee River near Chuluota (fig. 7) also was greater in 1960 than in any year since at least 1936. In relation to Wekiva River, Econlockhatchee River has a larger surface-water component and a smaller ground-water component. The annual discharge of Econlockhatchee River tends to reflect more directly the variations in the yearly rainfall.

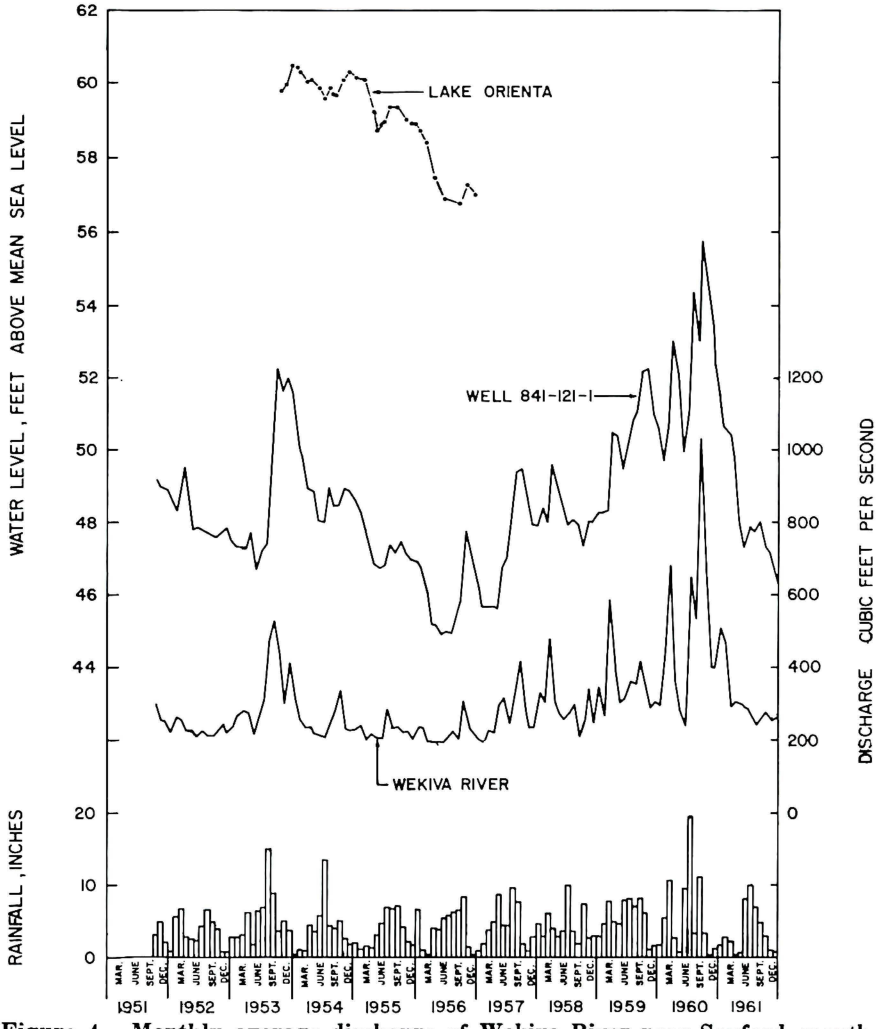


Figure 4.—Monthly average discharge of Wekiva River near Sanford, month-end water level in well 841-121-1 near Island Lake, and monthly rainfall at Orlando, September 1951 to December 1961.

Thus, from the general relation apparent between lake levels, groundwater levels, and the measured discharges of different types of streams of different sizes, it reasonably can be concluded that the stages of Lake Orienta and other lakes in the area of investigation, especially lakes in closed basins. were higher in September 1960 than they were at any time since at least 1936.

On the assumption that the discharge of Wekiva River near Sanford provides a valid index of the general level of nearby lakes, the average annual

discharge of Wekiva River was estimated for years before 1936 by regression methods (Riggs, 1968) using the following equation as a model: (1)

$$Q_0 = a + b_0P_0 + b_1P_1 + b_2P_2$$

Where Q_0 = average annual discharge of Wekiva River (water years), in cubic feet per second.

P_0 = annual rainfall at Orlando in the year corresponding to Q_0, in inches.

P_1 = annual rainfall at Orlando in first preceding year, in inches;

P_2 = annual rainfall at Orlando in second preceding year, in inches; and, a, b_0, b_1, and b_2 are regression coefficients.

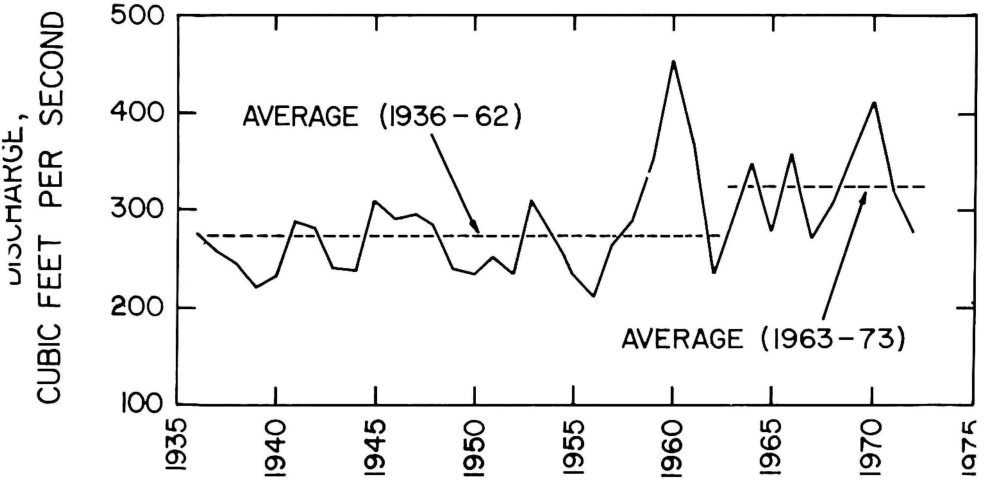


Figure 5.—Average annual discharge of Wekiva River near Sanford, Fla., 1936-72 water years; drainage area, 189 square miles.

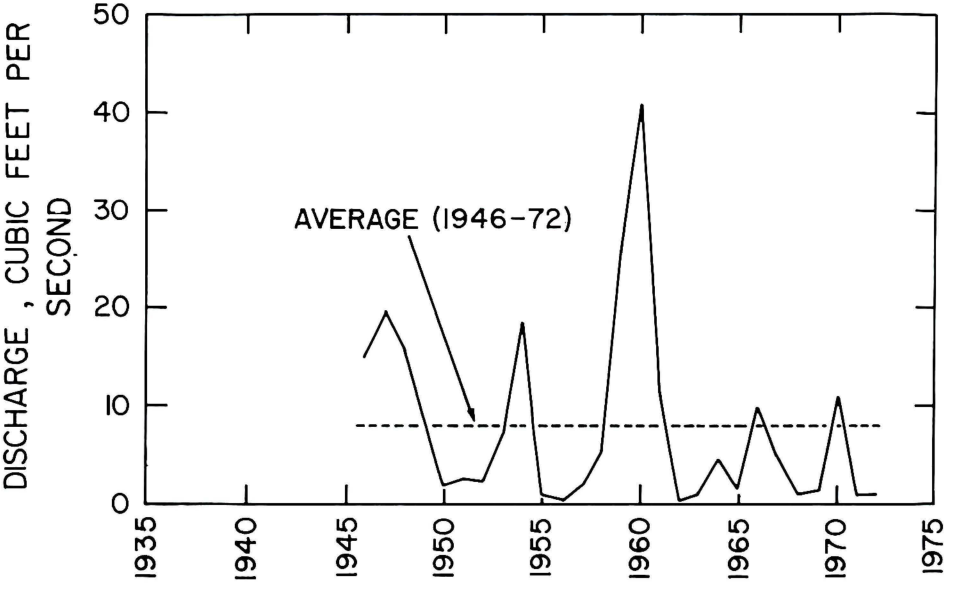


Figure 6.—Average annual discharge of Cypress Creek at Vineland, Fla., 1946-72 water years; drainage area, 30.3 square miles.

On basis of double-mass analyses of rainfall and streamflow, the annual discharge of Wekiva River near Sanford (fig. 5) in recent years appears to be larger than it was in the past, both in relation to rainfall in the general area and in relation to the discharge of nearby streams; consequently, only the data for 1936-62 was used in the regression analysis. The resulting regression equation was:

$$Q_0 = 4.19P_0 + 3.71P_1 + 1.45P_2 - 209 \qquad (2)$$

The annual discharges computed by equation 2 are generally within 15 percent of the discharges measured during 1936-62 (fig. 8). The estimated

discharge for 1960 was substantially greater than that computed for any year since 1895. (fig. 9).

Similar regression analyses were made using the average of rainfall at Orlando and Sanford, the average of rainfall at Orlando and Eustis—Eustis is about 30 miles northwest of Orlando—and the average of rainfall at all three stations. The rainfall record for Sanford begins in 1914; that for Eustis in 1891. The pattern of the computed annual discharges in each case was similar to that shown in figure 9: the computed discharge for 1960 was always substantially greater than any other.

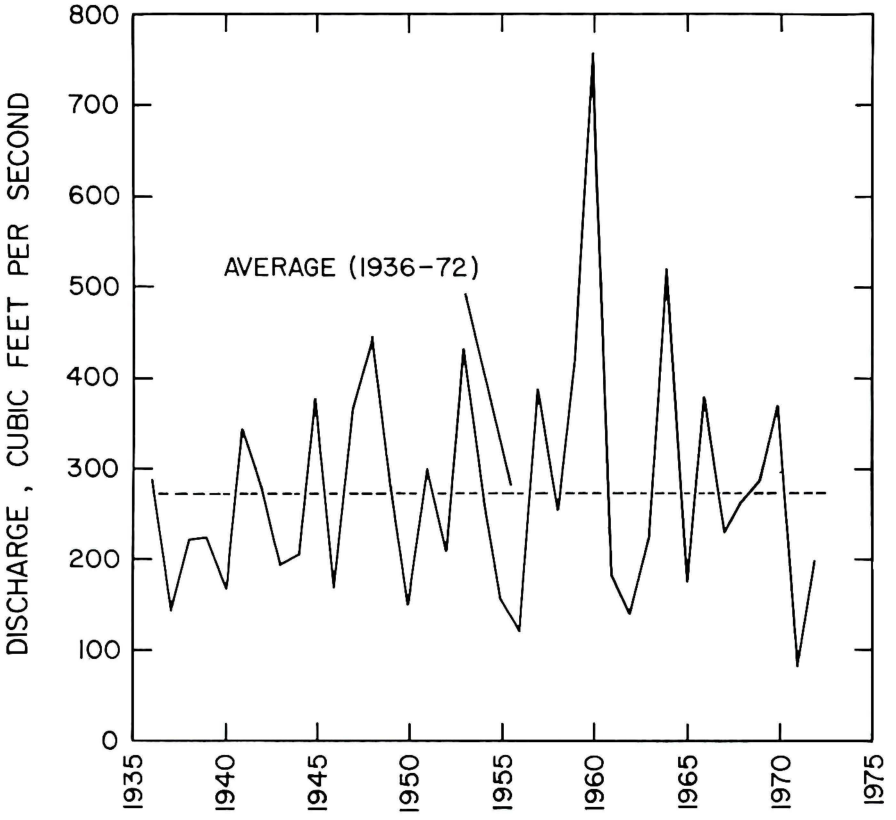


Figure 7.—Average annual discharge of Econlockhatchee River near Chuluota, Fla, 1936-72 water years; drainage area, 241 square miles.

In the different analyses the regression coefficients for P_0 and P_1 varied some with the choice of rainfall data but were of the same general magnitude and always of the same sign (positive). The coefficient for P_2 was relatively

small in each case but was negative when the average of rainfall at Orlando and Sanford was used.

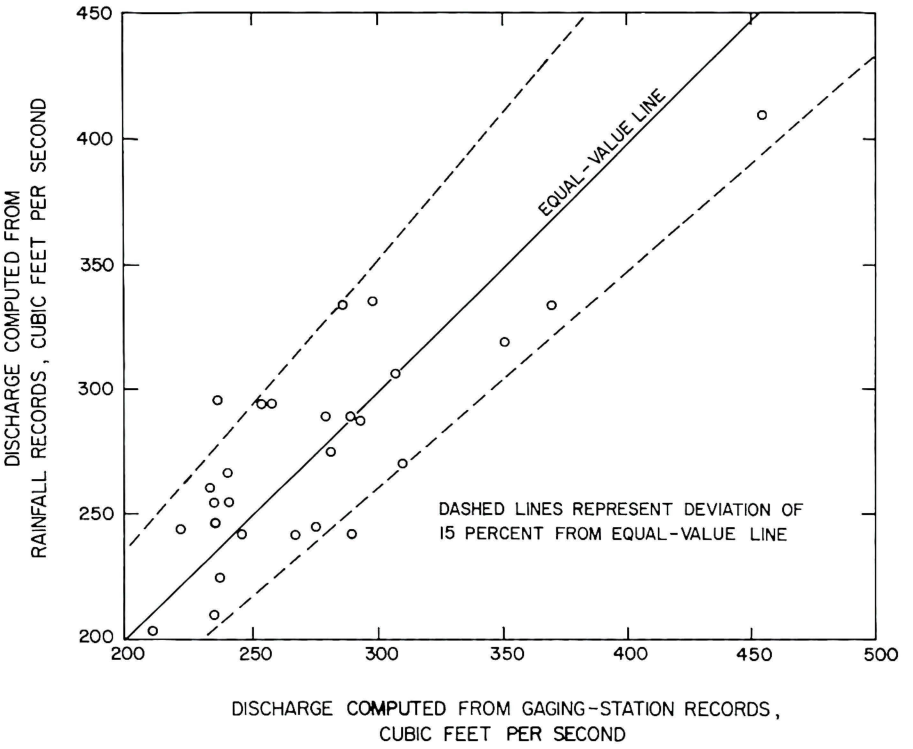


Figure 8.—Relation between average annual discharge of Wekiva River near Sanford, Fla., as computed from gaging-station records and as computed from rainfall records for Orlando by regression methods, 1936-62 water years.

According to Riggs (1968, p. 19, 20), as variables are added to or deleted from a regression, a change in sign of the coefficient of one of the variables indicates that the effect of the variable is small in relation to the sampling error. Seemingly, the same conclusion would apply if the use of different but comparable data in a regression produces a change in sign of the coefficient of one of the variables. The effect of antecedent rainfall on the current year's discharge doubtless decreases with each preceding year. Thus, for the purpose at hand, there is no need to consider the effect of rainfalls past the second preceding year.

On basis of the foregoing analysis of the average annual discharge of Wekiva River near Sanford, and other hydrologic data and relations previously described, it is concluded that the peak stages attained by lakes in

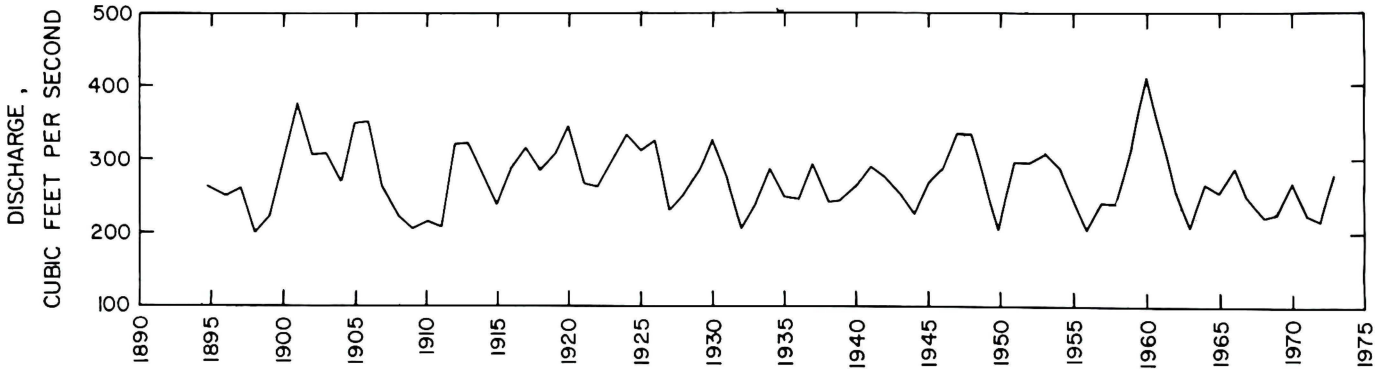


Figure 9.—Average annual discharge of Wekiva River near Sanford, Fla., computed from rainfall records for Orlando by regression methods, 1895-1973 water years.

southwest Seminole County in 1960 probably were higher than any occurring since at least 1895.

HYDROLOGIC SETTING ON SEPTEMBER 30, 1960

In the area investigated the potentiometric surface of the Floridan aquifer in 1960 was recorded in only one well (number 841-121-1 at Island Lake) which has served as a moniter well since 1951. Consequently, the maximum altitude of the potentiometric surface elsewhere in the area can only be estimated.

The estimated altitude and configuration of the potentiometric surface on September 30, 1960 (fig. 2) are based on the altitudes of water levels in wells observed by Barraclough (1962b) in January 1954 and June 1956. The 1960 altitudes of water levels in these wells were estimated on the assumption that the ratio of the difference between their 1954 and 1956 water levels to the difference between their 1956 and 1960 water levels was the same as the ratio of these differences for well 841-121-1. This assumption is reasonable because experience has indicated that correlation from well to well is fairly tight for wells tapping the Floridan aquifer, not only in this area but elsewhere in Florida as well. Along the western and southern boundaries of the area the potentiometric contours as shown in figure 2 conform with the potentiometric contours presented by Lichtler (1968, p. 102) for the September 1960 high-water conditions in Orange County.

Figure 10 shows the estimated altitudes of the water-table aquifer and the potentiometric surface of the Floridan aquifer at the end of September 1960 along section A-A′ (fig. 2) passing through Lake Orienta.

The high water table east of Lake Orienta (fig. 10) is typical of the condition existing east of a line running in an arc from just east of Lake Orienta, northeast to the area between Lakes Florida and Mobile, and thence northwest around the west side of Island Lake where it curves east. The Hawthorn deposits in the area of investigation lying east of this line must be relatively impermeable in order to permit head differences as much as 30 feet between the water table and Floridan aquifers. West of the line, smaller head differences (5 to 8 feet) between the aquifers indicate that the Hawthorn deposits are much more permeable than those to the east.

Ordinarily, evapotranspiration is sufficient to prevent the water table from rising to land surface in places where the terrane slopes to the lakes and sinks west of the area of high water table previously described. During wet periods, however, ground water comes to the surface along these slopes, as evidenced by the stench of septic-tank effluent in the subdivision east of Lake Orienta in the spring of 1970 (William Bush, Jr., oral commun., 1971).

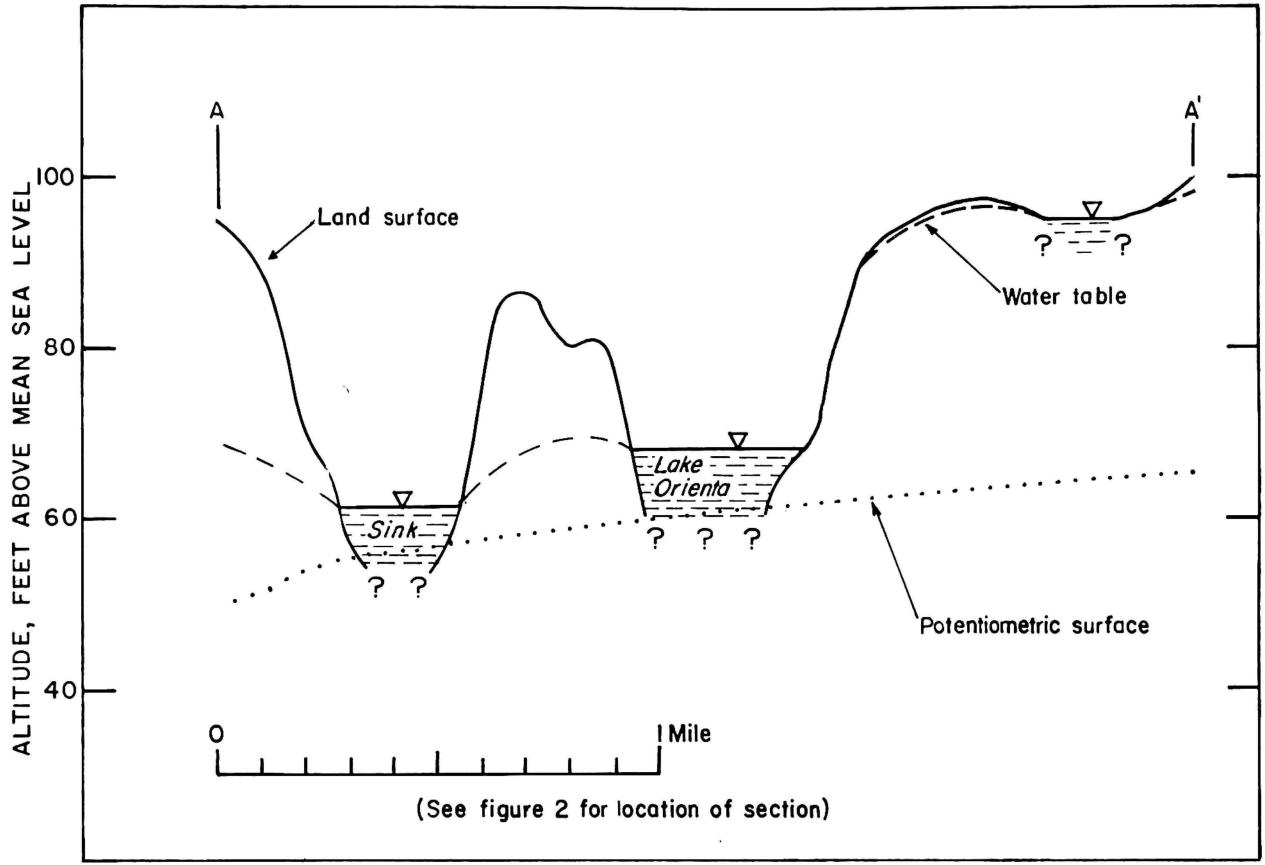


Figure 10.—Section A-A′ showing altitudes of surface-water bodies and estimated altitudes of water table and potentiometric surface of Floridan aquifer, September 30, 1960.

Described below are the processes that were probably going on in some of the water bodies on September 30, 1960, when their stages were at or near their maximum known altitudes. Rainfall in the general area was about 0.7 inch on September 29 and 30, 1960; whether overland flow occurred on the 30th would depend on how late in the day rain fell on the 29th:

Cranes Roost Sink Basin

Lake Mobile

Surface inflow - Street and storm-sewer drainage. possibly overland inflow.

Surface outflow - Overflow to down-gradient lakes.

Ground-water inflow - Lateral seepage from surrounding water-table aquifer.

Ground-water outflow - Minor vertical seepage through the bottom to the aquifers beneath the lakes.

Note.—Lake levels were higher than the potentiometric surface of the Floridan aquifer but probably lower than the surrounding water table.

Lakes Adelaide and Florida

Surface inflow - Street and storm-sewer drainage, overflow from up-gradient lakes, possibly minor overland inflow.

Surface outflow - Overflow to Cranes Roost.

Ground-water inflow - Lateral seepage from the surrounding water-table aquifer; vertical seepage through the bottom from the aquifers beneath the lake.

Ground-water outflow - None.

Note.—Lake levels probably were below both surrounding water table and potentiometric surface.

Cranes Roost

Surface inflow - Street and storm-sewer drainage, inflow from Lake Adelaide, possibly minor overland inflow.

Surface outflow - None.

Ground-water inflow - Probably none.

Ground-water outflow - Lateral seepage to the surrounding water-table aquifer and vertical seepage through bottom to the aquifers beneath the sink.

Note.—Sink water level probably higher than both surrounding water table and potentiometric surface.

Lake Orienta

Surface inflow - Street and storm-sewer drainage, overflow from lakes to the east, possibly minor overland inflow.

Surface outflow - None.

Ground-water inflow - Lateral seepage from the water-table aquifer.

Ground-water outflow - Vertical seepage through bottom to the aquifers beneath the lake.

Note.—The adjacent water table probably was higher than the lake. The lake level was higher than the potentiometric surface beneath the lake.

Palm Springs Sink Basin

Lake Marion

Surface inflow - Street and storm-sewer drainage, possibly minor overland flow.

Surface outflow - None.

Ground-water inflow - Lateral seepage from the adjacent water-table aquifer on east.

Ground-water outflow - Lateral seepage to adjacent water-table aquifer on west and vertical seepage through the bottom to the aquifers beneath the lake.

Note.—Lake level probably lower than adjacent water table at east end but higher than water table at west end. Lake level higher than potentiometric surface.

Palm Springs sinks (including Eleventh Hole Pond)

Surface inflow - Street and storm-sewer drainage, possibly some overland runoff from lawns and golf course fairways.

Surface outflow - None.

Ground-water inflow - Lateral seepage from the surrounding water-table aquifer and vertical seepage through bottom from the aquifers beneath the sinks if the sink levels were below the potentiometric surface.

Ground-water outflow - Vertical seepage through bottom to the aquifers beneath the sinks if the sink levels were above the potentiometric surface.

Note.—Sink levels probably were slightly above potentiometric surface if the stage was falling and slightly below if the stage was rising.

Grace Lake Sink Basin

Island Lake

Surface inflow - Street and storm-sewer drainage, possibly overland inflow.

Surface outflow - Overflow to down-gradient lakes.

Ground-water inflow - Lateral seepage from surrounding water-table aquifer.

Ground-water outflow - Minor vertical seepage through the bottom to the aquifers beneath the lakes.

Note.—Lake levels were higher than the potentiometric surface but probably lower than the surrounding water table.

Grace Lake

Surface inflow - Overflow from Island Lake, highway drainage, possibly minor overland inflow.

Surface outflow - Possibly overflowing to down-gradient sinks and lakes.

Ground-water inflow - Probably none.

Ground-water outflow - Vertical seepage through the bottom to the aquifers beneath the lake.

Note:—Lake level probably higher than both surrounding water table and potentiometric surface.

STAGE FLUCTUATIONS AND SEEPAGE RATES

To provide some insight to the nature of water-level fluctuations of the surface-water bodies and their relation to the Floridan aquifer, stage data were collected during the investigation for five water bodies and well 841-121-1 which taps the Floridan aquifer near Island Lake. These data are shown in figures 11-15; the hydrograph for the well is repeated on the hydrograph for each of the water bodies for comparison. For three of the water bodies—Lake Orienta, Cranes Roost, and Grace Lake—the approximate altitude is shown for the peak stages occurring about mid-March, 1970.

A similarity in the patttern of fluctuation in the water levels of Island Lake and well 841-121-1 is evident in figure 11, although the range of fluctuation is much less for the lake than for the well. The lake level being about 40 feet higher than the well level suggests a poor connection between the lake and the Floridan aquifer. This would preclude an appreciable amount of seepage from the lake to the aquifer.

On the assumption that seepage from Island Lake to the Floridan aquifer is insignificant, the hydrologic conditions at Island Lake between January 1

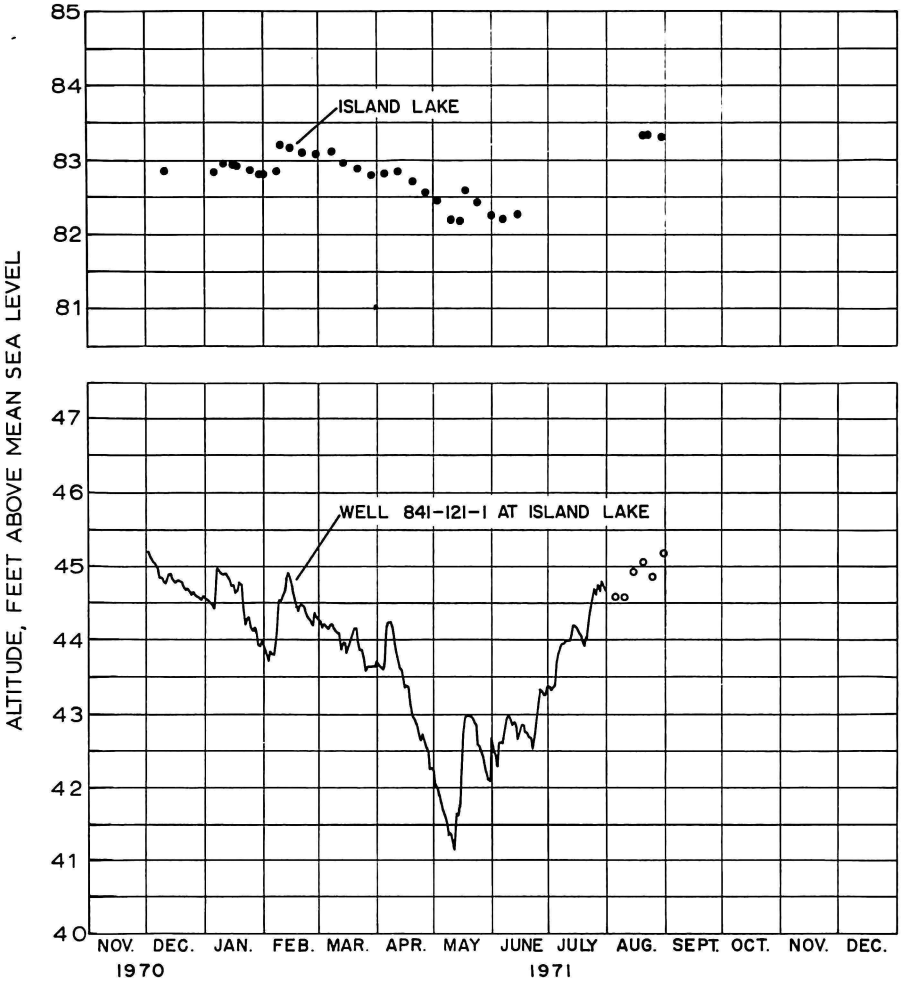


Figure 11.—Hydrographs for Island Lake and well 841-121-1.

and May 31, 1971 were favorable for making an estimate of the difference between rainfall and lake evaporation for the same 5-month period. The lake level was low enough that there was no surface-water outflow. Surface-water inflow probably was minimal because the highly permeable surficial sand in most parts of the contributing drainage area is conducive to the infiltration of rainfall. Rainfall during this period—10.7 inches at Orlando; 15.8 inches at Sanford; mostly in February and May—was not great enough to cause large quantities of runoff but was sufficient to account entirely for the few rises in lake level indicated by the hydrograph. Small quantities of runoff would

not contribute appreciably to a rise in lake level because the runoff would be distributed over the entire lake area which takes up a large percentage of the total drainage area. Ground-water inflow to the lake from the water-table aquifer probably was small because rainfall was over 11 inches below normal in the 6 months preceding January 1971. Thus, the 0.6 foot decline in the stage of Island Lake between January and May 1971 is considered to be a good measure of the excess of evaporation over rainfall for that period.

The estimate of 0.6 foot for the excess of evaporation over rainfall between January and May 1971 probably is applicable to other water bodies in the area for the same period. For example, the hydrograph for Lake Orienta (figure 12) shows that during this period the lake level declined about 1.1 feet. Therefore, the net of seepage into the lake from the water-table aquifer and out of the lake to the water-table and Floridan aquifers plus any surface-water inflow that occurred was 0.5 foot. (Although figure 10 shows that the ground-water level in the adjacent water-table aquifer is above the level of Lake Orienta on both the east and west sides of the lake, as it probably was at the end of the unusual wet period ending September 1960, during dry periods, such as January-May 1971, the water table probably slopes continuously downward from Lake Orienta toward the nearby sink to the west; if so, during dry periods some water would move from Lake Orienta through the water-table aquifer to the sink.) Inasmuch as the rainfall on the lake was sufficient to account for the few rises in lake level indicated by the hydrograph, surface-water inflow probably was minimal during this period. The magnitude of the individual components of seepage moving into and out of the lake cannot be determined from the data at hand.

Water probably moves always downward from Lake Orienta to the Floridan aquifer but the rate of movement varies appreciably between wet and dry periods. The level of Lake Orienta is several feet above the level of the potentiometric surface of the Floridan aquifer at Island Lake from the comparison of the lake-level graph with the water-level graph for well 841-121-1 (figs. 4 and 12); however, the level of the potentiometric surface changes appreciably over a distance of a few miles. Water-level data for 1954-56 (Barraclough, 1962b, p.11, 12, 40) indicate that the level of the potentiometric surface at Lake Orienta—as represented locally by the water level in well 839-121-5 (fig. 2)—on January 11, 1954, was 5.2 feet higher than the water level in well 841-121-1, and on January 5, 1956, was 4.2 feet higher. Thus, it is evident from figure 4 that the level of Lake Orienta locally was about 4 feet higher than the potentiometric surface in January 1954 and about 8 feet higher in January 1956. This indicates that from January 1954 to January 1956 the head differential between the two water bodies—and the resultant rate of water movement—increased by a factor of about 2.

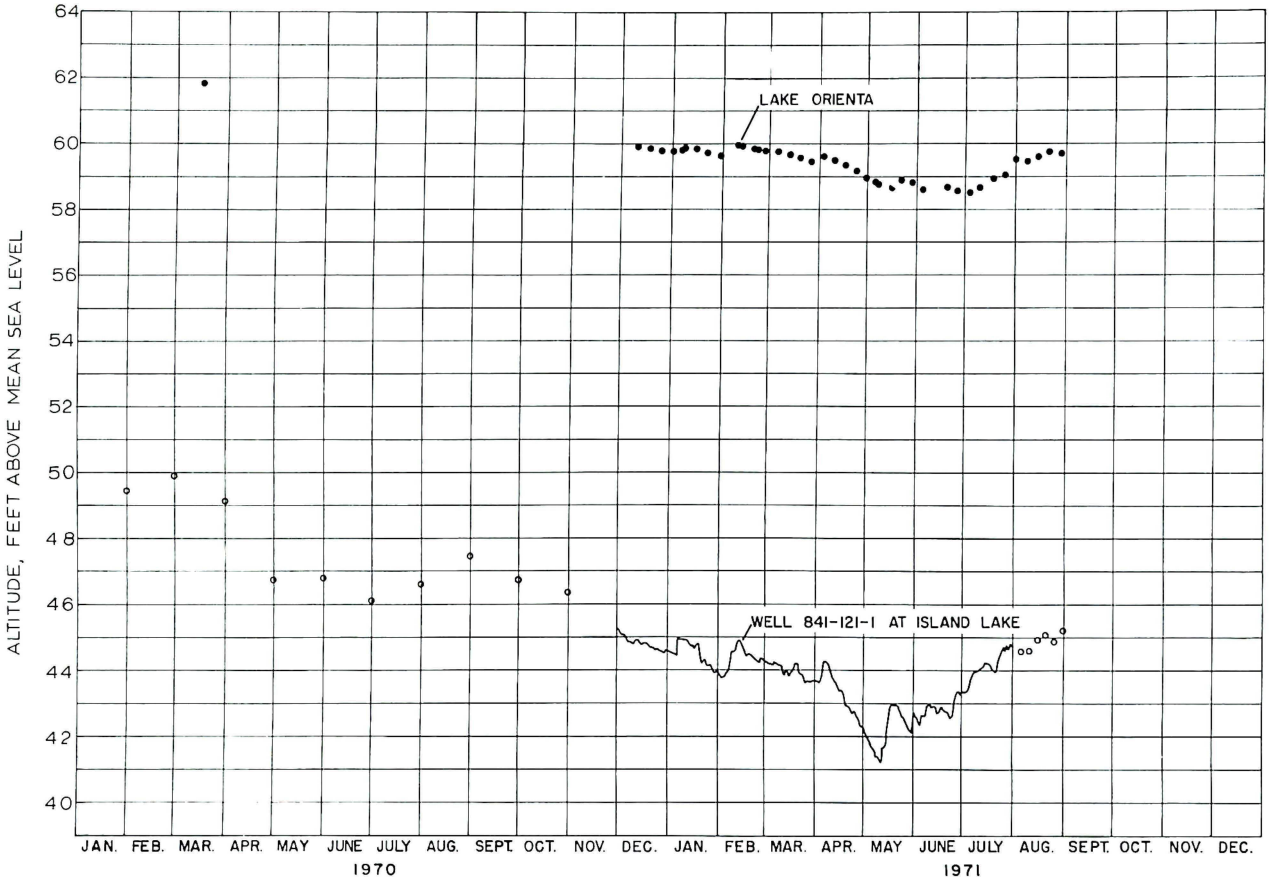


Figure 12.—Hydrographs for Lake Orienta and well 841-121-1.

Just as the level of the potentiometric surface declined more than the level of Lake Orienta in 1954-56, so it would have risen more than the lake level as they both rose to their peak stages of September 1960. Consequently, the head differential between the two water bodies—and the resultant rate of water movement—in September 1960 would have been substantially less than in 1956 or at other times when water levels were generally lower.

The fluctuation in the water level of the water table aquifer adjacent to the lake between wet and dry periods also probably is greater than the fluctuation in level of Lake Orienta. Consequently, the inflow to the lake increases during wet periods and decreases during dry periods. Thus at a time when ground-water outflow from Lake Orienta to the Floridan aquifer is at its least, ground-water inflow to Lake Orienta from the water-table aquifer is at its greatest.

Whereas ground-water outflow from Lake Orienta was greater than ground-water inflow during the relative dry period of January-May 1971, the opposite condition may have prevailed at the height of the wet period ending September 1960. In any event, the high level of Lake Orienta, and other lakes as well, in 1960 was caused by an increase in ground-water inflow to the lake, a decrease in ground-water outflow from the lake, in combination with a large excess of rainfall over lake evaporation, and some surface-water inflow.

The net of inseepage from the water-table aquifer and outseepage to the Floridan aquifer also can be estimated for Grace Lake for the period January 1 to May 31, 1971. During this period the level of Grace Lake declined about 3.1 feet, as shown in figure 13. There was no surface inflow from Island Lake and probably no runoff of consequence from rainfall on the drainage basin downstream from Island Lake. If lake evaporation exceeded rainfall by 0.6 foot, net seepage from Grace Lake was 2.5 foot for the 5-month period, or about 0.5 foot per month. Inseepage from the water-table aquifer probably was minimal during this relatively dry period; thus outseepage from the lake to the Floridan aquifer probably was only slightly greater than 0.5 foot per month.

Outseepage from Grace Lake varies considerably between extreme wet and dry periods. For example, when the peak stage of Grace Lake was 66 feet in the September 1960 wet period, the altitude of the potentiometric surface of the Floridan aquifer at Grace Lake probably was about 53 feet (fig. 2); thus, locally the head differential between the two water bodies probably was about 13 feet. In the January-May 1971 dry period the level of Grace Lake was about 17 feet higher than the water level in well 841-121-1 at Island Lake (fig. 13); however, figure 2 shows that the potentiometric surface of the Floridan aqui-

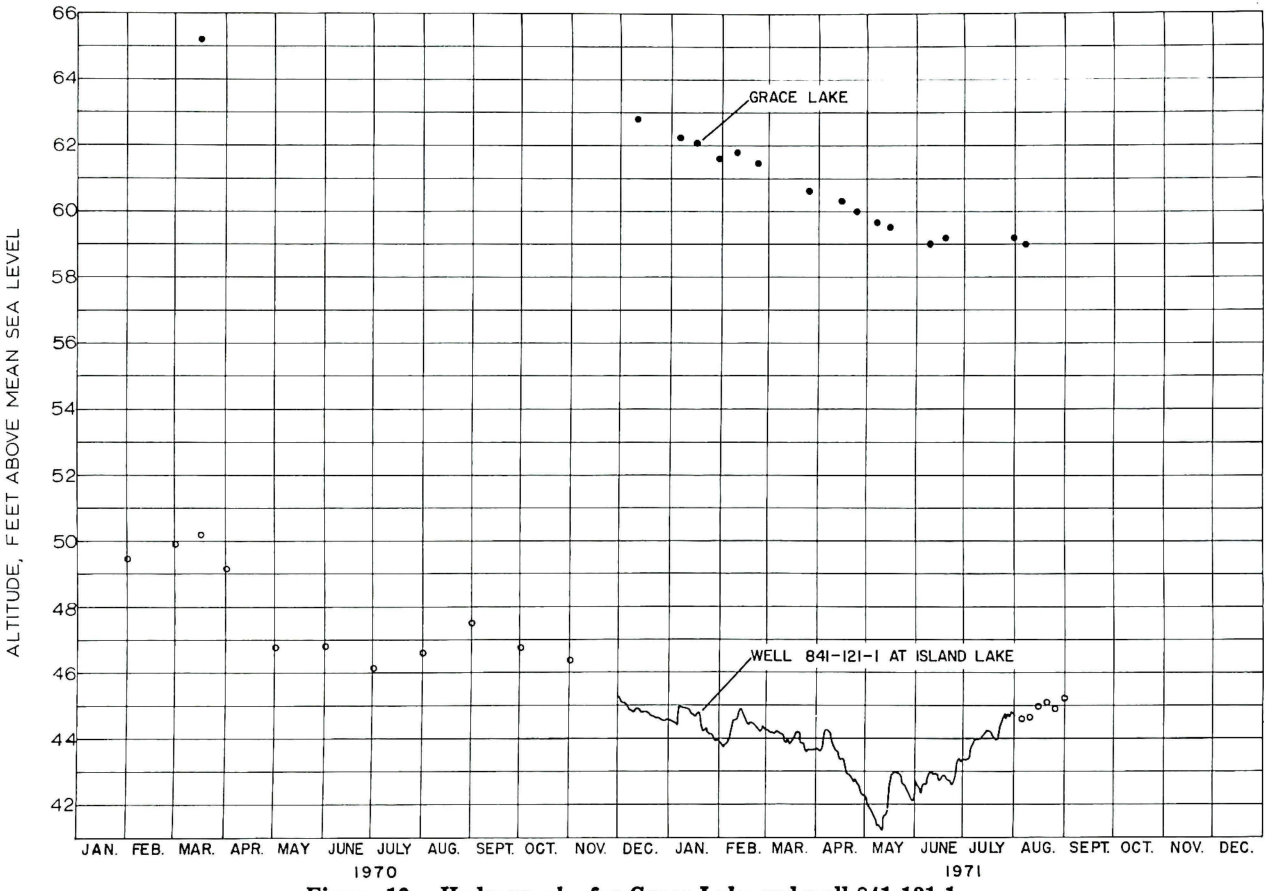


Figure 13.—Hydrographs for Grace Lake and well 841-121-1.

fer is about 3 to 4 feet lower at Grace Lake than at Island Lake. In January-May 1971, therefore, the level of Grace Lake was probably about 20 feet above the potentiometric surface locally. The rate of outseepage from the lake to the Floridan aquifer is proportional to the head differential between the two water bodies. Thus, if the area of the hydraulic connection between the lake and the Floridan aquifer remains the same irrespective of lake stage, outseepage from the lake to the Floridan aquifer was about one-third less in September 1960 than it was in January-May 1971. In terms of effect on the lake level, the difference in outseepage would be even greater because the lake area was considerably greater in September 1960 than in January-May 1971.

Grace Lake apparently overflows to sinks north of the lake during relatively wet periods. In August 1974 one of the authors observed water flowing at a rate of about 10 cfs through a normally dry culvert under the road north of the lake. Antecedent rainfall in the general area was ample but not outstandingly great. The occasional overflowing of Grace Lake accounts for the peak stage of 1960 being only slightly greater than the peak stage attained in 1970; in contrast, the 1960 stages of other water bodies, such as Lake Orienta and Cranes Roost, were much above those attained in 1970.

The fluctuation in the water level of Cranes Roost is greater than that of any of the other water bodies investigated and is controlled primarily by surface inflow from Lake Adelaide and outseepage to the Floridan aquifer. From January 1 to May 31, 1971, the water level in Cranes Roost declined about 5.3 feet as shown in figure 14. Both the surface-water inflow from Lake Adelaide and inseepage from the water-table aquifer probably were minimal during this period; hence, if 0.6 foot is allowed for the excess of evaporation over rainfall, about 4.7 feet of the decline in level was caused by outseepage from Cranes Roost to the Floridan aquifer.

Analysis of the 1960 and 1971 water levels indicates that the level of Cranes Roost on May 31, 1971 was not very far above the potentiometric surface of the Floridan aquifer. On September 30, 1960, the stage of Cranes Roost at 60.7 feet in altitude probably was about 11 feet above the potentiometric surface of the Floridan aquifer at the western end of the water body (fig. 2). The water level in well 841-121-1 at Island Lake was about 14 feet higher in altitude on September 30, 1960, than on May 31, 1971. In general, the range of fluctuation in the level of the potentiometric surface of a confined aquifer decreases down gradient. If the range of fluctuation in the level of the potentiometric surface at Cranes Roost were 80 percent of that at Island Lake, the level of the potentiometric surface at Cranes Roost would have been about 11 feet lower on May 31, 1971 than on September 30, 1960, or at an altitude of about 39 feet at the western end of the water body. Thus, at an altitude of 42

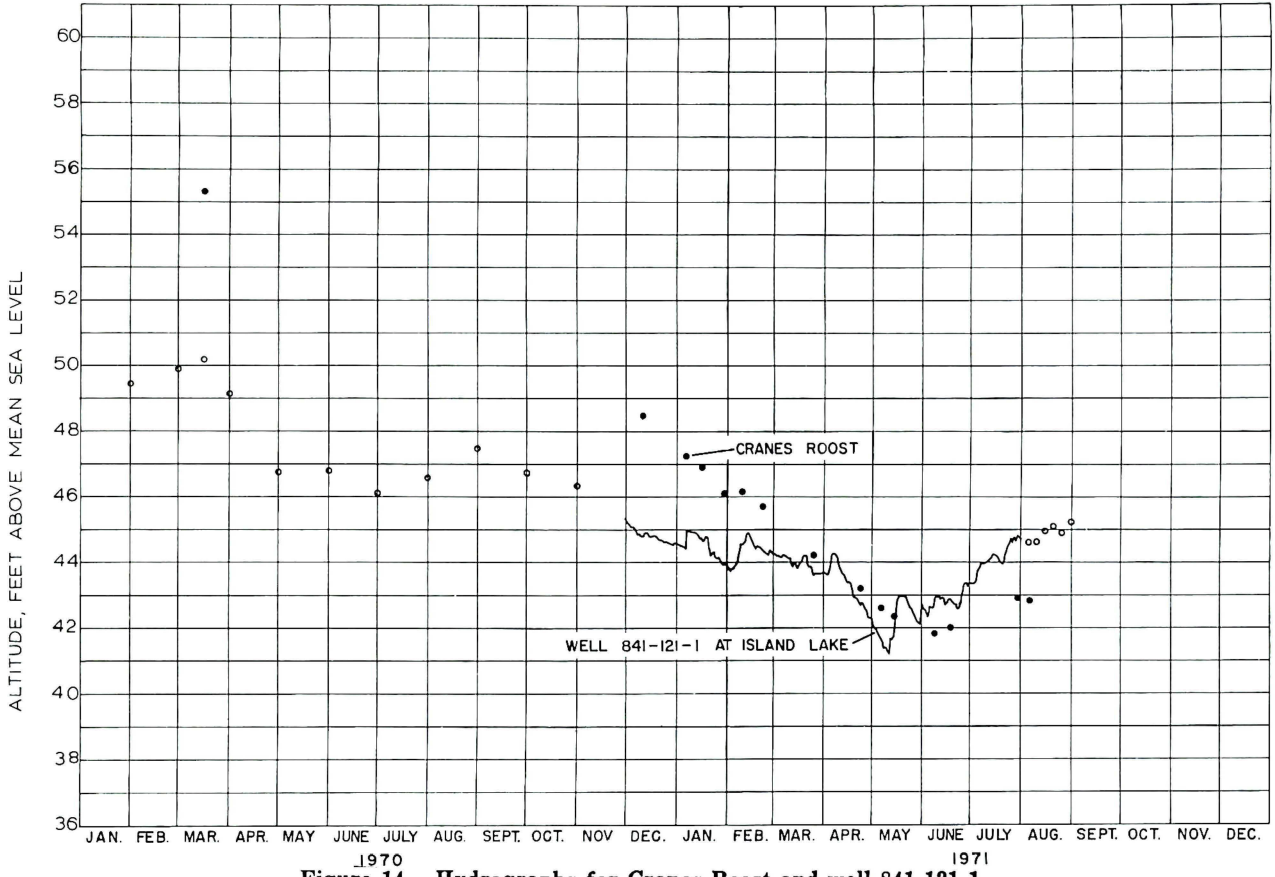


Figure 14.—Hydrographs for Cranes Roost and well 841-121-1.

feet in May 1971 the water level of Cranes Roost probably was only about 3 feet above the potentiometric surface.

At the end of a dry period the potentiometric surface of the Floridan aquifer in response to rainfall probably rises faster than the lake level until such time as rainfall is sufficient to cause surface inflow from Lake Adelaide. Under such conditions the potentiometric surface may briefly rise above the water level in Cranes Roost, thereby causing water to move upward from the Floridan aquifer into Cranes Roost. Had there been no surface inflow from Lake Adelaide, the water level in Cranes Roost still would have reached an altitude greater than 50 feet because the water level in the sink cannot naturally decline below the level of the potentiometric surface.

Conditions in the Palm Springs sink area are such that the pond levels, including Eleventh Hole Pond, probably are always close to the level of the potentiometric surface of the Floridan aquifer. The many sink holes and the extent of land subsidence in this area indicates a good hydraulic connection between the surficial material and the Floridan aquifer. The pond levels are about the same in altitude which indicates that movement of water through the Floridan aquifer is relatively unrestricted in this area.

In February-March 1971 the level of Eleventh Hole Pond (figure 15) declined slightly more rapidly than the water level in well 141-121-1 at Island Lake; this indicates that the pond level was above the local potentiometric surface at that time. However, the rise in the pond level in July-August 1971 was much greater than that of any of the other surface-water bodies investigated, and it follows closely the trend of the water level in well 841-121-1; this suggests that the potentiometric surface in the Palm Springs sink area probably was above the pond level during this period. The water level in the Palm Springs sinks probably are controlled almost exclusively by the potentiomeric surface of the Floridan aquifer; water seeps out of the pond into the Floridan aquifer when the potentiometric surface is falling and seeps into the pond from the Floridan aquifer when it is rising.

EFFECTS OF CULTURAL DEVELOPMENT IN THE SINK BASINS

The preceding remarks concerning water-level fluctuations and peak stages of different water bodies are applicable under the physiographic conditions that existed in the area at the time of the investigation and in some instances before 1960. The area has undergone considerable urbanization since 1960 and doubtless will be further urbanized; this development will affect the hydrologic relations in the basin.

Cultural development that increases the percentage of a basin covered by impervious materials, such as roofs and pavement, causes more of the rainfall to run off. Replacement of the natural soil cover with grass sod also may cause more rapid and voluminous runoff. The higher velocities associated with greater and more rapid runoff can cause greater erosion, especially where the soil is disturbed during construction. Eroded organic matter and clay accumu-

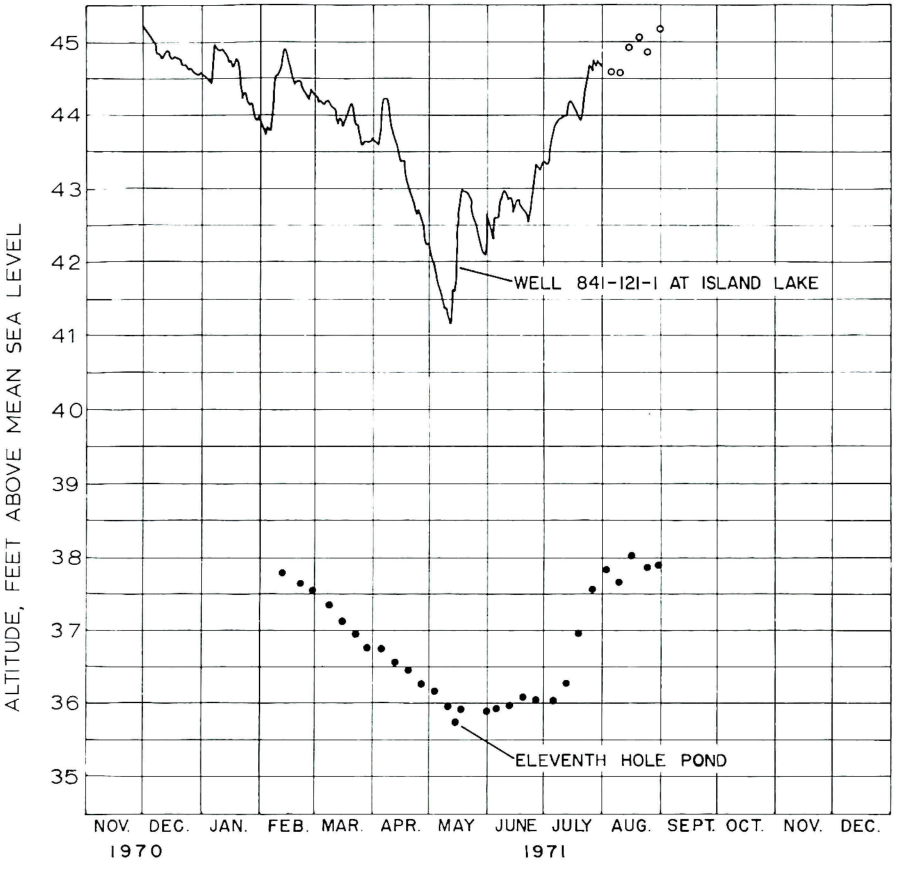


Figure 15.—Hydrographs for Eleventh Hole Pond and well 841-121-1.

lating in the bottoms of sinks or lakes may reduce the rate of seepage out of the sinks and lakes. The reduction in seepage coupled with the increased rate and volume of inflowing water can cause higher than normal water levels. Conceivably, lake stages that are seldom reached or exceeded under natural conditions could be reached or exceeded frequently under conditions of full cultural development. The hydrologic effects of future developments could be

considered before setting altitudes which supposedly represent a specified or limited degree of flood hazard.

Because of the increasing value of land in the sink basins, proposals have been made to increase the amount of usuable property in the sink basins by raising the level of part of the property by filling along the lip of a sink and using material excavated from the bottom of the sink. This procedure would increase the acreage above a designated flood level without reducing the storage capacity of the sink. Such a procedure would necessarily increase the slope of the sink wall and could cause the embankment of fill to slump if it should become saturated. Removal of material from the bottom of the sink would probably increase the rate of seepage from the sink, but would reduce the amount of filtration the water received before entering the Floridan aquifer. If the excavated material were removed from over a cavity, the roof of the cavity could be weakened to the point of collapse. If the excavated material were deposited over a cavity, the added weight could cause the roof of the cavity to collapse.

CONTROL OF WATER LEVELS IN SINK BASINS

A greater part of the property in the sink basins could be culturally developed if water levels were controlled to prevent their rising to high altitudes such as those reached in 1960. In Cranes Roost basin, the level of Lake Mobile could be controlled by enlarging the existing surface outlet and providing an adjustable control structure. The levels of Lakes Adelaide and Florida could be similarly controlled, but such measures might become ineffective if the level of Cranes Roost should rise to the altitude reached in 1960. The peak stages of Lake Orienta and Cranes Roost could be reduced slightly by improving the permeability of their bottoms, but effective control would require removal of water by pumping or by providing a surface outlet. Removal of water by pumping probably would prove impractical at Cranes Roost; during extreme wet periods massive pumping would be required to limit the magnitude of relatively sudden rises in level caused by surface inflow from upstream lakes; also, inseepage from the Floridan aquifer might be induced into Cranes Roost if its water level were drawn down below an altitude of about 55 feet. Improving the permeability of the lake bottoms probably would have the undesirable effect of lowering water levels below desirable stages during dry periods.

In Grace Lake sink basin, the water level of Island Lake could be controlled by enlarging its surface outlet and providing an adjustable control structure. The peak stage of Grace Lake could be reduced easily by lowering the swales in the divide between the lake basin and the sinks to the north. However, this would tend to increase the flood hazard in the sinks and lakes downstream.

The peak stage of Lake Marion in the Palm Springs sink basin could be controlled by removal of water by pumping or by providing a surface outlet. Peak stages of the Palm Springs sinks, including Eleventh Hole Pond, could be controlled in the same way; however, a surface outlet to Little Wekiva River would require a long, deep excavation. Massive pumping would be required to appreciably lower the peak stages of the sinks because they appear to be largely controlled by the level of the potentiometric surface of the Floridan aquifer. Any appreciable lowering of the stages of the Palm Springs sinks would induce seepage into the sinks from the Floridan aquifer.

SUMMARY AND CONCLUSIONS

All water bodies in the sink area in southwestern Seminole County are affected to about the same degree by rainfall and evaporation, yet the range in stage differs widely amongst them because some of the lakes are landlocked; some have surface outlets; in relation to their size, some lakes receive more surface inflow than others; the lakes differ widely in the extent to which they lose water by seepage to the Floridan aquifer and gain water by seepage from the water-table aquifer.

Island Lake, in Grace Lake sink basin, overflows readily through its surface outlet, and loses little water by seepage through the bottom to the Floridan aquifer; consequently, the lake level fluctuates through a fairly small range. The peak stage of Island Lake in September 1960 was only 3 to 4 feet above the low stages of May-June 1971.

The range in stage of Grace Lake is substantially greater than that of Island Lake. The peak stage of September 1960 was about 7 feet above the low stage of June 1971. Grace Lake receives much more surface inflow than Island Lake—in relation to its size—and overflows only at a relatively high stage. Grace Lake also loses a considerable quantity of water—0.5 foot per month in January-May 1971—by seepage through the bottom to the Floridan aquifer.

Lake Orienta—in Cranes Roost sink basin—has a larger range in stage than many of the other lakes investigated. The peak stage of September 1960 was about 10 feet higher than the low stages of June-July 1971, and was more than 11 feet higher than the low stage of October 1, 1956. The lake is landlocked and normally occupies about 15 percent of its drainage basin. The rise in lake level probably is caused primarily by the excess of rainfall over lake evaporation and by seepage from the adjacent water-table aquifer. The lake loses water by seepage through the bottom to the Floridan aquifer and, during dry periods, by seepage through the water-table aquifer on the west side of the lake. The exchange of water between the lake and the aquifers in January-May 1971 resulted in a loss of about 0.5 foot or 0.1 foot per month. The

loss decreases during wet periods; with water levels rising generally, inseepage from the water-table aquifer increases and outseepage to the Floridan aquifer decreases. Although Lake Orienta probably always loses water to the Floridan aquifer, inseepage from the water-table aquifer may exceed outseepage to the Floridan aquifer during extreme wet periods.

Cranes Roost is also landlocked and has the greatest range in stage of all the water bodies investigated. The peak stage of September 1960 was almost 19 feet higher in altitude than the low stage of June 1971. Cranes Roost probably receives substantial surface inflow from Lake Adelaide. Cranes Roost readily loses water by seepage through the bottom to the Floridan aquifer; in January-May 1971 seepage to the Floridan aquifer averaged almost 1 foot per month.

The water levels of the Palm Springs sinks, including Eleventh Hole Pond, also fluctuate considerably. The peak stage of Eleventh Hole Pond in September 1960 was about 12 feet higher in altitude than the low stages of May-June 1971. The sinks in general are landlocked and apparently are well connected hydraulically with the Floridan aquifer. The water levels of the sinks probably reflect closely the level of the potentiometric surface of the Floridan aquifer in the sink area.

The September 1960 peak stages of lakes in southwest Seminole County probably were the maximum attained since at least 1895. Results of a regression analysis of the annual discharge of Wekiva River near Sanford and rainfall at Orlando showed the discharge for the 1960 water year to be markedly greater than that for any other year since at least 1895. Similarities established between fluctuations of lake and ground-water levels and variations in discharges of nearby streams suggest that the rainfall which produces an outstandingly high discharge also will produce lake and ground-water levels that are equally outstanding.

As cultural development of the sinkhole area progresses, the peak lake stages that result from a specific amount of rainfall probably will become progressively greater because of an increase in the percentage of the basin that is covered by relatively impervious materials and because of other changes that affect the basin hydrology. With full development, lake stages seldom reached under natural conditions may be reached more frequently unless lake levels are controlled.

Control of the water levels of Lakes Mobile, Adelaide, and Florida—in Cranes Roost sink basin—would require enlargement of their exising surface outlets and the addition of adjustable control structures. During extreme wet periods such measures might be ineffective for Lakes Florida and Adelaide unless the water level of Cranes Roost also was controlled. The level of Cranes

Roost could be controlled by removal of water by pumping or by providing a surface outlet; pumping probably would be impractical because of the large pump capacity required to limit rises in level caused by surface inflow from upstream lakes. Lowering the water level of Cranes Roost below an altitude of about 55 feet might induce inseepage from the Floridan aquifer during extreme wet periods. The level of Lake Orienta could be effectively controlled by removal of water by pumping or by providing a surface outlet.

In the Palm Springs sink basin, the levels of Lake Marion and the Palm Springs sinks could be controlled by removal of water by pumping or by providing surface outlets. For the Palm Springs sinks, however, providing a surface outlet to Little Wekiva River would require an extensive excavation, and pumping might prove impractical during wet periods because any appreciable lowering of the water levels would induce seepage from the Floridan aquifer.

In Grace Lake sink basin, the water level of Island Lake could be controlled by enlarging its surface outlet and providing an adjustable control structure. The peak stage of Grace Lake could be reduced by lowering the swales in the divide between the lake basin and the sinks to the north; however, this would tend to increase the flood hazard in downstream sinks and lakes.

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